Poultry meat processing and quality

Edited by G. C. Mead

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Introduction

Since the modern poultry industry began, more than 50 years ago, global production of poultry meat has continued to expand and significant changes have occurred in the marketplace. Thus, a demand for mainly oven-ready carcasses has been superseded in the developed world by a market in which an increasing diversity of further-processed convenience items has become the dominant form. In consequence, poultry companies are as much involved now in food technology and product development as they are in meat production. Also, consumers have become better informed on a variety of issues, including food safety and quality, animal welfare and environmental protection, and their expectations have risen accordingly, as reflected in the raft of new European legislation and schemes for ensuring the use of best production practices. These developments have made considerable demands on the industry, which needs to have a sound knowledge-base on all aspects of its activities, underpinned by appropriate research. The purpose of the present book is to provide an up-to-date reference work for both practitioners and students on meat quality and its control during the production and processing of poultry.

The subject-matter of the book is broader than the title suggests. It recognises the key consumer requirements and both perceived and real health-hazards associated with poultry-meat products. Also included is the influence of production factors on product quality, especially the role of breeding and husbandry conditions, and subsequent effects of various processing, packaging and cold-storage systems on product quality, safety and shelf-life. In this way, the book deals with relevant parts of the entire supply chain and reviews the methods available for measuring quality attributes and functional properties of the meat for product manufacture. In view of the importance of further processing and the bewildering array of value-added products now available, the

book includes an analytical review of the products and their associated technologies that gives this topic a new perspective. In addition, it provides a detailed account of waste disposal and environmental pollution, which are likely to be major considerations in relation to future industry development in many countries.

Although there are other books relating to this field, most have a bias towards the processes and practices used in either one region or another, especially the European Union or North America. In the present book, such an overall bias is avoided by the multinational nature of the contributors, all of whom are established authorities in their chosen fields. I would like to thank them for their willing co-operation in producing the necessary material and ensuring that any overlap between chapters was kept to a minimum. I am also grateful to the publisher for unfailing assistance and support throughout the whole exercise.

G C Mead

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Meat quality and consumer requirements

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1.1 Introduction

Throughout the world, consumption of poultry meat continues to rise in both developed and developing countries. In 1999, global production of broiler chickens reached 40 billion for the first time and, by 2020, poultry is predicted to become the overall meat of choice (Bilgili, 2002). The continued growth and competitive nature of the industry have been attributed to a variety of factors, some of which relate to economies of scale in intensive production and processing, and extensive use of mechanisation, while others include the more recent development of a wide range of convenience and ready-to-eat products that meet both direct consumer demand and the rapid expansion of fast-food outlets. Poultry products are universally popular, because they are not subject to cultural or religious constraints and the meat itself is perceived as wholesome, healthy and nutritious, being relatively low in fat and with a more desirable unsaturated fatty-acid content than other meats. Most importantly, high-quality poultry products are available to many people at affordable prices, although production costs vary widely around the world (van Horne, 2002), and are likely to increase as new legislation appears and retailers and consumers become more demanding in their requirements. However, the technical and marketing sophistication of the industry in the developed world contrasts sharply with the situation elsewhere. In poorer regions, poultry are often sold live or are slaughtered at the point of sale, and 30% of all the world's poultry are said to be marketed in this way (Holroyd, 2001). Processing in developing countries tends to be more labour intensive and is often confined to the production of relatively simple items, such as whole carcasses and cut portions. Nevertheless, poultry production and consumption are increasingly significant in those countries,

especially where there are high population densities and sustained economic growth (Bilgili, 2002).

More recently, consumer demands in Europe and elsewhere have been influenced by a number of socio-economic factors and the industry has needed to respond to a rapidly changing market. In the UK, in particular, there is an ageing population in which life expectancy is still increasing. Many households consist of only one or two individuals and many women are now engaged in full-time employment. Taking meals outside the home, whether in the form of snacks, take-away meals or eating in catering establishments, has become much more widespread. Also, people are travelling more for pleasure and thereby experiencing a wider range of foods than ever before. In parallel with these changes in lifestyle, there has been a significant uptake of labour-saving devices in the home, including the microwave oven, while traditional skills in food preparation are often forgotten. This is largely because only limited time is available to prepare meals at home. Among more discerning consumers there is, however, a greater awareness of food safety, animal welfare and environmental issues associated with food production and processing. All of the above considerations have had, and are continuing to have, a major impact on food-product development and marketing, and the poultry industry has responded successfully to the market demands and opportunities that have arisen.

With regard to poultry, the most important growth area of recent times has been the development of value-added, further-processed products. In the USA, for example, less than 10% of all broilers are sold as whole carcasses (Thornton and O'Keefe, 2002). The majority of carcasses are cut up, deboned or further processed and the meat is either portioned, sliced, ground, flavoured, marinated or cooked. There is also a large production of breaded and coated items. At one company alone, manufacture of these products increased by 16.5% per annum between 1996 and 2000. Therefore, there is growing demand for convenient, high-quality food products that provide variety and are quick and easy to prepare, while remaining attractive in price. At the same time, quality expectations are rising and products of 'restaurant quality' are of increasing interest (Thornton and O'Keefe, 2002). Thus, the industry is becoming ever more sophisticated and involved in food technology, which contrasts with its origins more than 50 years ago in primary agriculture, with only the simplest means of producing carcass meat. First of all, this chapter will consider, in general terms, the meaning of 'quality', the basic quality characteristics of poultry that are important to consumers and possible negative quality attributes associated with production and processing. Attention will be paid to the range of chemical, microbiological and physical hazards in poultry meat production and the ways in which consumer concerns are being tackled through the development of a 'farm to fork' approach to meat quality and safety control. Lastly, future trends will be highlighted, including changes in consumer demand and prospects for a reduced risk of product contamination with hazardous agents.

1.2   Meat quality: concept and characteristics

Any definition of the term 'quality' must take account of the many factors that impinge on this concept and the fact that each stage of the supply chain will define it differently according to need. The subject has been discussed in detail by Becker (2002) and will be covered only briefly here in relation to consumers. As with other foods, it is clear that price is the key factor in the successful marketing of poultry products, and this is inextricably linked to quality; in fact, price can be a measure of quality. However, modern consumers have wide-ranging demands that may encompass not only the price and sensory quality of the foods they buy, but also convenience, product safety, nutritional quality and the manner in which the food is produced.

In developed countries, poultry production and processing practices are controlled, at least in part, by legislation, and good practices may be further specified in various quality schemes that are efforts to co-ordinate quality requirements at specific stages of the supply chain. Such schemes can be led by producers, retailers, industry associations or government agencies (see Section 1.5).

Consumers define quality according to their own perceptions, goals and personal preferences, but, in practice, the quality concept has both subjective and objective components, and Becker (2002) recognises 'quality cues' (QC) and 'quality attributes' (QA). The former are what the consumer observes at the point of sale as a means of predicting quality performance, when the food is consumed. Examples of QC are the reputation of the place of purchase and products from free range or organically produced birds. QA, on the other hand, are what the consumer actually wants in relation to product quality. These include the scientifically measurable characteristics of colour/appearance, texture (involving juiciness and tenderness) and flavour.

Of particular importance are appearance and colour, reviewed by Fletcher (2002). Skin colour appears to be critical for the marketing of fresh whole birds or cut portions. The colour of the meat is more relevant to deboned and skinless, raw items and is particularly significant in relation to many cooked products, where a pink or red appearance is associated with an impression of undercooking. Dark or black bones are recognised as a defect in cooked products and bone darkening may be observed in products that have been frozen prior to cooking. Other visual defects include bruises and haemorrhages of varying severity. Consumer preference for skin colour shows some interesting variation for broilers, with preferred colours ranging from white, through pale yellow to deeply pigmented, and choice being based on traditional market forms (Fletcher, 2002).

Preferences for one type of colour or another have tended to show a regional pattern in the USA, while some consumers in the UK prefer corn-fed (yellow-skinned) birds to those with the usual whiter appearance, on the assumption that such birds have a better eating quality. Factors affecting the pigmentation of poultry skin were discussed by Fletcher (1989). With regard to meat colour, this

can vary widely, especially in skinless breast fillets. Fletcher (1999) reported a US survey in which approximately 7% of retail packs of skinless fillets had one or more fillets that was clearly different from others in the same pack. Causes of colour variation in poultry meat were considered by Froning (1995) and include a variety of factors in bird rearing and processing. Although appearance and colour are undoubtedly important in initial product selection, consumers may also make judgements on other matters. In particular, some are likely to examine the label for nutritional information, details of any colourings, preservatives or other additives, as well as taking note of instructions on storage, handling and cooking of the product. Equally, consumers will take account of any negative quality attributes that are apparent. For whole carcasses, in particular, these can include dislocated or broken bones, cuts or tears in the skin, bruises, blisters, lesions, reddening of wing tips, residual feathers and fragments of tissue that are normally removed during processing, surface discolouration and excessive weepage of fluid into the pack. Such defects have their origin either on the farm or in the processing plant, and some may be associated with pre-slaughter handling of the birds. Generally, the most important visual defects are those due to bruises and haemorrhage (Fletcher, 2002), the latter being more visible when the skin has been removed. The difference between the two is that bruising results from physical trauma, without laceration, and involves rupture of capillary blood vessels; haemorrhage, on the other hand, is an escape of blood from the circulatory system into the surrounding tissue and is often seen as blood spots of varying size in skinless cut portions.

Meat flavour and texture can only be appreciated when the product is consumed, but usually there are no indications at this stage of chemical and microbiological aspects of product quality, which have to be taken on trust. Included here are any possible chemical contaminants and microorganisms derived from both the rearing and processing environments. Microbes can be important for two reasons. Firstly, in those products where microbial growth is favoured, they are potentially responsible for ultimate spoilage, especially in the case of chill-stored, raw-meat products, and shelf-life depends partly on the numbers of spoilage organisms present initially. Secondly, microbial contaminants may sometimes include low numbers of particular foodborne human pathogens. Problems associated with these and other potential hazards are considered below.

1.3   Food safety: poultry microbial hazards

Food safety is a major global issue and, in the developed world, the claim that 'our food has never been safer' is continually being challenged. Greater public awareness and concerns over food safety issues have been fuelled by various crises that have arisen, while consumer fears greatly increased following the widespread and damaging publicity given to these problems by the news media. Food 'scares', whether real or even partly imaginary, have become a

phenomenon of the modern age and their consequences cannot be taken lightly. In 1999, for example, a major problem was caused by dioxin-contaminated feed given to livestock in Belgium (Erickson, 1999). The source of the contamination was a fat-rendering company, where transformer oil with high levels of dioxins and other toxic chemicals was used in the manufacture of animal feed. When this was discovered, all poultry and eggs were withdrawn from sale in Belgium, and other countries soon took the same action. The ban was later extended to further food items containing poultry products that might have been contaminated. Obviously, food scares of this kind affect consumer confidence in the products concerned and can lead to a sharp, if temporary, fall in consumption that is extremely damaging to suppliers and retailers alike. Even without major scares, foodborne illness is an important issue in modern society, with financial implications that increasingly involve litigation. Possible food safety hazards affecting the poultry industry are shown in Table 1.1 and include microbial, chemical and physical agents that may be acquired at various stages of the supply chain. The main overt causes of foodborne human illness are microorganisms, of which *Salmonella* and *Campylobacter* are currently considered to be the most important in relation to poultry (Bryan and Doyle, 1995). There are, however, consumer concerns about residues of veterinary drugs, pesticides and other environmental pollutants in foods of animal origin, including poultry meat. Most consumers are probably unaware that maximum residue limits have been established for a range of these substances and are

Table 1.1   Possible food safety hazards associated with poultry meat

Agents involved	Examples
Microbial hazards	
Infectious and toxigenic foodborne pathogens	*Campylobacter* spp.
	Salmonella serotypes
	Clostridium perfringens
Bacteria resistant to antimicrobials	*Salmonella* Typhimurium DT104 (most strains)
	Enterococcus spp. (some strains)
Mould toxins	Ochratoxin A, aflatoxin
Chemical hazards	
Residues of:	
antimicrobials	Chlortetracycline, sulphaquinoxaline
pesticides	DDT, dieldrin
heavy metals	Lead, mercury
other environmental chemicals	Dioxins, polychlorinated biphenyls
hormones or hormone-like substances	Trenbolone, clenbuterol
Physical hazards	
Foreign bodies	Bone, glass, metal, plastic

considered safe on the basis of available scientific evidence. Such limits are set by relevant international bodies, including the European Union (EU), the Food and Agriculture Organisation of the United Nations and the World Health Organisation, to facilitate trade and prevent artificial trade barriers. Nevertheless, some people fear that years of exposure to even low levels of these substances could lead to undesirable consequences, varying from changes in gut microflora to mutagenic, teratogenic or carcinogenic effects. Concerns over veterinary drug residues include possible toxicity, allergic responses in some individuals and the development of microbial drug resistance, which is discussed in Section 1.3.3. Possible sources of contamination are given by Bremner and Johnston (1996). Chemical residues are discussed in more detail in Chapter 12.

Consumer complaints received by supermarkets include the presence of foreign bodies, such as glass, metal, plastic and fragments of bone, that may cause injury or discomfort to consumers if accidentally swallowed when the product is eaten. The presence of these bodies can be minimised by means of appropriate on-line detection systems in the processing plant and preventative measures, including rules to prohibit staff from wearing jewellery at work and the use of suitable forms of hair covering.

There is no doubt that consumers expect the food that they buy to be free from any health hazard and, generally, they are unwilling to pay a premium for this requirement. Not only is it impossible to guarantee a food supply that is entirely free from risk, but it would not be feasible to develop any method of sampling and testing the end-product that could ensure such a requirement had been met, since this would involve examining every batch of food in its entirety for all known hazards. A much more workable approach is to use procedures and practices in food production, throughout the supply chain, that minimise the opportunity for food safety hazards to occur. These include the development of appropriate Quality Assurance schemes and application of Hazard Analysis Critical Control Point (HACCP) principles. The approach is considered further in Chapter 15.

1.3.1   Foodborne pathogens associated with poultry

Microbial hazards derive from contamination, survival or growth of the causative agents at any stage of the supply chain, and during preparation, cooking and post-cooking handling in the kitchen. More recent surveys in the USA have indicated that chicken and turkey were responsible for about 10% of foodborne disease outbreaks, for which the vehicles were identified (Bryan and Doyle, 1995). In relation to England and Wales, an analysis of 1426 foodborne general outbreaks between 1992 and 1999 showed that 20% were associated with consumption of poultry, including chicken, turkey and duck (Kessel *et al.*, 2001). However, foodborne illness is known to be greatly under-reported and most reported incidents are 'sporadic', i.e. single cases, with no proven link to any other or, usually, to a specific food item. Therefore, the true extent to which

poultry meat products are the cause of foodborne illness in the human population remains uncertain. In attempting to control the problem at source, the main difficulty is that the bacteria of greatest concern (*Salmonella* and *Campylobacter* spp) are usually present in the alimentary tract of carrier birds without causing any clinical sign of disease. This means that reliable detection of the organisms will depend upon extensive and costly testing of flocks and processed carcasses. Most countries accept that some raw food products, such as poultry meat, are susceptible to contamination with foodborne pathogens and take steps to minimise their occurrence, in the knowledge that prevention of any ultimate hazard can be achieved by appropriate measures in handling and cooking. A more draconian approach is taken in Sweden and other parts of Scandinavia, where poultry and other meats that are found to be contaminated with *Salmonella* are not allowed to enter the food chain in the raw state and, depending on serotype, may even be destroyed.

Although poultry meat may be contaminated from time to time with a variety of microbes that have the potential to cause foodborne illness in man, those covered here are only the more important pathogens, according to recent experience.

Salmonella

Serotypes of the species *Salmonella enterica* have been the principal causative agents of food poisoning in many countries, according to analyses of outbreaks in which the aetiology of infection was established (Sockett, 1995). Thus, salmonellas were responsible for 75% of more than 7000 outbreaks between 1985 and 1989 and reported in 16 European countries. For England and Wales between 1992 and 1999, the corresponding figure was almost 60% (Kessel *et al.*, 2001). Although various *Salmonella* serotypes appear capable of infecting poultry, the organisms are usually relatively poor colonisers of the alimentary tract and flourish best in young birds, where microbial competition is less during the period that the natural microflora is developing. Any period of shedding may lead to external contamination of the birds and provide further opportunity for subsequent spread during processing. The most troublesome strains for the poultry industry have been those that are invasive in the bird and capable of reaching internal organs, such as the liver, spleen and reproductive tract. In recent years, there has been a pandemic of human salmonellosis due to serotype Enteritidis that followed widespread infection of broiler and layer flocks and has spread across several continents (Rodrigue *et al.*, 1990). Strains of this serotype are unusual in being able to invade the reproductive tract of the bird and can be transmitted directly from parent to progeny via the contents of contaminated eggs, i.e. vertical transmission. For this and other salmonellas, lateral spread of infection may also occur via contaminated feed or water, or various sources in the rearing environment. Recently, control of serotype Enteritidis has been achieved, largely through culling of infected breeders and the successful application of vaccines to breeding stock and egg-laying flocks (Report, 2001).

Both the proportion of contaminated raw-meat products and numbers of viable salmonellas on individual products have been studied extensively (Waldroup, 1996). While the incidence of positive samples differs between countries, it also varies widely from flock to flock, but numbers of cells are consistently low and rarely exceed 100 per carcass. Despite such low levels, food poisoning can sometimes result from a relatively small challenge dose and efforts continue to be made in many countries to minimise the incidence of positive products.

Campylobacter
The so-called thermophilic campylobacters, especially *Campylobacter jejuni* sub-species *jejuni* and *Camp. coli*, are recognised as a major, worldwide cause of human enteritis. In developed countries, mortality is relatively rare, but a small proportion of individuals may develop any one of a variety of complications, including reactive arthritis and Guillain-Barré Syndrome, which is a neurological disorder. Poultry is often considered to be the primary source of infection, but others include contaminated water supplies, raw milk and contact with pets or other animals. Outbreaks are relatively uncommon, most cases being sporadic, and the precise role of poultry is presently unknown. Human infections from poultry are associated with consumption of undercooked meat or handling of raw products, although one study has suggested that contact with raw poultry can have a protective effect, presumably through the development of natural resistance (Adak *et al.*, 1995). Cross-contamination from raw poultry is likely to be an important means of transmission in the kitchen, and campylobacters are easily transferred to cutting boards, plates, hands and foods other than poultry (de Boer and Hahné, 1990). With a low infective dose, susceptible individuals can readily acquire the organisms by this route.

Live poultry, including chickens, turkeys and ducks, are commonly infected with *Campylobacter* spp. and constitute a large reservoir of the organisms. The exact sources of flock infection and modes of transmission remain unclear, but are likely to involve environmental spread from various animal vectors or human agency. The scientific literature indicates that the proportion of carcasses carrying campylobacters varies between zero and 100% (Waldroup, 1996), but figures tend to be higher in more recent studies, which may reflect improvements in isolation methods. Carcasses show a relatively even distribution of the organisms (Hood *et al.*, 1988), which often reach 10^6 colony-forming units per carcass, a reflection of the correspondingly high level in the alimentary tract of the live bird. At least some of the strains present appear to be invasive in the bird and can infect certain organs, such as the liver. Contamination of processed giblets (heart, liver, gizzard and neck) can be particularly high and, because of the microbial load, the UK Advisory Committee on the Microbiological Safety of Food recommended that giblet packs should no longer be included with whole carcasses (Report, 1996).

Clostridium perfringens

This organism is well known as a cause of necrotic enteritis in poultry. Some strains are also capable of causing human food poisoning, especially those of type A that produce unusually heat-resistant spores, which can survive normal cooking processes used for poultry and other meats (Roberts, 1972). If the cooked meat is kept too long at ambient temperature or cools too slowly prior to storage, heat-activated spores may germinate and multiply to reach hazardous levels. Although the organism is an anaerobe, it grows well in poultry meat under conditions occurring in the kitchen, and at 43–47ºC has a mean generation time of less than ten minutes (Mead, 1969). Up to 80% of processed carcasses have been reported to contain *Cl. perfringens* at levels below ten per gram or cm^2 (Waldroup, 1996) and faecal contamination is the most likely source. Lillard (1971) detected the organism in 2.6% of 118 samples of cooked chicken products. Food poisoning from *Cl. perfringens* has been especially evident in December in England and Wales, and mainly associated with inappropriate storage of cooked turkey around Christmas time (Kessel *et al.*, 2001).

Listeria monocytogenes

Listeria infections in man can be severe and may even lead to death of affected individuals. *L. monocytogenes* is ubiquitous and commonly found in food processing environments. The organism is cold-tolerant and able to multiply slowly in food at refrigeration temperatures; it is also more resistant to adverse environmental conditions than many other organisms, and is of particular concern in cooked, ready-to-eat products that may be consumed without any further heat treatment. Although very few incidents of human listeriosis have been associated with the consumption of poultry meat products, a case in the USA that incriminated turkey frankfurters in 1989 led to a 'zero tolerance' approach to the pathogen for products of this kind (Anon., 1989). Subsequently, substantial recalls of contaminated, ready-to-eat meat products have occurred in that country, involving food worth millions of dollars. The policy was supported by a recommendation of the WHO Informal Working Group on Foodborne Listeriosis (Anon., 1988).

   L. monocytogenes is a common contaminant of raw poultry and up to 60% of processed chicken carcasses may harbour low numbers of the organism (Cox *et al.*, 1999). Live birds are rarely found to be positive and contamination occurs mainly during processing. Carcasses may carry a range of serotypes, most of which are considered potentially pathogenic. However, serotype 4b, which predominates in both outbreaks and sporadic cases of human listeriosis, is less common on raw poultry. With raw meat products, the presence of listeria has implications for cross-contamination of other foods in the kitchen, especially those that are ready to eat. Because contaminated pâté was held responsible for more than 350 cases of listeriosis in the UK from 1987 to 1989, and often contained serotype 4b, susceptible consumers, such as pregnant women, were advised to avoid this and other high-risk foods. Although pâté production is now under stricter hygiene control, the advice still stands.

Enterohaemorrhagic *Escherichia coli*
Unlike the normal, commensal strains of *E. coli* that occur in the alimentary tract of man and other animals, verotoxigenic *E. coli* (VTEC) are a known cause of serious human diseases, including haemorrhagic colitis and haemolytic uraemic syndrome, that may lead to kidney failure and even death. Of particular importance is serotype O157:H7, which has been the cause of various food-associated outbreaks. This organism was first recognised as a pathogen in 1982 and has often been linked to the consumption of undercooked beef. It is capable, however, of colonising the chicken gut asymptomatically and Schoeni and Doyle (1994) showed that an inoculated strain could persist for at least three months from a relatively small challenge dose. Despite this, the organism is uncommon in live poultry, although Heuvelink *et al.* (1999) isolated it from 1.3% of 459 pooled faecal samples taken from commercial turkey flocks. Only one of the isolates showed potential pathogenicity for humans. On the other hand, Hafez *et al.* (1998) reported the presence of both O157 and non-O157 VTEC in flocks of broiler chickens sampled during processing. Strains of O157:H7 were isolated by Doyle and Schoeni (1987) from 1.5% of 263 poultry samples that included chicken legs and turkey drumsticks. The organism was also found in frozen chicken nuggets. Subsequently, there appear to have been few isolations from poultry products, whether raw or further-processed, but occasional incidents of poultry-associated human infection have been reported (Kessel *et al.*, 2001).

1.3.2   Other foodborne pathogens
Among a number of possible pathogens, *Staphylococcus aureus* is common in the nasopharynx of live birds and may occur on the skin and among the feathers. It is also found at low levels on many processed carcasses, although higher numbers may result from colonisation of processing equipment (reviewed by Mead and Dodd, 1990). Most strains do not produce the enterotoxin that causes food poisoning in man, but unusually high levels of contamination may lead to the meat being rejected for use in manufactured meat products. Other organisms of more recent concern are those related to the thermophilic campylobacters discussed previously, and including *Arcobacter butzleri, A. cryaerophilus, A. skirrowii* and *Helicobacter pullorum*. Although these species are common on poultry carcasses (Corry and Atabay, 2001) and include organisms that have been implicated in foodborne illness, neither their origin(s) nor their exact public health significance in relation to poultry have been elucidated.

Finally, mention should be made of two further cold-tolerant types of bacteria, *Aeromonas* spp. and *Yersinia enterocolitica.* The former are common on processed carcasses and appear to be able to multiply during refrigerated storage but, despite the presence of known virulence factors, they have not been involved in foodborne illness. The yersinias on raw poultry are found in only a small proportion of carcass samples and the serotypes present are generally regarded as non-pathogenic (Report, 1996). Thus, yersiniosis from poultry consumption has not been reported.

1.3.3   Antibiotic usage in poultry

In animal husbandry, antimicrobial agents are used for three distinct purposes: therapy, prophylaxis and animal-growth enhancement, and these strategies have been applied universally to all kinds of intensively reared food animals. Residues of the substances used find their way into the environment and sometimes into food products themselves. One consequence of widespread usage of antimicrobials in agriculture is that some bacteria, whether in the animal host, the environment or food products, will have acquired resistance to these agents. Such resistance is the result of selective pressure on the organisms and occurs either by mutation, the appearance of new resistance genes or through the acquisition of resistance genes from other bacteria (transferable resistance). The last route implies that resistance could be acquired by human pathogens from organisms of animal origin. Whatever the means by which it is acquired, antimicrobial resistance is an important phenomenon because it increases morbidity, mortality and costs associated with disease and has become a major health problem in both human and veterinary medicine (Helmuth, 2000). With regard to poultry, there is concern over resistance in *Salmonella* and *Campylobacter*, but the problem is not the same everywhere, being least in situations where antimicrobial usage is low and correspondingly greater where usage is high. In practice, resistance may be confined to a particular geographical region, a single *Salmonella* serotype or even a specific rearing site. With serotype Typhimurium, which is common in animal populations, resistance has generally increased. Also, there has been a rise in multiple resistance, defined, usually, as resistance to four or more antimicrobials simultaneously, as seen in serotype Typhimurium DT104. Resistance in *Salmonella* and *Campylobacter* has even developed rapidly against fluoroquinolones, a newer class of antimicrobial. Better control of antimicrobial usage and more prudent selection of treatment options are now widely acknowledged to be necessary.

The general public has been made aware of antimicrobial resistance and its consequences through extensive coverage in the media and, in some cases, from personal experience of failures in disease treatment. Thus, the diminishing effectiveness of antimicrobials is a matter of growing concern. In the EU, one of the first steps was to prohibit the use of avoparicin, a growth promoter with apparent links to vancomycin-resistance in enterococci. A ban on other growth promoters soon followed. In 1986, all such substances were banned in Sweden and this example has since been followed in other European countries, partly in response to legislation and partly to satisfy customer demands. There is, however, a realisation that the usual, low-level inclusion of specific antimicrobials in the feed supply was not only beneficial for growth enhancement in the birds. These substances also played a part in suppressing certain disease agents, especially *Cl. perfringens*. The irony is that withdrawal of antimicrobial growth promoters, partly to satisfy consumers, has led to greater use of antimicrobials for therapeutic purposes, thereby losing much of the initial benefit.

1.4   Ethical concerns: animal welfare, genetic modification and organic production

1.4.1   Animal welfare

Many consumers are concerned about the welfare of food animals, especially during rearing, transport and slaughter of broilers. To some people, intensive husbandry systems equate with 'factory farming' and they find that the manipulation of animals to improve production performance is unacceptable. While attitudes to these issues vary widely between countries and among individuals, there can be little doubt about the importance of welfare considerations across the world and their impact in shaping modern agricultural practices. A key question was posed by Harrison (1964): 'where in a civilised society do we draw the line in our exploitation of the animals we use for food?' Starting from the assumption that humans have a right to eat meat and other foods of animal origin, because they have evolved to do so, there are many individuals who feel a moral responsibility for the way in which the animals themselves are treated. The difficulty with this view lies in determining the extent to which animals perceive external stimuli and the circumstances under which any associated suffering can occur. Certainly, poultry show evidence of feeling pain through signs of distress and aversion behaviour, and are capable of experiencing hunger, thirst and fear, for example, but the full range of their perceptions and needs remains obscure. In attempting to define suitable conditions for the rearing and handling of food animals, a pragmatic approach was adopted by the UK Farm Animal Welfare Council, which developed the so-called 'five freedoms'. These are:

1.   freedom from thirst, hunger and malnutrition
2.   freedom from discomfort
3.   freedom from pain, injury and disease
4.   freedom from fear and distress
5.   freedom to express normal behaviour.

Although much can be done to accommodate the first four requirements, the fifth is more contentious. A complicating factor here is that domestication has brought about some profound changes in the nature of livestock, and the modern broiler, for example, is now very different from the original jungle fowl, with selective pressures having changed the morphology, physiology and behaviour of the bird. Most importantly in the present context, the bird is likely to have become better adapted to the husbandry conditions under which it is now kept (Siegel, 2002).

Over the past 40 years, selective breeding programmes and modern husbandry practices have achieved a phenomenal improvement in bird performance and feed utilisation. Broilers now reach an average body weight of over two kg in less than 40 days. However, high stocking densities and emphasis on improving production traits have had some unfortunate side-effects that have been well publicised by opponents of intensive farming. These have

included the appearance of circulatory defects, incidents of heart failure, ascites and various skeletal disorders, including leg weakness. The main problems are now being successfully addressed by the industry (Rennie, 2002), and considerable improvements are being claimed.

1.4.2   Other ethical concerns

In Europe, at least, many consumers distrust the claims made for biotechnology and especially genetic manipulation, whether this is applied to food animals or plants. Objections are expressed on the grounds that the technology is unnecessary, harmful to humans and damaging to the environment. Overall, consumers seem unaware that they stand to gain from better quality, lower prices and products that are more closely tailored to their particular needs. There is little or no evidence of any potentially harmful effects (unless allergens are introduced inadvertently during genetic manipulation). Partly because of consumer resistance, the EU regulates the importation of foods containing genetically modified (GM) ingredients and requires appropriate labelling so that consumers are made aware of their presence. Consumer antipathy has created difficulties for the poultry industry in relation to GM soya. Soya is an essential ingredient in poultry feed and large amounts need to be imported. With the supply of non-GM soya becoming increasingly scarce at present, a premium is charged which is having an adverse effect on the competitiveness of European poultry producers. This situation contrasts with that in the USA, where GM crops are said to be welcomed by farmers and consumers alike (but see Chapter 6). At present, more than 60% of food products in US supermarkets contain GM ingredients (Ahmed, 2002).

The concerns among European consumers about the intrinsic safety of GM foods also extends to the problem of containment on the farm and, in the case of plant crops, the risk of cross-pollination between GM and non-GM crops. There is, therefore, an environmental dimension to the question of safety, which adds to other environmental issues currently being debated. With the spectre of climate change now apparent, there is much talk of 'sustainable livestock production', which must take account of pollution control. The need is certainly relevant to large-scale poultry production, which continues to increase worldwide and inevitably involves the generation of dust and gaseous emissions, and the spread of microorganisms, as well as the accumulation of large amounts of spent litter, manure and dirty wash-water for disposal. For this and other situations, many countries have developed a range of standards, codes of good practice and other policy measures aimed at protecting the general environment. New EU legislation, the Integrated Pollution Prevention and Control (IPPC) Directive, not only seeks to control pollution throughout the agro-food sector, but to minimise water and energy consumption. While new, far-ranging measures may appear costly at first sight, there are potential economies in the use of water and energy that could be attractive to producers (Watson, 2000) and have beneficial outcomes for the public at large.

1.4.3   Free-range and organic production

In the affluent countries, there are some consumers that prefer their foods of animal origin to come from production systems that are considered to be more natural than those of intensive rearing. They perceive such systems as more conducive to animal welfare and the food itself as safer, due to the presumed absence of chemical residues. These consumers are prepared to pay a premium price that partly reflects the increased cost of production. Free-range broilers may be housed, with ready access to the exterior, but are otherwise little different from conventional meat birds. On the other hand, organic production, which is also free-range, involves specific criteria that are established and monitored by various public and private certifying organisations. Organic foods are also required to conform to national and international regulations regarding production conditions and subsequent labelling. For the producer, the objective is to develop a production system that is designed to produce optimum quantities of food of good nutritional quality through management practices that aim to avoid the use of agro-chemical inputs and to minimise damage to the environment and wildlife. While bird welfare was observed to be better in 'conventional' free-range systems (Ellendorff, 2002), consumers were unable to distinguish between intensively reared and organic birds on the basis of a sensory assessment of the meat. There were also some disadvantages in that the organic system, in particular, consumed more ecologically valuable resources, while both it and the conventional free-range system were more likely to contaminate groundwater with nitrate and phosphate. In addition, birds kept outside cannot be subjected to biosecurity measures, and appear more prone to colonisation by thermophilic campylobacters, for example (Heuer *et al.,* 2001), parasites and avian disease agents. Despite the drawbacks and greater cost of production, organic systems do appear to satisfy at least some of the requirements of ecologically aware consumers, and the growing market for organic foods in many parts of the world suggests that this sector will continue to flourish, provided that people are able to afford the premium price.

1.5   Quality improvement, consumer demands and the structure of this book

The demands and expectations of modern consumers place increasing pressure on the industry, with greater opportunity than ever before for litigation, should food safety be compromised at any point in the production chain. There are also high penalties in some countries for contravention of the growing body of legislation on matters to do with animal welfare and environmental protection. Control systems are being developed and applied 'from farm to fork' and product traceability to the point of origin on the farm has become a feature, along with 'early warning' and product recall arrangements.

Traceability is defined in the EU General Food Law Regulation (178/2002/EC) as 'the ability to trace and follow a food, feed, food producing animal or

substance intended to be or likely to be incorporated into a food or feed, through all stages of production, processing and distribution'. The system may be used within an individual company or it could link several companies in identifying the unique trail of a particular product and its ingredients and derivatives, throughout the entire food chain. The key consumer benefits include rapid collation of information on food safety incidents, pin-pointing the cause of any food safety hazard, so that corrective action can be taken, and providing information on the content and manufacturing history of individual foods (Stockdale, 2003). The use of traceability systems in the poultry industry applies to trade in both live birds and hatching eggs on the one hand and processed products on the other. The need to assess the relative merits of changes in production factors has led to sophisticated systems of tracking that also extend to veterinary treatments (Fallon, 2001).

Many consumers want to know more about the manner in which the food that they purchase has been produced. Over the past decade, various food assurance schemes have been developed in the UK. A key factor has been the 1990 Food Safety Act and its creation of the defence of 'due diligence'. Thus, the Act places a responsibility on food businesses to sell safe food and to take all reasonable precautions over the safety of both end-products and the supply of raw materials. In the wider context of the EU, there is a Product Liability Directive which covers primary agricultural products and makes farmers and agri-businesses legally liable for any illnesses caused by unsafe foodstuffs. At first, UK retailers used their own inspection systems to cover farm production, but there is a tendency now for greater reliance on the independent assurance schemes, which aim to raise food safety standards thorough the application of good production practices. These also take account of animal welfare and environmental protection. Features of the schemes are a greater transparency with respect to production systems and independent and regular verification of the required standards. Foods produced in this way carry a characteristic logo on the label and can command a premium price, although the significance of the logo will not be apparent to all consumers, and this aspect of communication needs to be addressed. Similar schemes operate in other parts of Europe. An example is Eurepgap, an association of European retailers that operates a certification scheme to ensure good agricultural practice among participating producers.

For many years, the agricultural and processing aspects of poultry meat production were relatively separate activities as far as management was concerned. Today, the importance of a fully integrated approach to controlling food quality and safety is widely recognised. This book acknowledges the influence of the live bird and its rearing and processing conditions on the ultimate quality of the end-product. It also endeavours to provide detailed coverage of all stages in bird handling, slaughter and processing, as well as key factors in the development of a wide range of value-added, further processed products that provide variety and convenience for consumers in accordance with present-day lifestyles. Central to the control of meat quality is an understanding

of the structure and physiology of muscle in the live bird and the changes that occur *post mortem* in relation to pre-slaughter handling and processing conditions. Equally important in that context are the means available for measuring quality attributes, including the functional properties of meat used in product manufacture. The book also considers the microbiological and chemical hazards that can arise during production and processing, and ways in which the hazards can be reduced or prevented. These include control of the microorganisms responsible for spoilage of raw, chill-stored products. With the present emphasis on an integrated, systems approach to the management of product safety and quality, attention is given to the application of Good Manufacturing Practices (GMP) and HACCP principles in production and processing, taking account of animal welfare requirements and environmental protection, where relevant. The latter interest is also served by Chapter 16, which deals with disposal of processing waste.

1.6   Future trends

Over a long period of time, consumer perceptions of food safety hazards have changed to a more scientifically informed view and an appreciation that microbial contamination of foods is the principal cause of overt foodborne illness (Schilpzand, 1999). Despite distortions of the truth that inevitably occur as a result of high-profile food 'scares', it is likely that there will be a better understanding of food safety matters in the future and, increasingly, consumers will accept that zero-risk foods are a myth and relative risk must be taken into account. A particular problem with the growth in fast-food consumption, snacking and eating outside the home is that traditional skills in food preparation, and the precautions necessary to avoid foodborne illness, have been largely lost. Many people fail to realise that such illness is often due to errors in food handling and lack of personal hygiene, which can also apply in catering establishments. On the other hand, the popularity of television programmes on cooking suggests that there is still some interest in the culinary art. Unfortunately, the programmes rarely make any point about safe handling of food and thus lose a valuable opportunity to educate viewers on this vital aspect. It is clearly important that better ways are sought to deliver the message on food hygiene and safety to the public at large (Mead, 1998). This may require more involvement of consumer organisations and other influential bodies as well as better instruction at school level.

   As the consumption of poultry meat rises worldwide, the industry will remain responsive to the demands of consumers, both in the range and nature of the products that are developed. Quality will continue to be the watchword and the uniformity of product quality is likely to improve still further. Also, there will be a greater demand for 'restaurant quality' products (Thornton and O'Keefe, 2002). Furthermore, there will be technical innovations in processing that will lead to safer products, for example, the cooking of pre-packaged items by infra-

red heating to eliminate any listerias and other pathogens, which is already available. Improvements in quality and safety could also arise from progress in genetic manipulation of the birds, for example by altering fat content and composition, and increasing resistance to colonisation by foodborne pathogens. As consumers learn to recognise the benefits of new technologies, there may be wider acceptance of food irradiation, which can readily destroy pathogens on raw poultry and extend shelf-life, without causing significant changes in the meat itself. This is happening already for red meat in the USA due to the problem of *E. coli* O157:H7 in ground beef (Deeley, 2002). The main driving factors are growing public awareness of the risks from bacterial contamination of meats, better media coverage of radiation treatment and fear of bioterrorism in relation to centralised food production. However, there is still less enthusiasm for food irradiation in Europe and little prospect of its widespread use in the near future.

1.7   Sources of further information

Quality aspects associated with chemical and microbiological contamination of food are covered by a number of contributors in a book edited by van der Heijden *et al.* (1999). Among a variety of topics, the book includes chapters on consumer perceptions of food safety hazards and the role of the media in shaping the views of the public. In addition, it covers the part played by regulatory bodies and legislation in controlling food safety, and the requirements for harmonisation of international trade in food products of various kinds. Environmental issues are also considered. The nature and management of purely microbiological hazards are fully described in another book edited by Blackburn and McClure (2002). Here, emphasis is given to risk assessment as the essential foundation for food safety management, and good practices are examined for all stages in the supply chain, starting on the farm. At the other extreme, there is an account of safe practices for consumers and food handlers in the retail and catering sectors, where the aim is to avoid situations that could lead to foodborne illness.

Because poultry production is often the most intensive of all systems used for rearing domestic livestock, it has a high profile in relation to animal welfare and this, in turn, has important economic implications for the industry. The extent to which intensively reared animals suffer stress from the constraints placed upon them is a fundamental aspect of welfare, which is discussed by Broom and Johnson (1993), and the role of bird behaviour in assessing welfare requirements is considered by Dawkins (1999). In future, the welfare of farmed poultry and other animals could benefit from the application of biotechnology, and the possibilities are reviewed by Burt (2002). Poultry genomics is a rapidly expanding area with the potential to improve not only bird health and welfare, but also product quality, and to ensure that the industry continues to satisfy the needs of consumers in that respect.

The development of organic farming, including poultry production, goes some way to meeting the demands of modern consumers in relation to their perceptions of food safety, animal welfare and even environmental protection. The last-named follows logically from reduced usage of antimicrobials and agro-chemicals. The principles and applications of organic farming are described by Lampkin (1994). For all systems of livestock production, however, there is a growing need to define and describe good production practices and, in some countries, this has led to the establishment of the assurance schemes mentioned previously. Those that operate in the United Kingdom and their relative merits are usefully reviewed by Kirk-Wilson (2002). The ultimate aim of such schemes must be to ensure that good practices are consistently and uniformly applied throughout the farming sector. In the more distant future, they may be extended well beyond the farm and even into catering.

1.8   References

ADAK G K, COWDEN J M, NICHOLAS S and EVANS H S (1995), 'The Public Health Laboratory Service national case-control study of primary indigenous sporadic cases of *Campylobacter* infection', *Epidemiology and Infection*, 115, 15–22.

AHMED F E (2002), 'Detection of genetically modified organisms in foods', *Trends in Biotechnology*, 20, 215–223.

ANONYMOUS (1988), 'WHO Working Group: Foodborne listeriosis', *Bulletin of the WHO*, 66, 421–428.

ANONYMOUS (1989), '*Listeria* zero tolerance is warranted, USDA says', *Food Chemical News*, 31 (19), 41–48.

BECKER T (2002), 'Defining meat quality', in *Meat Processing: Improving Quality*, eds Kerry J, Kerry J and Ledward D, Cambridge, Woodhead Publishing, 3–24.

BILGILI S F (2002), 'Poultrymeat processing and marketing – what does the future hold?' *Poultry International*, September, 12–22.

BLACKBURN C DE W and McCLURE P J (eds) (2002), *Foodborne Pathogens: Hazards, Risk Analysis and Control*, Cambridge, UK, Woodhead Publishing.

BREMNER A and JOHNSTON M (eds) (1996), *Poultry Meat Hygiene and Inspection,* London, W B Saunders.

BROOM D M and JOHNSON K G (1993), *Stress and Animal Welfare*, London, Chapman & Hall.

BRYAN F L and DOYLE M P (1995), 'Health risks and consequences of *Salmonella* and *Campylobacter jejuni* in raw poultry', *Journal of Food Protection*, 58, 326–344.

BURT D W (2002), 'Applications of biotechnology in the poultry industry', *World's Poultry Science Journal*, 58, 5–13.

CORRY J E L and ATABAY H I (2001), 'Poultry as a source of *Campylobacter* and related organisms', *Journal of Applied Microbiology*, 90, 96S–114S.

COX N A, BAILEY J S and RYSER E T (1999), 'Incidence and behavior of *Listeria monocytogenes* in poultry and egg products', in *Listeria, Listeriosis and Food Safety*, eds Ryser E T and Marth E H, New York, Marcel Dekker, 565–600.

DAWKINS M S (1999), 'The role of behaviour in the assessment of poultry welfare', *World's Poultry Science Journal*, 55, 295–303.

DE BOER E and HAHNÉ M (1990), 'Cross contamination with *Campylobacter jejuni* and *Salmonella* spp from raw chicken products during food preparation', *Journal of Food Protection*, 53, 1067–1068.

DEELEY C (2002), 'Food irradiation: setting new standards or a slippery slope?', *Food Science and Technology*, 16(2), 52–55.

DOYLE M P and SCHOENI J L (1987), 'Isolation of *Escherichia coli* O157:H7 from retail fresh meats and poultry', *Applied and Environmental Microbiology*, 53, 2394–2396.

ELLENDORFF F (2002), 'Comparison of broiler production systems', *Archiv für Geflügelkunde*, 66, 58.

ERICKSON B E (1999), 'Dioxin food crisis in Belgium', *Analytical Chemistry*, 71, 541–543.

FALLON M (2001), 'Traceability of poultry and poultry products', *OIE Scientific and Technical Review,* 20, 538–546.

FLETCHER D L (1989), 'Factors influencing pigmentation in poultry', *CRC Critical Reviews in Poultry Biology*, 2(2), 149–170.

FLETCHER D L (1999), 'Color variation in commercially packaged broiler breast fillets', *Journal of Applied Poultry Research*, 8, 67–69.

FLETCHER D L (2002), 'Poultry meat quality', *World's Poultry Science Journal*, 58, 131–145.

FRONING G W (1995), 'Color of poultry meat', *Poultry and Avian Biology Reviews*, 6(1), 83–93.

HAFEZ H M, SCHULZE D and KOSTERS J (1998), 'Surveillance on verotoxin producing *E. coli* in broiler flocks and processing plants', in *COST Action 97 Pathogenic Microorganisms in Poultry and Eggs, 5 Poultry and Food Safety*, eds Nagy B and Mulder R W A W, Luxembourg, Office for Official Publications of the European Communities, 49–54.

HARRISON R (1964), *Animal Machines*, London, Vincent Stuart.

HELMUTH R (2000), 'Antibiotic resistance in *Salmonella*', in *Salmonella in Domestic Animals*, eds Wray C and Wray A, Wallingford, UK, CABI Publishing, 89–106.

HEUER O E, PEDERSEN K, ANDERSEN J S and MADSEN M (2001), 'Prevalence and antimicrobial susceptibility of thermophilic *Campylobacter* in organic and conventional broiler flocks', *Letters in Applied Microbiology,* 33, 269–274.

HEUVELINK A E, ZWARTKRUIS-NAHUIS J T M, VAN DEN BIGGELAR F L A M, VAN LEEUWEN W J and DE BOER E (1999), 'Isolation and characterization of verocytotoxin-producing *Escherichia coli* O157 from slaughter pigs and poultry', *International Journal of Food Microbiology*, 52, 67–75.

HOLROYD P H (2001), *Future Trends of Poultry Science and Practice*, Temperton Fellowship Report No. 10, Newport, UK, Harper Adams University College.

HOOD A M, PEARSON A D and SHAHAMAT M (1988), 'The extent of surface contamination of retailed chickens with *Campylobacter jejuni* serogroups', *Epidemiology and Infection*, 100, 17–25.

KESSEL A S, GILLESPIE I A, O'BRIEN S J, ADAK G K, HUMPHREY, T J and WARD L R (2001), 'General outbreaks of infectious intestinal disease linked with poultry, England and Wales, 1992–1999', *Communicable Disease and Public Health*, 4, 171–177.

KIRK-WILSON R (2002), *Review of Food Assurance Schemes*, London, Food Standards Agency.

LAMPKIN N (1994), *Organic Farming*, Tonbridge, UK, Farming Press.

LILLARD H S (1971), 'Occurrence of *Clostridium perfringens* in broiler processing and further processing operations', *Journal of Food Science*, 36, 1008–1010.

MEAD G C (1969), 'Growth and sporulation of *Clostridium welchii* in breast and leg muscle of poultry', *Journal of Applied Bacteriology*, 32, 86–95.

MEAD G C (1998), *The Safety of Poultry Products: Present Trends and Future Developments,* Temperton Fellowship Report No. 7, Newport, UK, Harper Adams Agricultural College.

MEAD G C and DODD C E R (1990), 'Incidence, origin and significance of staphylococci on processed poultry', *Journal of Applied Bacteriology Symposium Supplement*, 81S–91S.

RENNIE S (2002), 'Leg health in broilers – DEFRA-funded awareness campaign', *NFU Poultry Forum*, July/August, 5.

REPORT (1996), *Report on Poultry Meat*, Advisory Committee on the Microbiological Safety of Food, London, Her Majesty's Stationery Office.

REPORT (2001), *Second Report on* Salmonella *in Eggs*, Advisory Committee on the Microbiological Safety of Food, Norwich, Her Majesty's Stationery Office.

ROBERTS D (1972), 'Observations on procedures for thawing and spit-roasting frozen dressed chickens, and post-cooking care and storage: with particular reference to food-poisoning bacteria', *Journal of Hygiene, Cambridge*, 70, 565–588.

RODRIGUE D C, TAUXE R V and ROWE B (1990), 'International increase in *Salmonella enteritidis:* a new pandemic?', *Epidemiology and Infection,* 105, 21–27.

SCHILPZAND R A (1999), 'Shifts in food safety perception by consumers and consumer organisations', in *International Food Safety Handbook*, eds van der Heijden K, Younes M, Fishbein L and Miller S, New York, Marcel Dekker, 661–671.

SCHOENI J L and DOYLE M P (1994), 'Variable colonization of chickens perorally inoculated with *Escherichia coli* O157:H7 and subsequent contamination of eggs', *Applied and Environmental Microbiology*, 60, 2958–2962.

SIEGEL P B (2002), 'Interpretation of behaviour', *Archiv für Geflügelkunde*, 66, 27.

SOCKETT P N (1995), 'The epidemiology and costs of diseases of public health significance, in relation to meat and meat products', *Journal of Food Safety*, 15, 91–112.

STOCKDALE E (2003), 'Traceability in the food chain', *Food Science and Technology,* 17, 29–31.

THORNTON G and O'KEEFE T (2002), 'Value addition – the US poultrymeat industry's second transformation', *Poultry International*, October, 10–14.

VAN DER HEIJDEN K, YOUNES M, FISHBEIN L and MILLER S (eds) (1999), *International Food Safety Handbook*, New York, Marcel Dekker.

VAN HORNE P L M (2002), 'Production cost development of broilermeat', *Archiv für Geflügelkunde*, 66, 26–27.

WALDROUP A L (1996), 'Contamination of raw poultry with pathogens', *World's Poultry Science Journal*, 52, 7–25.

WATSON A (2000), 'IPPC – an opportunity not a threat', *Food Science and Technology Today*, 14, 203–205.

2

Breeding and quality of poultry

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2.1 Introduction

As a consequence of selection and improvements in rearing and management of nutrition, the characteristics of poultry production have changed dramatically over the last few decades. Improvements in bird growth performance and muscle development have been spectacular, as exemplified by the body weight and breast meat yield of six-week-old chickens, which have risen respectively from 1 to 2 kg and from 11 to 16% in less than 20 years (Nicholson, 1998). The broiler-meat industry mainly uses fast-growing commercial hybrids that are slaughtered between six and seven weeks. However, it has also developed free-range systems in response to consumer demand for more flavoursome products and enhanced animal welfare (Sauveur, 1997). These systems, particularly popular in European countries, use slow-growing birds that are given a mainly grain diet, have access to outdoors and are slaughtered at around 80 days of age (King, 1984). In 2000, more than 20% of all French poultry (90 million birds) were produced by the free-range system. The consequences of breeding and farming practices for the sensory quality and functional properties of the meat for further processing have not received much attention. Nevertheless, research has shown that meat-quality attributes may be affected by several factors associated with either the animal or its environment. These factors can affect the chemical composition of muscle, its structure and metabolism and, therefore, the mechanisms involved in turning muscle into meat. The objective of this chapter is to evaluate the impact of breeding factors (age, genotype, sex, rearing conditions) on the sensory and processing attributes of poultry meat. Because production of best-quality poultry meat depends on the control of breeding and slaughter-related parameters, the interactions between them will also be considered.

2.2   Factors affecting quality of poultry meat: age

In practice, animals selected for increased growth rate are slaughtered at a younger age. Studies on the effect of age at slaughter have focused mainly on the sensory attributes of meat in relation to the physico-chemical characteristics of muscle. Increasing the slaughter age for broilers increases the protein content of breast and thigh meat (Singh and Essary, 1974; Touraille *et al.*, 1981b; Grey *et al.*, 1983; Zanusso, 2002), but data for the lipid fraction of muscle are more equivocal. According to Singh and Essary (1974), there is no drastic effect of age on the lipid content of breast muscle between four and 10 weeks, and even a decrease in lipid after eight weeks has been reported by Touraille *et al.* (1981b) and Grey *et al.* (1983). By contrast, Zanusso (2002) showed that lipid increases continuously in chicken breast and thigh muscle from six to 22 weeks of age. As the birds grew (aged one year or more), there was either a decrease (Rabot, 1998) or an increase (Nakamura *et al.*, 1975; Grey *et al.*, 1983) in the lipid content of breast and thigh muscle. In turkey, the lipid fraction of breast muscle increased significantly between 16 and 20 weeks (Ngoka *et al.*, 1982). Similarly, the lipid and protein content of breast muscle in Muscovy or mule ducks significantly increased between eight and 12 weeks (Baéza *et al.*, 1998a, 2000).

Although it is unclear whether or not the total amount of muscle collagen is affected by age, its heat resistance increases and salt solubility decreases with advancing age in chickens (Nakamura *et al.*, 1975; Touraille *et al.*, 1981a,b; Zanusso, 2002), probably as a result of the formation of cross-linkages between molecules. Changes in the properties of the collagen molecule are likely to affect the tenderness and juiciness of chicken meat (Fig. 2.1), which generally decrease as birds become older (Brant and Hanson, 1962; Nakamura *et al.*, 1975; Yamashita *et al.*, 1976; Touraille *et al.*, 1981a,b; Sonayia and Okeowo, 1983). In more recent studies, however, the effect of age on meat tenderness was less obvious. Indeed, Sonayia *et al.* (1990) reported no differences in the tenderness of breast and thigh meat between five and eight weeks of age in broilers. Moreover, juiciness was greater in the breast meat of older birds. Similar results were obtained by Mohan *et al.* (1987), when comparing birds at six and eight weeks of age, and Delpech *et al.* (1983), who found no differences in tenderness or juiciness between birds at seven, nine or 11 weeks of age. Tawfik *et al.* (1990) and Farmer *et al.* (1997) even obtained significantly higher scores for the tenderness of meat from older birds. Differences in results reported in all these studies may reflect the use of broiler lines that differed in growth rate and therefore the onset of maturity. A decrease in tenderness with advancing age has been reported for turkey breast meat (Ngoka *et al.*, 1982). In this species, there is some evidence that tough breast meat can be associated with a less-organised distribution of muscle fibres and the presence of large, round fibres clustered in groups (Grey *et al.*, 1986). Fibre diameter increases considerably with advancing age (Rémignon *et al.*, 1995) and research is needed to evaluate the specific role of fibre size and distribution in determining the textural properties of poultry meat. In Muscovy duck, tenderness and juiciness also decrease with advancing
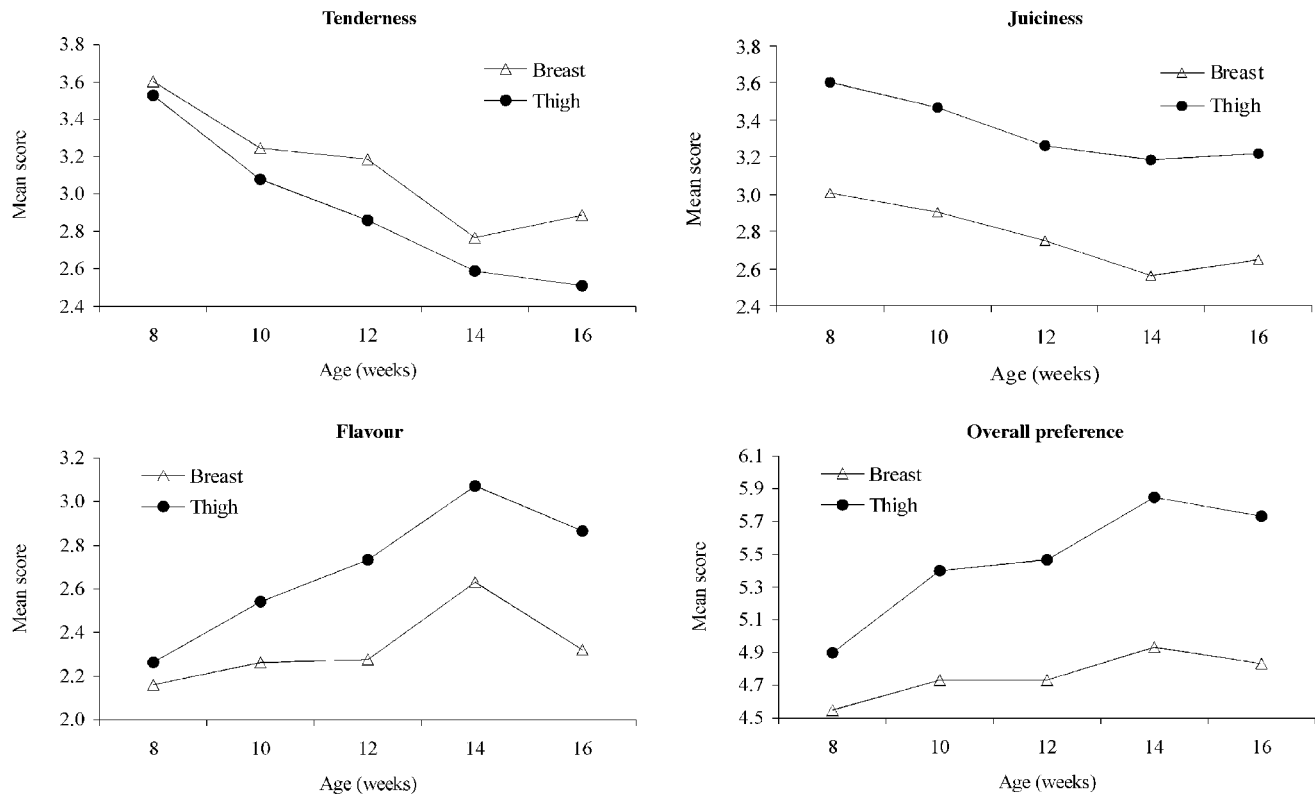
Fig. 2.1 Effect of age on mean scores for sensory traits of broiler breast and thigh meat. Panel rated traits from 1 low to 5 high for tenderness, juiciness and flavour, and from 1 low to 10 high for overall preference (from Touraille *et al.*, 1981b).

age, along with the ultimate pH and water-holding capacity (increased drip-loss) of breast muscle (Baéza *et al.*, 1998a). A study carried out on mule duck suggested that the decrease in tenderness with age in this species was not related to collagen content, which diminishes with advancing age, or to its solubility, which is unaffected by age (Baéza *et al.*, 2000). The lowest degree of tenderness in duck breast muscle is likely to be related to an increase in fibre size, as already demonstrated in beef by Crouse *et al.* (1991).

Increasing the age of slaughter also enhanced meat flavour and odour in broiler chicken and duck, especially for dark meat (Chambers *et al.*, 1989; Sonayia *et al.*, 1990; Tawfik *et al.*, 1990; Farmer *et al.*, 1997; Baéza *et al.*, 1998a), maximum flavour being found during the sexual maturation of broilers (Fig. 2.1; Touraille *et al.*, 1981a,b). Concomitant changes in the lipid fraction, such as variations in phospholipid or fatty-acid composition (Touraille *et al.*, 1981b; Sonayia, 1988; Rabot, 1998; Baéza *et al.*, 2000; Zanusso, 2002) could partly account for these observations. Increasing age was also associated with darker breast meat colour in broilers (Delpech *et al.*, 1983). In the same way, the breast meat of ducks becomes significantly redder and darker with advancing age, which is a likely consequence of the increase in haem-iron content of muscle (Baéza *et al.*, 2002).

Obviously, the sensory quality of meat is closely related to bird age at slaughter. Commercial selection for growth rate has led to birds being less mature, with meat that is generally more tender and juicy, but of a less intense flavour. However, the impact of such changes on the global acceptability of the product is not straightforward and preferences are directly linked to the eating habits of consumers. Indeed, in the French studies of Touraille *et al.* (1981a,b), older birds had greater global acceptability, mainly because of the more intense flavour and firmness of their meat. This result partly explains the success of the French free-range production system (more than 60% of the chickens sold in France as whole carcasses in 2002), which requires that the birds are killed at an age up to 81 days. By contrast, Yamashita *et al.* (1976) reported that Japanese consumers preferred meat from younger chickens, because of its extreme tenderness.

2.3   Factors affecting quality of poultry meat: genotype

2.3.1   Effects on eating properties of meat

The effect of age on meat quality must partly explain the differences between broiler genotypes with differing growth rates. Therefore, to assess the effect of genotype on meat quality, broilers have been compared at the same age. Under such conditions, Touraille *et al.* (1981a) and Delpech *et al.* (1983) found no effect of selection for growth *per se* on sensory meat quality. However, by comparing an ISA and a Ross chicken genotype, Farmer *et al.* (1997) showed significant differences between the genotypes in various measures of texture and cooked appearance of roast breast meat, and in the texture and cooked odour of

thigh meat. Moreover, a Canadian study reported differences in the sensory attributes of dark meat from light, experimental bird strains and heavy commercial broilers (Chambers *et al.*, 1989). Among broilers of similar age, it appears that dark meat from larger birds had a more intense flavour, was more tender and exhibited a higher overall acceptability score than that from smaller birds, which suggests that broiler size, that is, growth rate, can affect the sensory attributes of the meat. According to Chambers *et al.* (1989), carcass fatness, which, at a given age, is much greater in modern broilers, only explains a small part (8%) of the differences between bird strains in dark-meat flavour, tenderness and juiciness. Ricard *et al.* (1983) drew similar conclusions after examining the sensory properties of meat from two experimental, divergent lines of broilers, selected for high (24.3 g/kg) or low (5.9 g/kg) levels of abdominal fat. There were no clear differences between these two lines in relation to cooking losses or the flavour and juiciness of breast and thigh meat. Only tenderness was slightly greater in the high-fat birds. The results of these two studies suggest that a reduction in carcass fatness accounted for only a small proportion of the variation observed in sensory traits. Since the 1970s, poultry selection has led to an increased breast meat yield and reduced carcass fatness (Barton, 1994). According to the above results (Ricard *et al.*, 1983; Chambers *et al.*, 1989), carcass fatness in broilers has been reduced with little corresponding effect on the eating quality of the meat. This could be due partly to the fact that reducing the amount of abdominal fat barely affects the lipid content of muscles. Only the fat between thigh and drumstick muscles was reduced in the lean broiler (Ricard *et al.*, 1983). No data are available concerning the specific effect of increasing muscle yield on the sensory traits of breast meat. Nevertheless, it can be expected that structural changes in muscle associated with increased muscle development will, at least, affect the textural properties of breast meat.

In Muscovy duck, selection for growth rate alters the chemical composition of the breast meat by increasing protein and decreasing the total amount of collagen, without affecting its solubility (Baéza *et al.*, 2002). In this species, selection for meat yield and against fatness significantly reduces the lipid content of breast muscle and increases its light colour (Baéza *et al.*, 1997).

2.3.2   Effects on technological traits of meat

Recently, the technological traits of broiler breast meat have been considered in relation to muscle development (Table 2.1). Experimental selection for increased breast meat yield and reduced abdominal fat was associated with breast meat that was lighter in colour and exhibited a lower drip-loss (Le Bihan-Duval *et al.*, 1999). By comparison with unselected birds, the breast meat also showed a lower rate of decline in pH *post mortem* and a higher ultimate pH, which were consistent with the lower reserves of muscle glycogen in these birds (Le Bihan-Duval *et al.*, 1999; Berri *et al.*, 2001). A genetic study carried out on the same experimentally selected strain emphasised the importance of ultimate muscle pH and, to a lesser extent, the initial pH in determining water-holding

Table 2.1 Effect of an experimental selection for body conformation on the technological attributes of breast meat (Le Bihan *et al.,* 1999; Berri *et al.*, 2001)

	Control line	Selected line	Line effect
Body weight, g	2,237 ± 180	2,223 ± 144	NS
Breast yield, %	12.5 ± 1.7	15.1 ± 1.9	***
Abdominal-fat yield, %	2.45 ± 0.76	1.84 ± 0.55	***
Breast, pH 15 min	6.31 ± 0.13	6.42 ± 0.12	***
Breast, ultimate pH	5.84 ± 0.14	5.90 ± 0.14	**
L* (lightness)	52.1 ± 1.7	54.1 ± 2.0	***
a* (redness)	1.58 ± 0.97	0.58 ± 0.64	***
b* (yellowness)	10.81 ± 1.44	10.76 ± 1.35	NS
Drip-loss, %	2.04 ± 0.10	1.07 ± 0.05	***

The experimental line had been selected at the Station de Recherches Avicoles (INRA, France) through 15 generations for body weight, high breast yield and low abdominal fat (Le Bihan-Duval *et al.*, 1998).
L*, a*, b* and drip-loss were recorded three days *post mortem.*
NS, non significant; **, $P < 0.01$; ***, $P < 0.001$.

ability, which increases as both of these traits increase (Le Bihan-Duval *et al.*, 2001). It also confirms the considerable effect of ultimate pH on the light colour of the meat, which increases as ultimate pH decreases. By contrast, the comparison between selected and unselected broilers suggested that differences in breast meat lightness and redness would be more likely to arise from differences in haem-pigment content (Berri *et al.*, 2001). The comparison between a commercial broiler line selected for both growth rate and breast yield and its unselected counterpart confirmed that selection led to breast meat with higher initial and ultimate pH values and a lighter colour (Berri *et al.*, 2001).

Breast meat from a commercial, heavy line of turkey was also lighter in colour than that from less selected genotypes (Santé *et al.*, 1991). With turkey, there is some evidence that paleness of breast meat could be a consequence of the combination of accelerated *rigor mortis* and high muscle temperature after slaughter, which typically causes protein denaturation leading to pale, soft, exudative (PSE) meat with poorer functionality (Sosnicki *et al.*, 1998). In this species, the ultimate cause of the PSE syndrome is still uncertain, but a sustained, seasonal heat stress has been shown to increase the frequency of PSE meat (McKee and Sams, 1997). Recently, sensitivity to halothane was evaluated as a possible method for detecting turkeys prone to developing PSE. Results suggest that halothane sensitivity is associated with the susceptibility of turkeys to heat stress and the development of pale meat (Owens *et al.*, 2000). Moreover, halothane screening appeared to be better at predicting the development of PSE meat during heat stress in strains selected for large breast yield than in those selected for rapid, overall growth. Santé *et al.* (1991) compared growth-selected and slow-growing turkeys and suggested that *post-mortem* pH fall was more rapid in the breast of fast-growing birds. However, this was not confirmed by Wheeler *et al.* (1999). Moreover, according to Filus *et al.* (1995), the rate of

rigor mortis, as well as the water-holding capacity and the occurrence of typical muscle lesions associated with a PSE-like syndrome, vary among strains, but are not related to bird growth performance. Fernandez *et al.* (2001), too, reported no significant variation in initial and ultimate pH values of breast muscle from three turkey lines that differed in growth rate, even though fast-growing birds exhibited a lower glycogen content in breast muscle than slow- or medium-growing birds. In this experiment, breast muscle from the slow-growing turkeys was lighter in colour and tougher, showed greater drip-loss and curing-cooking yield and also a higher proportion of giant fibres (Rémignon *et al.*, 2000). These findings suggest that factors other than the *post-mortem* pH value of muscle contribute to the technological properties of the breast meat.

Changes in muscle fibre type might be expected to alter meat quality. In poultry, however, selection for growth performance or increased breast meat yield do not markedly affect the type of muscle fibre present (Aberle and Stewart, 1983; Rémignon *et al.*, 1995, 1996; Rémignon *et al*., 2000). By contrast, increased growth performance and breast meat yield in commercial broiler and turkey genotypes coincided with an increase in fibre diameter (Bentley, 1999 and Rémignon *et al.*, 2000 for turkeys; Rémignon *et al.*, 1995 and Guernec *et al.*, 2003 for broilers). However, the consequences of such a structural change on the sensory and processing quality of the meat have not yet received much attention, and further investigation is needed to determine the extent to which fibre hypertrophy, brought about by selection, can affect the quality of the meat.

An experiment carried out on quail that had been selected for fear reaction showed that birds from the high-fear line were more sensitive to an acute stress than birds selected for low-fear reaction (Rémignon *et al.*, 1998). When subjected to an acute stress, quails from the high-fear line had higher levels of plasma creatine kinase and a smaller increase in corticosterone levels, and the ultimate pH value of the breast meat and drip-loss were higher. From these preliminary results, it seems possible, therefore, to partly reduce the negative effects of the stress on meat quality by selecting birds for low fearfulness.

2.3.3   Estimates of the genetic parameters of the processing quality of poultry meat

Le Bihan-Duval *et al.* (2001) published the first estimates of genetic parameters of broiler breast meat quality. These estimates were obtained for an experimental broiler line reared and slaughtered under controlled conditions, which ensured a minimal effect of environment on meat traits (Table 2.2). Results indicated that the technological characteristics of the meat (pH, drip-loss, colour) had very significant heritabilities, between 0.35 and 0.57, the highest values being obtained for meat colour. Moreover, the ultimate pH value of muscle appeared to be a determining factor for broiler meat quality, since very high correlations were found between this trait and lightness in the colour of the meat and drip-loss. By contrast, body weight and breast meat yield were poorly correlated with meat traits, which suggested

Table 2.2 Estimates of genetic parameters[a] for breast meat quality and growth performance[b] in a broiler chicken line (Le Bihan-Duval *et al.*, 2001)

	pH_{15min}	pHu	L*	a*	b*	DL	BW	BRY	AFP
pH_{15min}	**0.49**	0.02	0.13	−0.23	0.05	−0.29	−0.06	0.12	−0.04
pHu		**0.35**	−0.91	0.14	−0.43	−0.83	0.07	0.13	−0.54
L*			**0.50**	−0.48	0.20	0.80	0.16	−0.07	0.50
a*				**0.57**	0.54	−0.25	−0.30	−0.29	−0.24
b*					**0.55**	0.16	−0.13	−0.39	−0.02
DL						**0.39**	−0.04	−0.16	0.29
BW							**0.35**	0.17	0.19
BRY								**0.55**	−0.17
AFP									**0.62**

[a] Heritabilities on the diagonal, genetic correlations above the diagonal.
[b] pH_{15min} = pH 15 min *post mortem*; pHu = ultimate pH; L* = lightness; a* = redness; b* = yellowness; DL = drip-loss; BW = body weight; BRY = breast yield; AFP = abdominal fat percentage.

that selection for growth and muscle development would not inevitably cause changes in the quality of broiler breast meat. A second study, carried out on a commercial turkey line (BUT Ltd) under commercial conditions, found lower levels (0.12 to 0.22) of heritability for breast-muscle pH and colour traits (Table 2.3; Le Bihan-Duval *et al.*, 2003). In thigh muscle, heritabilities were even close to zero. A strong negative correlation was obtained between breast pH, either at 20 min or 24 h *post mortem*, and lightness, which emphasises the role of a fall in muscle pH in determining the colour of turkey breast meat. In any case, the highest muscle pH values at 20 min and 24 h *post mortem* were associated with the highest body weights and breast meat yields, which do not support the idea that intensively selected turkeys would be more susceptible to meat defects. These initial results emphasise the importance of the genetic approach in improving meat quality in broilers and turkeys.

Table 2.3 Estimates of genetic parameters[a] for breast meat quality and growth performance[b] in a commercial turkey line (Le Bihan-Duval *et al.*, 2003)

	BW	BRY	PH_{20}	pHu	L*	a*	b*
BW	**0.35**	0.13	0.55	0.55	−0.41	0.15	−0.38
BRY		**0.32**	0.61	0.22	−0.24	−0.16	−0.29
PH_{20}			**0.22**	0.60	−0.79	−0.25	−0.20
pHu				**0.16**	−0.53	0.08	−0.01
L*					**0.12**	0.21	0.47
a*						**0.21**	−0.05
b*							**0.14**

[a] Heritabilities on the diagonal, genetic correlations above the diagonal.
[b] BW = body weight; BRY = breast yield; pH_{20} = pH 20 min *post mortem*; pHu = ultimate pH; L* = lightness; a* = redness; b* = yellowness.

2.4   Factors affecting quality of poultry meat: sex

Although males grow faster and are leaner, but exhibit a slightly lower breast meat yield than females (Ricard, 1988), the sensory attributes of the meat are barely affected by gender, when birds are compared at the same age. Breast meat from standard male chickens has been observed to be slightly more tender in some studies (Goodwin *et al.*, 1969; Culioli *et al.*, 1990) and tougher in another (Ricard and Touraille, 1988). It has also been observed to be slightly juicier (Culioli *et al.*, 1990; Ristic, 1991). When both sexes are reared together under optimal growth conditions, males reach sexual maturity (around 14 weeks) before females and their meat has a stronger flavour (Ricard and Touraille, 1988). A recent study (Zanusso, 2002) confirmed the low impact of sexual status (entire or castrated male and female) on the physico-chemical properties and eating quality of chicken breast and thigh meat. Even in species that exhibit a high degree of high sexual dimorphism, such as Muscovy duck, the influence of sex on the sensory and technological attributes of the meat is slight (Baéza *et al.*, 1998a). Breast meat from Muscovy males appeared to be only slightly more tender, juicier and less flavoursome than that of females.

2.5   Factors affecting quality of poultry meat: rearing conditions and production practices

2.5.1   Rearing conditions
In commercial broiler production, high stocking density reduces bird activity and, therefore, creates an array of carcass defects (Ricard, 1988; Elfadil *et al.*, 1996; Gregory, 1998). For instance, birds interact more among themselves and are more prone to scabby hips, which form unsightly blemishes on the carcasses and lead to carcass downgrading. High density can also increase litter moisture and, when the birds sit on wet litter, they are prone to developing hock burn (scabs on the hocks), which also lead to carcass downgrading. Bad management of litter can also be a cause of breast blisters and burns. Burns on the skin, which may become infected through prolonged exposure to moisture, is more common in males than females. All these carcass quality problems are avoided by not overstocking, by managing the litter correctly and avoiding conditions that lead to diarrhoea in the birds. As stocking density rises and the birds compete more for feed, growth rate and breast development start to decline. However, stocking density does not have any marked effect on the sensory attributes of the meat (Ricard *et al.*, 1986). Only the study of Farmer *et al.* (1997) suggests that reducing stocking density from 17 to 4.25 birds/m^2 increases the odour intensity of cooked thigh meat. High ambient temperatures may improve the flavour of chicken meat (Sonayia *et al.*, 1990) and increase the proportion of polyunsaturated fatty acids in carcass fat depots (Sonayia, 1988). The tenderness of broiler breast meat can be affected by season of the year, with more tender meat being obtained in the fall and tougher meat in the summer (Simpson and Goodwin, 1975). Also, when broilers were exposed

experimentally to a cyclic temperature-humidity regime that approximated a summer day in Mississippi, they showed lower carcass weights and protein content, as well as paler and drier meat, comparable with the PSE meat commonly observed in processing plants (Tankson *et al.*, 2001). As already mentioned above, the occurrence of a PSE-like syndrome in turkeys, which leads to tough, pale meat, has been reported to increase in summer (McCurdy *et al.*, 1996) or after sustained heat exposure during rearing (McKee and Sams, 1997).

Rearing conditions are expected to be even more important under the less intensive systems used for free-range birds. Extensive systems provide plenty of space for exercise, but the impact of access to the open air *per se* on the eating quality of chicken meat is not significant, even though broilers produced in this way have an increased breast meat yield and lower abdominal fat (Ricard *et al.*, 1986; Bastiens *et al.*, 1991; Garcia Martin *et al.*, 1995). In guinea fowl, free-range rearing conditions (including feeding) produce, at a given age, smaller and less fatty birds, with slightly tougher and leaner breast meat. Similarly, keeping ducks and geese on pasture is said to have hardly any effect on the sensory quality of the meat (Knust *et al.*, 1995 for ducks; Baéza *et al.*, 1998b for geese), although it can change carcass composition by reducing the proportion of fat (Pingel and Knust, 1993 for ducks).

2.5.2   Production practices

In some European countries, like France, extensive systems of poultry production have been developed as a reaction to intensive poultry production, which has tended to give chicken the image of a cheap, low-quality product. The meat has been considered tasteless, or even having a bad flavour, and too soft (Laszczyk-Legendre, 1999). In France, the concept of 'Label Rouge', traditional, free-range poultry was created in 1960. This concept is based on the criteria currently demanded by European consumers, namely bird welfare, environmental protection, meat of superior organoleptic quality, product traceability and total control of hygiene, with all guarantees provided by a recognised system of certification based on third-party controls.

The rearing specifications for Label Rouge require that birds come from special breeds, selected for their low growth rate, high meat quality and good skin appearance. Label Rouge poultry are reared in the open air and profit from large, shaded, open spaces ($2\,m^2$ minimum per chicken up to $10\,m^2$ for geese). The growing area is limited to $400\,m^2$ per poultry house, $1600\,m^2$ per farm, and the stocking density to 11 birds per m^2. Feed must contain cereals (75% minimum), no animal matter, a restricted number of supplements and no growth enhancers. Transport to the slaughterhouse must not exceed two hours or 100 km, and the conditions involved have been strictly defined. Label Rouge production increased four-fold in 20 years and the birds are mainly sold as whole carcasses. However, this rate of growth is slowing down, partly because of the demand for cut portions and further processed products, which developed rapidly at the expense of whole carcasses (Jehl, 2000).

The impact of production practices on the characteristics of poultry meat have been studied by comparing standard and Label Rouge-type strains, raised and slaughtered according to their own production norms (Table 2.4). Under these conditions, the body weight at slaughter of 11–12-week-old Label Rouge chickens and 6–7-week-old standard broilers were equivalent. The breast and thigh meat from Label Rouge birds was generally less juicy, but firmer and more flavoursome than that of the standard broiler (Touraille *et al.*, 1985; Culioli *et al.*, 1990; Girard *et al.*, 1993), mainly as a result of their greater age at slaughter. Culioli *et al.* (1990) also reported that differences in tenderness and juiciness between Label Rouge and standard birds were more marked for males, while the better flavour of Label Rouge was more marked for female birds. According to Farmer *et al.* (1997), sensory differences between Label Rouge and more intensively reared chicken may be explained by a combined effect of genotype, age, diet and stocking density. Texture and appearance would be most influenced by genotype, diet and age, while cooked-meat odour and flavour seem related more to age, the genotype–diet interaction and, to a lesser extent, stocking density.

More recently, the processing characteristics of breast meat from slow-growing Label Rouge-type and fast-growing standard chickens have been evaluated (Table 2.4). The processes associated with *rigor mortis* occur more rapidly in the breast muscle of Label Rouge-type birds (Culioli *et al.*, 1990; Berri *et al.*, 2002), mainly because they struggle more during shackling and are more sensitive to pre-slaughter stresses (Debut *et al.*, 2003). When subjected to heat stress for three hours before slaughter, Label Rouge-type birds reacted by

Table 2.4   Comparison of breast-meat traits for 12-week-old Label Rouge-type and seven-week-old standard chickens (Breast sensory-trait data from Culioli *et al.*, 1990; Technological traits and further-processed product quality data from Berri *et al.*, 2002)

	Type of production		Bird-type effect
	Standard	Label Rouge	
Breast: sensory traits			
Tenderness	7.13	5.66	***
Juiciness	5.25	4.44	***
Flavour	4.72	5.05	NS
Preference	5.59	6.02	*
Breast: technological traits			
pH 15 min	6.44 ± 0.12	6.22 ± 0.17	***
Ultimate pH	5.80 ± 0.11	5.66 ± 0.12	***
Drip-loss, %	0.56 ± 0.32	1.64 ± 0.67	***
Curing-cooking yield, %	105.7	100	Not determined
White cured-cooked meat traits			
Dry texture	3.1 ± 1.6	4.5 ± 1.8	**
Moist appearance	4.2 ± 1.8	3.0 ± 1.3	*
Slice cohesiveness	4.0 ± 1.2	5.3 ± 1.4	**

NS, non significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

reducing their consumption of muscle glycogen (Berri, unpublished results), which leads to a decrease in the ultimate pH value, especially for thigh meat (Debut *et al.*, 2003). Because of the greater rate of fall in pH and/or lower ultimate pH, Label Rouge-type breast meat exhibited poor water-holding ability, which resulted in lower yields during curing-cooking but, in further processed meat with lower levels of moisture, a drier texture and better slicing characteristics. These findings would need to be taken into account if ever free-range production turned towards the further processed product market.

2.6   Future trends: improving poultry quality

The quality of poultry meat depends on a large number of animal-related factors. The available literature demonstrates the major role of genetics and age at slaughter on the sensory attributes of the meat. There is also some recent evidence that these two factors could change the technological properties of meat in conjunction with the effects of processing. This underlines the importance of future research in assessing the interactions between breeding and processing in determining meat quality. The objective of the work should be to ensure optimal meat quality by either adapting the birds to the technological constraints and products that exist now or in the future, or adjusting processes and markets to the output of the different modes of poultry production.

2.7   Sources of further information and advice

- Animal and Poultry Science Department, University of Guelph, Ontario, Canada NIG 2W1
- British United Turkeys, Broughton, Chester CH4 0EW, UK
- Department of Agriculture for Northern Ireland, Food Science Division and the Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX UK
- Department of Food Science & Human Nutrition and Department of Chemistry, Michigan State University, East Lansing, Michigan 48824–1224, USA
- Department of Population Medicine, Ontario Veterinary College, University of Guelph, Canada
- Department of Poultry Science, Mississippi State University, Mississippi 39762, USA
- Department of Poultry Science, Texas A & M University, College Station 77843–2472, USA
- Ecole Nationale Supérieure Agronomique Toulouse, Castanet Tolosan, France
- Station de Recherches Avicoles, INRA, 37380, Nouzilly – France
- Station de Recherches sur la Viande, INRA, 63122, Saint-Genès-Champanelle – France.

2.8   References

ABERLE E D and STEWART T S (1983), 'Growth of fiber types and apparent fiber number in skeletal muscle of broiler- and layer-type chickens', *Growth*, 47, 135–144.

BAÉZA E, DE CARVILLE H, SALICHON M R, MARCHÉ G and LECLERCQ B (1997), 'Effect of selection, over three or four generations, on meat yield and fatness in Muscovy ducks', *British Poultry Science*, 38, 359–365.

BAÉZA E, SALICHON M R, MARCHÉ G AND JUIN H (1998a), 'Effect of sex on growth, technological and organoleptic characteristics of the Muscovy duck breast muscle', *British Poultry Science,* 39, 398–403.

BAÉZA E, GUY C, SALICHON M R, JUIN H, ROUSSELOT-PAILLEY D, KLOSOWSKA D, ELIMINOWSKA-WENDA G, SRUTEK M and ROSINSKI A (1998b), 'Influence of feeding systems, extensive versus intensive, on fatty liver and meat production in geese', *Arch. Geflügelk*, 62(4), 169–175.

BAÉZA E SALICHON M R, MARCHÉ G, WACRENIER N, DOMINGUEZ B and CULIOLI J (2000), 'Effects of age and sex on the structural, chemical and technological characteristics of mule duck meat', *British Poultry Science*, 41, 300–307.

BAÉZA E, DESSAY C, WACRENIER N, MARCHÉ G and LISTRAT A (2002), 'Effect of selection for improved body weight and composition on muscle and meat characteristics in Muscovy duck', *British Poultry Science,* 43, 560–568.

BARTON N F (1994), 'Breeding meat type poultry for the future targets for selection, limits to performance and market requirements for chicken', *Proceedings of the Ninth European Poultry Conference*, Glasgow, UK, 33–38.

BASTIENS A, DEROANNE C, CARLETTI G and ZAYAN R (1991), 'Influence of age, strain and breeding method on the eating quality of broiler chicken', *Proceedings of the Thirty-Seventh International Congress of Meat Science and Technology*, Kulmbach, Germany, 1, 37–43.

BENTLEY J S (1999), 'Meat characteristics of turkeys, a breeder's perspective', *Proceedings of the Fourteenth European Symposium on the Quality of Poultry Meat*, Bologna, Italy, 9–28.

BERRI C, WACRENIER N, MILLET N and LE BIHAN-DUVAL E (2001), 'Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines', *Poultry Science*, 80, 833–838.

BERRI C, LE BIHAN-DUVAL E, BAEZA E, CHARTRIN P, QUENTIN M, PICGIRARD L, JEHL N and DUCLOS M (2002), 'Qualité technologique de la viande de poulet en relation avec le mode de production', *Proceedings of the Neuvièmes Journées des Sciences du Muscle et Technologie de la Viande*, Clermont-Ferrand, France, 115–120.

BRANT A W and HANSON H L (1962), 'Age, sex and genetic effect on poultry flavor', *Proceedings of the Twelfth World's Poultry Congress*, Sydney, Australia, 409–413.

CHAMBERS J R, FORTIN A, MACKIE D A and LARMOND E (1989), 'Comparison of sensory properties of meat from broilers of modern stocks and experimental strains differing in growth and fatness', *Canadian Institute of Food Science and Technology Journal,* 22, 353–358.

CROUSE J D, KOOHMARAIE M and SEIDEMAN S D (1991), 'The relationship of muscle fibre size to tenderness of beef', *Meat Science*, 30, 295–302.

CULIOLI J, TOURAILLE C, BORDES P and GIRARD J P (1990), 'Carcass and meat characteristics of ''Label Fermier'' chickens', *Archiv für Geflügelkunde,* 53, 237–245.

DEBUT M, BERRI C, BAÉZA E, SELLIER N, ARNOULD C, GUEMENE D, JEHL N, BOUTTEN B, JEGO Y, BEAUMONT C and LE BIHAN-DUVAL E (2003), 'Variation of chicken technological

meat quality in relation to gemotype and preslaughter stress conditions', *Poultry Science*, 82, 1829–1838.

DELPECH P, DUMONT B L and NEFZAOUI A (1983), 'Influence du rationnement et du patrimoine génétique de poulets sur les caractéristiques physico-chimiques et sensorielles de la viande à différents âges', *Proceedings of the Sixth European Symposium on the Quality of Poultry Meat*, Ploufragan, France, 21–27.

ELFADIL A A, VAILLANCOURT J -P and MEEK A H (1996), 'Impact of stocking density, breed and feathering on the prevalence of abdominal skin scratches in broiler chickens', *Avian Diseases*, 40, 546–552.

FARMER L J, PERRY G C, LEWIS P D, NUTE G R, PIGGOT J R and PATTERSON, R L S (1997), 'Responses of two genotypes of chickens to the diets and stocking densities of conventional UK and Label Rouge production systems: II Sensory attributes', *Meat Science*, 47, 77–93.

FERNANDEZ X, SANTÉ V, BAÉZA E, LE BIHAN-DUVAL E, BERRI C, RÉMIGNON H, BABILÉ R, LE POTTIER G, MILLET N, BERGE P and ASTRUC T (2001), 'Post mortem metabolism and meat quality in three genetic types of turkey', *British Poultry Science*, 42, 462–469.

FILUS K, JANKOWSKI J, MELLER Z and ROTKIEWICZ T (1995), Meat quality and quantity of different hybrids of slaughter turkeys', *Proceedings of the Twelfth European Symposium on Quality of Poultry Meat*, Zaragoza, Spain, 21–27.

GARCIA MARTIN E, CEPERO R, CAMPO M M, LAFUENTE R, SANUDO C and CANTI, M (1995), 'Effects of production system on the meat quality of Label chickens and capons', *Proceedings of the Twelfth European Symposium on the Quality of Poultry Meat*, Zaragoza, Spain, 207–217.

GIRARD J P, CULIOLI J, DENOYER C, BERDAGUÉ J L and TOURAILLE C (1993), 'Comparison between two populations of two poultry species according to their fat composition', *Archiv für Geflügelkunde,* 57, 9–15.

GOODWIN T L, ANDREWS L T and WEBB (1969), 'The influence of age, sex and energy level on the tenderness of broilers', *Poultry Science*, 48, 548–552.

GREGORY N G (1998), *Animal Welfare and Meat Science*, Wallingford, UK, CAB International.

GREY T C, ROBINSON D, JONES J M, STOCK S W and THOMAS N L (1983), 'Effect of age and sex on the composition of muscle and skin from a commercial broiler strain', *British Poultry Science*, 24, 219–231.

GREY T C, GRIFFITHS N M, JONES J M and ROBINSON D (1986), 'A study of some factors influencing the tenderness of turkey breast meat', *Lebensmittel Wissenschaft und Technologie*, 19, 412–414.

GUERNEC A, BERRI C, CHEVALIER B, WACRENIER-CERÉ N, LE BIHAN-DUVAL E and DUCLOS M J (2003), 'Muscle development, insulin-like growth factor-I and myostatin mRNA levels in chickens selected for increased breast muscle yield', *Growth Hormones and IGF Research*, 13(1), 8–18.

JEHL N (2000), 'Segmentation du marché du poulet: 15% de produits élaborés', *Viandes Prod. Carnés*, 21, 64–70.

KING R B N (1984), 'The breeding nutrition, husbandry and marketing of Label Rouge poultry', A report for the Ministry of Agriculture, Fisheries and Food Agricultural and Development and Advisory Service, London.

KNUST U, WICKE M, PINGEL H, LENGERKEN G V and SALOMON V (1995), 'Muscle structure and meat quality of ducks reared on pasture and under intensive conditions respectively', *Proceedings of the Twelfth European Symposium on the Quality of*

Poultry Meat, Zaragoza, Spain, 189–193.

LASZCZYK-LEGENDRE A (1999), 'Label Rouge traditional free range poultry: a concept including quality environment and welfare', *Proceedings of the Fourteenth European Symposium on the Quality of Poultry Meat*, Bologna, Italy, 255–264.

LE BIHAN-DUVAL E, MIGNON-GRASTEAU S, MILLET N and BEAUMONT C (1998), 'Genetic analysis of a selection experiment on increased body weight and breast muscle weight as on limited abdominal fat weight', *Br. Poult. Sci.*, 39, 346–353.

LE BIHAN-DUVAL E, MILLET N and RÉMIGNON H (1999), 'Broiler meat quality, effect of selection for increased carcass quality and estimates of genetic parameters', *Poultry Science*, 78, 822–826.

LE BIHAN-DUVAL E, BERRI C, BAÉZA E, MILLET N and BEAUMONT C (2001), 'Estimation of the genetic parameters of meat characteristics and of their genetic correlations with growth and body composition in an experimental broiler line', *Poultry Science*, 80, 839–843.

LE BIHAN-DUVAL E, BERRI C, BAÉZA E, SANTÉ V, ASTRUC T, RÉMIGNON H, LE POTTIER G, BENTLEY J, BEAUMONT C and FERNANDEZ X (2003), 'Genetic parameters of meat technological quality in a pure commercial line of turkey', *Genetics, Selection, Evolution*, in press.

MCCURDY M C, BARBUT S and QUINTON M (1996), 'Seasonal effects on PSE in young turkey breast meat', *Food Research International,* 29, 363–366.

MCKEE S R and SAMS A R (1997), 'The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey meat', *Poultry Science*, 76, 1616–1620.

MOHAN B, NARAHARI D, VENKATESAN E S and JAYA PRASAD I A (1987), 'The influence of age and sex on the chemical composition, tenderness and organoleptic characteristics of broiler meat', *Cheiron*, 16, 145–151.

NAKAMURA R, SEKOGUCHI S and SATO Y (1975), 'The contribution of intramuscular collagen to the tenderness of meat from chickens with different ages', *Poultry Science*, 54, 1604–1612.

NGOKA D A, FRONING G W, LOWRY S R and BABJI A S (1982), 'Effects of sex, age, preslaughter factors, and holding conditions on the quality characteristics and chemical composition of turkey breast muscles', *Poultry Science*, 61, 1996–2003.

NICHOLSON, D (1998), 'Research, is it the broiler industry's partner into the new millennium?' *World's Poultry Science Journal*, 54, 271–278.

OWENS C M, HIRSCHLER E M, MCKEE S R, MARTINEZ-DAWSON R and SAMS A R (2000), 'The characterization and incidence of pale, soft, exudative turkey meat in a commercial plant', *Poultry Science*, 79, 553–558.

PINGEL H and KNUST U (1993), 'Review on duck meat quality'*, Proceedings of the Eleventh European Symposium on the Quality of Poultry Meat*, Tours, France, 26–38.

RABOT, C (1998),*Vitesse De Croissance et Caractéristiques Lipidiques et Sensorielles Des Muscles de Poulet,* PhD thesis, INA-PG, Paris, France.

RÉMIGNON H, GARDAHAUT M F, MARCHÉ G and RICARD F H (1995), 'Selection for rapid growth increases the number and the size of muscle fibres without changing their typing in chickens', *Journal of Muscle Cell and Motility*, 16, 95–102.

RÉMIGNON H, DESROSIERS V and MARCHÉ G (1996), 'Influence of increasing breast meat-yield on muscle histology and meat quality in the chicken', *Reproduction, Nutrition and Development*, 36, 523–530.

RÉMIGNON H, MILLS A D, GUEMENE D, DESROSIERS V, GARREAU-MILLS M, MARCHE M and MARCHE G (1998), 'Meat quality traits and muscle characteristics in high or low

fear lines of Japanese quails (*Coturnix japonica*) subjected to acute stress', *British Poultry Science*, 39, 372–378.

RÉMIGNON H, ZANUSSO J, ALBERT G and BABILÉ R (2000), 'Occurrence of giant myofibres according to muscle type, pre- or post-rigor state and genetic background in turkeys', *Meat Science*, 56, 337–343.

RICARD F H (1988), 'Influence of stocking density on growth rate and carcass characteristics of floor reared meat type domestic chicken', *Annales de Zootechnie*, 37, 87–98.

RICARD F H and TOURAILLE C (1988), 'Studies of sex effect on chicken meat sensory characteristics', *Archiv für Geflügelkunde*, 52, 27–30.

RICARD F H, LECLERQ B and TOURAILLE C (1983), 'Selecting broilers for low and high abdominal fat, distribution of carcass fat and quality of meat', *British Poultry Science*, 24, 511–516.

RICARD F H, TOURAILLE C and MARCHE G (1986), 'Influence des méthodes d'élevage sur la qualité des carcasses du poulet', *Proceedings of the Seventh European Poultry Conference*, Paris, France, pp 870–873.

RISTIC M (1991), 'Influence of age and sex on carcass value and meat quality in broiler, *Fleischwirtschaft*, 71, 443–446.

SANTÉ V, BIELICKI G, RENERRE M and LACOURT A (1991), 'Post mortem evolution in the Pectoralis superficialis muscle from two turkey breeds, relationship between pH and colour changes', *Proceedings of the Thirty-Seventh International Congress of Meat Science and Technology*, Kulmbach, Germany, 465–468.

SAUVEUR B (1997), 'Les critères et facteurs de la qualité des poulets Label rouge', *INRA Production Animale*, 10, 219–226.

SIMPSON M D and GOODWIN T L (1975), 'Tenderness of broilers as affected by processing plants and seasons of the year', *Poultry Science*, 54, 275–279.

SINGH S P and ESSARY E O (1974), 'Factors influencing dressing percentage and tissue composition of broilers', *Poultry Science*, 53, 2143–2147.

SONAYIA E B (1988), 'Fatty acid composition of broiler abdominal fat as influenced by temperature, diet, age and sex', *British Poultry Science*, 29, 589–595.

SONAYIA E B and OKEOWO O O (1983), 'Live performance, abdominal fat, and toughness of 6–16 weeks old broilers', *Journal of Animal Production Research,* 3, 103–114.

SONAYIA E B, RISTIC M and KLEIN W F (1990). 'Effect of environmental temperature, dietary energy, age, sex on broiler carcase portions and palatability', *British Poultry Science*, 31, 121–128.

SOSNICKI A A, GREASER M L, PIETZRAK M, POSPIECH E and SANTÉ V (1998), 'PSE-like syndrome in breast muscle of domestic turkeys, a review', *Journal of Muscle Foods*, 9, 13–23.

TANKSON, J D, VIZZIER-THAXTON Y, THAXTON J P, MAY J D and CAMERON J A (2001), 'Stress and nutritional quality of broilers', *Poultry Science*, 80, 1384–1389.

TAWFIK, E S, OSMAN A M A, RISTIC M, HEBELER W and KLEIN W F (1990), 'Effect of environmental temperature and growth, carcass traits and meat quality of broilers from both sexes and different ages. 4: Report, sensoric test of meat quality', *Archiv für Geflügelkunde,* 54, 14–19.

TOURAILLE C, KOPP J, VALIN C and RICARD F H (1981a), 'Chicken meat quality. 1: Influence of age and growth rate on physico-chemical and sensory characteristics of the meat', *Archiv für Geflügelkunde*, 45, 69–76.

TOURAILLE C, RICARD F H, KOPP J, VALIN C and LECLERQ B (1981b), 'Chicken meat quality. 2: Changes with age of some physico-chemical and sensory characteristics of the

meat', *Archiv für Geflügelkunde*, 45, 97–104.

TOURAILLE C, LASSAUT B and SAUVAGEOT F (1985), 'Qualités organoleptiques de viandes de poulets Labels', *Viandes et Produits Carnés*, 6, 67–72.

WHEELER B R, MCKEE S R, MATTHEWS N S, MILLER R K and SAMS A R (1999), 'A halothane test to detect turkeys prone to developing pale, soft, and exudative meat', *Poultry Science*, 78, 1634–1638.

YAMASHITA C, ISHIMOTO Y, MEKADA H, EBISAWA S, MURAI I and NONAKA S (1976), 'Studies on meat quality of broilers. II: Influence of age of chickens on the meat taste', *Japanese Poultry Science*, 13, 14–19.

ZANUSSO J (2002), Engraissement, Structure des Muscles et Qualité de la Viande de Volailles, Exemple du Gavage Chez le Canard de Barbarie et de la Castration Chez le Poulet, PhD thesis, ENSA, Toulouse, France.

3

Husbandry techniques

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3.1 Introduction

Husbandry employed during live-bird production of fowl readily affects the amount of meat produced and its quality. The relevance of the term 'meat' is not limited to those who actually eat the product, but pertains to characteristics of the live bird, as well as all intermediate aspects of processing, marketing, etc., until consumption. In turn, the whole carcass, its cut parts, skinless, boneless meat, cooking effects and sensory attributes are all appropriate considerations. While genetics, sex and age determine each bird's yield and quality potential at any one time throughout live-bird production, the existing environment and all aspects of feed modify and provide for their expression. Simplistically, the environment represents a complex of conditions that are imposed externally, whereas feed, with its uniqueness of feedstuffs, nutrient balance and non-nutrient additives, must be consumed before expression. Flooring, temperature, humidity and pen density are obvious environmental concerns, whereas nutritional support is the central objective of feeding. The following is a cursory view of the factors most often encountered with environment and feed that may affect the amount and quality of poultry meat. Microbial aspects have been excluded other than those that are implicit in the expression of husbandry. Broiler chickens and turkeys are the focus of attention, from initiation of formal production until the last feed is withdrawn in preparation for processing. Finally, any aspect of husbandry must also consider its impact on the welfare of the animal and consequences for the environment and society at large.

3.2   Environmental influences on the quality of poultry meat

Surfaces of the bird affected by environment are either localized at specific sites or are all-encompassing. Flooring and bird density invariably create localized effects arising from intermittent contact. Temperature and lighting are influences that are continuously perceived by the flock at large. Impairments in appearance are usually contact repercussions, whereas lighting acts indirectly and is more pervasive.

3.2.1   Flooring

In one form or another, the floor is in direct contact with the bird throughout live-bird production. Repercussion from these contacts usually escalates with body weight and deterioration of the floor. Although various forms of wire floors, their combination with plastic and wooden slats exist, use of loose litter covering a solid surface predominates. Litter can be sugar-cane bagasse, dried citrus pulp, wood shavings, straw, rice hulls and many other forms, depending on cost and accessibility. Regardless of source, carcass problems attributable to litter are generally less severe than those encountered with any of the other floorings (Table 3.1). Carcass problems attributable to litter largely involve the feet and breast, because these parts have the greatest frequency of contact. Birds suffer progressively with age, particularly males, once past the inflection point in the growth curve. Expression at this time involves both litter quality and bird behavior. Accentuation of hock 'burns' from ammonia and keel problems is likely to follow a transition from diverse juvenile activities to a more sedentary mode, with adolescence and heavier weight. Accrual of excreta in litter and its associated moisture enable accentuated microbial activity, with resultant metabolic by-products, particularly ammonia. An increased concentration of ammonia occurs concurrently with a rise in pH, and high levels are central to the appearance of carcass defects. Blisters and buttons on the keel, variation in keel

Table 3.1   Effect of flooring type on live-bird performance and incidence of defects in the breast muscle of male broilers[1]

Flooring Type	Body weight (g)	Total Feed : gain	Mortality (%)	Breast defects %			
				fleshing	keel	infection	blisters
Pen–litter floor	1852	1.72	3.6	2.6	7.8	4.0	4.0
Cage–wire floor	1830	1.90	12.1	5.6	16.7	2.8	81.8
Cage–plastic mesh	1894	1.82	10.8	4.0	8.2	48.9	4.1
Cage–plastic mesh	1850	1.90	3.8	4.0	1.3	23.6	31.6
Cage–plastic liner	1908	1.76	7.2	5.2	6.6	10.6	55.9
Cage–rubber weave	1824	1.75	12.0	11.1	16.2	8.4	27.8

Note
[1]Areas corresponded to 40 males at 51 days of age in 1.22 × 2.44 m.
Selected data from May *et al*. (1982).

shape and infection of adjacent feather follicles all necessitate the trimming and loss of breast meat. Various forms of dermatitis on the feet are a well-known occurrence and seriously impair their quality and use as a food.

High moisture is probably the single most influential factor leading to carcass problems from litter (Martland, 1985). Moisture accrual occurs not only by progressive contributions from excreta, but from drinker spillage and poor ventilation that reduce the effect of corrective evaporation. Drinker design and management of their height, water depth and valve sensitivity can have a marked effect on litter moisture in the immediate area (Elson, 1989). As litter moisture increases, so also does the incidence of sticking, caking and microbial activity. Although foot and breast down-grading inextricably involve microbial infections, the addition of broad-spectrum antibiotics to feed has generally provided little relief compared to litter treatments that maintain a low pH. Ammonia *per se* would appear to be the primary culprit, rather than ammonium ion. Litter having an acid pH also releases less free ammonia into the atmosphere and substantially improves air quality. The adverse effects of high ammonia on air quality and live-bird performance have been established, but any direct effects on carcass and meat have not been documented.

The only quality problem directly attributable to litter that involved meat *per se* occurred with chips from wood preserved with chlorophenol. Molds inherently associated with the original shavings metabolically formed small amounts of trichloroanisole that caused a musty 'off' flavor in the meat. Although these molds and chlorophenols would dissipate with accrual of excreta and overall microbial activity, sufficient chloroanisole was present to contaminate the meat (Land *et al.*, 1975). Direct treatment of litter with other organohalides, particularly pesticides, is also possible; however, no effects on either carcass quality or sensory attributes have been observed.

3.2.2   Temperature

Extremes of temperature encountered during live-bird production can influence the amount of meat and its quality, both as a direct consequence and by indirect means. Direct effects are attributed to alterations in the vascular system. Mayes (1980a) reported an increase in superficial bruising of broilers as temperatures increased during the last day of production. Presumably, vasodilation and vascular fragility with increasing temperature were the basis for light bruising, because no correlation existed with extensive or deep bruising. Similarly, the extent of pale, soft, exudative (PSE) breast meat is accentuated in turkeys subjected to heat stress during live-bird production (McKee and Sams, 1997), when increased vascular throughput may maximize and provide the wherewithal for accelerated biochemical changes. On the other hand, Kranen *et al.* (1998), examined the meat of broilers reared at a low temperature and reported vascular rupturing in thighs, but with no obvious effect on the breast. Accentuated hemorrhaging of thigh meat was attributed to hemodynamic and metabolic adaptations, with increased need for energy and oxygen to maintain body warmth.

High and low temperatures sufficient to impair live-bird performance also decrease meat yield. In both situations, breast suffers inordinately, but for opposite reasons. Essentially, birds suffering from heat stress accommodate to their environment by decreasing the extent of heat-evolving activities, for example work of feed intake and digestion-absorption, as well as energy expenditure for protein synthesis and other aspects of metabolism. A reduction in feed consumption can lead to distinct inadequacies in those nutrients that are usually marginal in relation to optimum performance, particularly phosphorus and limiting amino acids. Inclusion of additional phosphorus in the feed can compensate; however, increasing the levels of limiting essential amino acids fails to fully correct the problem. Synthesis of muscle protein, particularly breast, is purposely restricted because of its extensive consumption of energy and evolution of heat (Temin *et al.*, 2000).

Decreasing the by-product heat associated with protein synthesis, together with that from the work of food intake and gastrointestinal activity, provides substantial relief from heat stress; however, the decrease in live-weight gain is expressed more as meat, while fat depots become over emphasized. Accentuated depot fat creates quality problems for the carcass as a result of traumas inflicted on the surface during processing. Dietary energy that is not consumed in support of protein synthesis appears as body fat, with fat provided by the feed being used preferentially. This deposition is a favorable alternative to fatty-acid catabolism that evolves considerable by-product heat; thus, carbohydrate catabolism by glycolysis is the preferred path. The 'oily bird syndrome' is common at high temperatures and is characterized by carcasses having a very oily, greasy appearance, with liquid fat depots under the skin. These oily depots are particularly obvious on the lower back and frequently break after scalding and plucking of the carcass. Summer-grown broilers are given high dietary fat to improve their live weight and feed conversion. Feeds thus formulated are particularly conducive to the appearance of oily bird syndrome and the condition is exacerbated at high scald temperatures.

3.2.3   Light

Perception of light by the fowl's eye is a particularly acute sense in the finding and comprehending of feed. Essentially, duration of light determines access to feed and the amount consumed. Continuous lighting provides for maximum growth; however, additional mortality in the heaviest birds, plus loss of feed efficiency with increased physical activity, has led to the use of other lighting schedules. 'Light-tight' housing permits differing intermittency of lighting at chosen ages to restrict feed intake. As light restriction proceeds, depletion of nutrients from within the gastrointestinal system occurs initially, followed by a subsequent dependence on body reserves and loss of live-bird weight. Expending glycogen progresses to the necessity for gluconeogenesis from protein to metabolically support complete fatty-acid oxidation. Because breast muscle is particularly favorable for the purpose, this source of meat decreases to

the greatest extent and continues to suffer until resumption of light and recovery of live-bird weight.

Intermittent lighting is usually structured to avoid extensive protein catabolism. Such restriction schedules generally relieve bird-to-bird interactions at high stocking densities and associated energy expenditure to improve feed efficiency; however, additional feeders and drinkers are necessary to support the additional activity in these areas. As light restriction is extended, then additional time beyond that needed for recovery of live-bird weight is necessary to fully realize breast meat potential. Turkeys are usually the best candidates for intermittent lighting, because their extended rearing period usually improves the ease of managing lighting restriction and subsequent metabolic compensation.

Continuous lighting is favorable for the overall development of broilers marketed at early ages and those grown to a heavy weight specifically for skinless, boneless breast meat. However, a restricted lighting schedule generally optimizes product recovery when heavy birds are used for either whole carcasses or cut portions by virtue of reduced deaths. Although decreased breast meat continues, cut portions with all associated skin and bone minimize expression. The breast portion of 'eight-piece cuts' will decrease as a percentage of the whole carcass, due to its loss in meat to the advantage of corresponding drumsticks, but the changes are generally small. Restricted lighting, when imposed, is usually employed between seven and 21 days of age to decrease a particularly rapid rate of development at this time, and subsequent losses from crippling leg defects, ascites death and carcass abdominal fat. Imposition of restriction is concurrent with the maximum rate of tibial elongation and abdominal adipocyte regeneration; however, the pectoralis major muscle is also growing particularly rapidly. Renden *et al.* (1993) note that, although light restriction for broiler males can decrease leg problems and abdominal fat after recovery of body weight, the yield of skinless, boneless breast meat continues to suffer and keel problems are more in evidence.

3.2.4   Stocking density

The stocking density of birds reared together influences their interactive behavior and, therefore, the incidence of surface imperfections that downgrade the carcass. Contact sufficient to cause trauma is correlated with stocking density, while live-bird performance shows a reverse relationship (Elwinger, 1995). A large part of the adverse effects of high stocking density can be attributed to an associated rise in the temperature and humidity of the microclimate, and an increase in litter moisture contributed by body heat and respiration. Generally, changes in the nature of carcass defects can be expected as body weight per unit area increases, particularly with those parts of the bird that are most exposed. Thigh and back scratching and bruising usually dominate in this respect (Table 3.2). Clipping of the claws is known to reduce greatly the incidence of these defects; however, a decrease in mobility as a consequence of the treatment is probably a contributing factor. The total area of the house that is

Table 3.2 Effect of stocking density and planes of nutrition on live-bird performance and incidence of carcass defects in male broilers reared to 42 days of age

Stocking density (m^2 / bird)	Body weight (g)	Total feed : gain	Carcass yield (%)	Breast bruises (%)	Thigh scratches (%)	Wing blisters (%)	Wing tears (%)	Back bruises (%)	Back tears (%)
0.08	2139	1.81	63.2	9.2	2.9	8.8	1.3	32.5	1.3
0.07	2108	1.78	63.9	10.9	4.2	6.4	0.4	20.9	0.3
0.06	2078	1.79	63.9	7.1	7.2	7.9	0	19.2	1.3
	$P > 0.05$[1]	$P > 0.05$	quadratic	$P > 0.05$	linear	$P > 0.05$	$P > 0.05$	linear	$P > 0.05$
Nutrient level[2]									
high	2142	1.75	63.8	8.6	4.7	9.0	0.3	27.3	0.6
low	2074	1.84	63.5	9.4	4.7	8.4	0.8	21.1	1.7
	$P < 0.05$	$P < 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$

Notes
[1]Level of significance or nature of relationship.
[2]Corresponds to 22.6, 20.6 and 18% crude protein with 3246, 3291 and 3335 kcal ME/kg for 0–21, 22–35 and 35–42 days of age respectively, for high level of nutrients, while low level nutrients included 21.4, 19.5 and 17.7% crude protein having 3071, 3116 and 3160 kcal ME/kg in the same order.

Selected data from Bilgili *et al.* (1991).

accessible to the flock should be considered, along with bird density. Although stocking rate did not alter the incidence of breast blisters in commercial broiler flocks, Mayes (1980b) reported a negative correlation with site-size, suggesting that bird behavior also changes with total area of confinement.

3.3   The influence of feed and nutrition on the quality of poultry meat

The response of a bird to its feed is closely related to the progression of changes occurring with growth of the skeleton, muscle and depot fat as a whole. A simplistic view of body development with age aids in rationalizing alterations due to feed and environment. Infancy in the broiler approximates to the period from hatch to one week of age and corresponds to the body using yolk-sac reserves until the gastrointestinal system assumes responsibility for nutrition. Subsequent juvenile growth involves the most rapid rate of body weight gain and is separate from subsequent pre-adolescent changes by the inflection point at about 36–44 days of age. Transition at the inflection point is best indicated by a change from an increasing to a decreasing rate of skeletal development, particularly affecting the long bones; however, the proportions of meat and fat continue to increase. The major and minor breast muscles are the largest contributors to total meat and are the most responsive to growth. While the contribution of breast is small during infancy, its extreme rate of growth through juvenile development and early pre-adolescence provides for ultimate dominance. The percentage of body fat increases with age; however, its rate of accrual is not equivalent among all depots. Early development favors depots in the abdominal cavity, followed by those in the main feather tracts of the skin, which gain throughout juvenile development to establish the bird's 'finish'. Subdermal and intramuscular areas and accentuation of the abdominal depots predominate during pre-adolescence. Differing genetic sources of meat-type birds can be expected to vary in the extent and nature of development based on selection strategy. Similarly, feed and nutrition are likely to have the greatest impact on the needs of tissue growth that predominate at that point.

3.3.1   Energy : protein ratio

The concept of energy-to-protein ratio, as used by the practicing nutritionist, is the relationship between the metabolizable energy (ME) of feed and its crude protein content. Given that energy is the primary driving force for feed consumption, then the amount of nutrient per unit feed will determine the total daily intake. If growth potential is to be realized, then protein, minerals and vitamins needed for optimum performance must be provided in the total amount of feed consumed. Not surprisingly, the energy : protein ratio is fallible, especially due to differences among commercial strains, between the sexes and alterations in nutrient-need with time.

As the dietary energy needed exceeds the optimum level of protein necessary to attain its delivery, then body fatness increases and muscle mass decreases, while the reverse occurs when protein is in excess of energy. These changes in meat yield largely relate to the breast, because of its extensive rate of growth and dominance throughout production. Alterations in abdominal fat in response to energy : protein ratio have been well documented; however, other depots are expected to follow the same pattern, when they are in their most responsive phases of development. Basker *et al.* (1987) fed broilers rations that increased progressively in energy relative to protein, then representatives from each experimental group were kosher processed at 6.5, 7.5 and 8.5 weeks of age. Carcasses were deboned by hand and the various cuts were combined in their natural proportions into a loaf that was cooked in a dry heat. The highest score for relative taste preference occurred with males, when the starter diet had provided 136 kcal per 100 g of protein, and decreased sharply once past 150, regardless of age. Females had no definitive energy : protein ratio that would provide a distinct sensory advantage, as did males, and the level of fat in the loaf did not correlate with sensory scores. Generally, the energy–protein relationship supporting the most favorable live-bird performance corresponded to an optimization of the sensory value.

ME : crude protein ratios are also fallible because considerable variation exists in the use of ME by the bird for purposes other than growth. Pelleting is well known to decrease the work of consumption and increase the proportion of productive energy realized from existing ME. Ideally, productive energy should be employed in this ratio, rather than ME, and an 'ideal relationship' among the amino acids corresponding to the requirements should be used in place of crude protein. ME is practical, because the contribution of each feedstuff is additive in estimating the dietary total. Similarly, crude protein is reasonably effective, because feeds are formulated to provide requirement levels of the essential amino acids.

The ME : crude protein ratio can be maintained while the concentrations of both energy and protein or plane of nutrition can be altered to optimize unit costs. Moran (1980) gave broilers feeds that maintained the ME : crude protein ratio, while reducing the overall plane of nutrition below the 3200 kcal/kg level that the National Research Council (1994) uses as a base to express requirements. As the plane of nutrition was lowered, resultant body weight progressively decreased; however, the loss was not attributted to breast meat as much as body fat. The fleshing grade or subjective assessment of breast meat relative to keel was maintained, whereas finish grade or subjective estimation of fat in the main feather tracts decreased. Reduced finish could be attributed largely to decreasing proportions of added and total dietary fat; thus, as the ME-protein level decreased so too did total consumption. Therefore, the additional 'work' of lipogenesis would be necessary to compensate, if deposition for depot growth was to continue. On the other hand, if the density of the diet is increased to exclude excessively high levels of added fat, then body weight-gain, carcass yield and abdominal fat again decrease, while muscle formation is maintained

(Skinner *et al.*, 1992). Under these conditions, a large proportion of the fat consumed must be catabolized directly, because its contribution to total energy is extensive and deposition is limited. Then, overall metabolism would be under the influence of glucagon and that would discourage lipogenesis as well as depot-fat accrual. Heat losses from fatty-acid synthesis and catabolism have a useful purpose in the overall metabolic scheme and should be considered strategically, when formulating feed to cope with hot or cold environments.

Fatty acids provided by the feed are an important aspect of nutrition and go towards full realization of productive energy. An emphasis on the provision of essential fatty acids early on in bird development to support membrane growth, while having the more saturated acids at hand for depots, are additional factors that are favorable to productive energy yield. Meaningful amounts of ME are lost as heat, if synthesis must originate from dietary carbohydrate. Similarly, catabolizing dietary fatty acids as a source of energy to drive protein synthesis and growth, is not as efficient as glucose utilization and heat also appears in the process as a by-product. Ideally, the amounts of fatty acids consumed should be equivalent to concurrent deposition in membranes and depots, in order to realize fully the productive energy potential from ME. Amounts of dietary fatty acids that are necessary for such purposes change with age and sex, commensurate with their use for growth. Addition of beta-adrenergic agonists to feed is being employed to decrease fat deposition and improve carcass quality, without resorting to changes in formulation. Beta-adrenergic agonists lead to hormonal changes in broilers that facilitate fatty-acid combustion in support of growth, particularly formation of breast muscle, while discouraging depot development (Gwartney *et al.*, 1992). Changes in breast muscle caused by beta-agonists lead to an increased fiber diameter that creates a toughening of the meat, according to shear values.

3.3.2   Ideal amino acid balance

This is generally accepted to be the array of essential amino acids that are present in feed, each at their requirement level. Such a situation is impossible in practice, because combining feedstuffs unavoidably leads to over-supply of the more abundant amino acids. Furthermore, an ideal balance is not a fixed arrangement, but needs to be continuously modified with age, among strains and between the sexes. At best, the bulk of dietary crude protein represents essential amino acids in excess of their individual requirements, with a few at their approximate level of need. Marginal inadequacies in these few are frequent occurrences, but usually have minimal repercussions on live-bird performance and carcass quality. Under these conditions, the only possible adverse effects are changes in the amount of meat and/or depot fat. As essential amino acids, lysine and threonine are commonly limiting and any inadequacies are expressed in an opposite manner. Sub-marginal levels of lysine lead to reductions in muscle relative to all other tissues, especially breast, while the energy not expended on protein synthesis defers to fat deposition, and depots increase. Threonine, on the

other hand, is heavily involved in the maintenance of feathers and the gut mucosal surface, and the proportions of breast muscle and abdominal fat are not readily altered. In practice, inadequacies in essential amino acids are generally small and not easily perceived, given all other possible sources of variation.

3.3.3   Non-essential amino acids

These were ignored as a factor in meat-bird production until commercial access to limiting essential amino acids permitted partial feedstuff displacement. As a result, substantial decreases in non-essential amino acids and over-supply of the essential ones were reflected in decreased usage of crude protein, although all requirements were still attained. Such changes are beneficial, because corresponding decreases in excreta nitrogen have relieved environmental pollution. Although live-bird performance is not perceptibly changed by this nutritional strategy, the carcass may show quality problems, if the reduction in crude protein is extreme (Table 3.3). Generally, such carcasses have additional abdominal fat and a reduced proportion of breast meat, while exhibiting additional structural defects and bruising. The fat and breast meat problems appear to be a separate issue from the defects. Simple addition of glutamic acid ameliorates defect problems, regardless of whether associated crude protein either remains low or is increased, but reduction in fat and improved meat yield only occur when total nitrogen approaches the crude protein levels normally encountered.

Collagen, elastin and glycosaminoglycans are components of connective tissue, and all are heavily dependent on the non-essential amino acids for their biosynthesis. Presumably, adding non-essential amino acids, such as glutamic acid and glycine, to a formulation lacking in crude protein facilitates connective-tissue formation during rapid development. The relationship of either crude protein or non-essential amino acids to the amounts of muscle and fat formed remains elusive.

3.3.4   Feed restriction regimens

Feed restriction imposed to reduce early growth is usually approached in one of two ways. The first involves an absolute reduction in access to a balanced feed over a period of time each day, and essentially leads to the same result as that mentioned earlier for light restriction. Again, both fatness and breast meat yield are reduced by slaughter age, even though subsequent compensation enables body weight and feed conversion to recover fully. Given additional time, breast muscle recovers fully as well. The second approach to restricting growth involves *ad libitum* access to feed, in which dietary protein is severely reduced relative to the energy content. Under these conditions, abdominal fat is encouraged to increase, while growth of breast muscle is impaired. Again, subsequent compensatory nutrition eventually leads to recovery of performance, but a further delay before slaughter is necessary to realize optimum carcass quality and breast meat yield.

Table 3.3 Effects of reducing dietary crude protein, while satisfying essential amino-acid requirements, on live-bird performance and processing yields for both sexes of a broiler strain and breast meat yield at eight weeks of age

Variable	Body weight (g)	Total feed : gain	Mortality (%)	Litter NDM[1] (%)	Carcass (%)		wing	drums	Cone-deboned parts[2] (%)			
					yield[3]	abdominal fat[4]			fillets[5]	tenders[5]	frame	thigh meat[5]
Crude protein												
Normal	3108	1.98	6.6	3.97	68.1	4.0	11.3	14.3	20.3	4.9	33.6	15.5
Low	3070	2.02	7.6	3.00	67.6	4.2	11.6	14.6	19.3	4.8	34.1	15.6
	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P < 0.001$	$P > 0.05$	$P < 0.05$	$P < 0.001$	$P < 0.05$	$P < 0.01$	$P < 0.05$	$P > 0.05$	$P > 0.05$
Strain												
PxAA	3084	2.00	7.9	3.53	67.7	4.1	11.6	14.8	19.0	4.7	34.1	15.6
RxAA	3094	2.00	6.3	3.45	68.0	4.1	11.3	14.1	20.6	5.0	33.6	15.6
	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$	$P < 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P > 0.05$	$P > 0.05$
Sex												
Male	3424	1.91	9.4	3.33	66.9	3.6	11.5	14.8	19.6	4.7	33.5	15.9
Female	2754	2.09	4.8	3.64	68.8	4.6	11.4	14.1	20.0	5.0	34.2	15.3
	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P > 0.05$	$P < 0.01$	$P < 0.001$	$P > 0.05$	$P < 0.001$	$P < 0.05$	$P < 0.001$	$P < 0.001$	$P < 0.01$

Notes

[1] Nitrogen in dry matter.

[2] Proportions of parts relative to the chilled carcass without neck, giblets and abdominal fat. Difference in the sum of percentages from 100 corresponds to cutting loss of *ca*. 3.4%.

[3] Yield of carcass without neck and giblets after four hours of static slush-ice chilling relative to the full-fed live weight.

[4] Depot fat removed from the abdominal cavity after chilling.

[5] Skinless, boneless meats: fillets = *M. pectoralis major*; tenders = *M. pectoralis minor*; thigh meat is without skin and femur.

Selected data from Moran and Bushong (1992).

The time necessary to compensate live-bird performance and ultimate carcass quality is dependant on the quality and balance of feeds subsequent to restriction, together with a favorable environment. High dietary protein and thermo-neutral temperatures foster a rapid recovery. Given the extensive energy expenditure necessary to accomplish protein synthesis, combined with its previously mentioned generation of heat, recovery becomes more difficult as temperatures progress beyond thermo-neutrality. When restriction has been too extensive and/or conditions for recovery are not satisfactory, then the loss in breast muscle is perpetuated and lesser protection of the keel leads to defects, such as blisters.

The physical dimensions of breast fillets (*M. pectoralis major*) are important in relation to the amounts of strips, patties and nuggets obtained, when using surface area as the basis for portion control. The decrease in weight of breast fillets arising from feed restriction and failure to recover fully reduces their length, width and depth to a similar extent, and impairs usage; however, light reflectance is not extensively altered, suggesting that quality is less of an issue than quantity (Table 3.4). Effective restriction of growth is known to improve flock livability, when live-bird performance is exceptionally good; however, any final advantage may not be realized if either skinless, boneless breast meat is required or unfavorable conditions in rearing do not permit a satisfactory recovery.

3.3.5   Dietary fat

Added fat provides many different fatty acids for use by the body. When incorporated into depots and membranes, the nature of these substances can significantly influence carcass and meat quality. Fatty acids contributed by all feed ingredients are quite diverse; however, the body can avoid extremes by absorption and hepatic modification, either by increasing the number of carbon atoms, when the acids are short to medium in length, or an increase in unsaturation, when they are saturated. Long-chain polyunsaturated fatty acids generally remain unaltered. Thus, animal tallow added to the feed, with its large quantity of stearic acid, has relatively little impact on the carcass, because much is converted to oleic acid. On the other hand, the oils present are influential by virtue of their high proportions of unsaturated fatty acids that are incorporated directly into tissues.

Carcass quality changes attributable to unsaturated fatty acids differ in expression when they become associated with depots, as compared with membranes. Although the presence of highly unsaturated triglycerides in depots leads to a glistening appearance and softer texture, their limited size and thickness in fowl have minimal repercussions on carcass appearance, compared with the changes that occur in the more prominent depots of swine (Moran, 1986). However, fowl have depots located at the carcass surface along the main feather tracts and immediately below the skin covering the lower back that suffer additional tearing during plucking, as molecular size and degree of

Table 3.4 Effect of feed restriction in a summer environment, using adverse energy : protein diets, on live-bird production, carcass quality and breast-fillet characteristics of seven-week broiler males

Regimen	Phase of investigation			
	Live-bird performance			
	Body weight (g)	Feed : gain	Mortality (%)	
Adequate	2712	1.73	4.1	
Restricted	2306	1.80	5.9	
	P > 0.05	P < 0.001	P < 0.001	
	Carcass quality			
	Yield (%)	Abdominal fat (%)	Breast blisters (%)	
Adequate	70.3	2.24	2.3	
Restricted	69.3	3.21	19.0	
	P > 0.05	P < 0.001	P < 0.001	
	Fillet dimensions[1]			
	Weight (g)	Length (mm)	Width (mm)	Depth (mm)
Adequate	167	184	90.5	21.3
Restricted	117	175	79.8	18.8
	P < 0.001	P < 0.001	P < 0.001	P < 0.001
	Fillet Hunter reflectance[2]			
	L	a	b	Hue
Adequate	49.1	−0.11	5.32	3.54
Restricted	50.1	0.30	6.50	3.41
	P < 0.01	P < 0.001	P < 0.001	P > 0.05

Notes
[1]Weight, length, width and depth of one, trimmed fillet.
[2]Surface reflectance at the center of the skin side for 48-hour *post-mortem* fillets.

Selected data from Dozier and Moran (2001).

unsaturation increase (Hammershoj, 1997). Furthermore, depot fatty acids can subsequently influence meat quality in relation to preparation of the carcass for cooking and sensory appeal to the consumer. Oven-cooking of turkey carcasses with depots having a high degree of unsaturation from dietary soybean oil leads to an increased cooking loss that is largely due to additional fat in the drip, when compared with birds given beef tallow (Table 3.5). Differences in fatty acids between soybean oil and tallow appear to have minimal influence on the tenderness of breast meat, but the unsaturated state improves flavor, while reducing perceived juiciness. The raw breast meat has extra fat, when soybean oil has been fed, in comparison with birds given tallow. The difference between the two reflects the fatty-acid profile in each case. While cooking leads to little change in the amount of breast fat present, an increase in overall unsaturation suggests a differential mobility among the triglycerides (Table 3.6).

Membrane phospholipids have an inherently large proportion of poly-unsaturated fatty acids in order to provide fluidity and to function as an aqueous

Table 3.5   Cooking characteristics and sensory scores for turkeys[1] given dietary fat as beef tallow or soybean oil

	Oil	Tallow
	Cooking[2]	
Initial carcass g	10,205	10,064
Cooking loss %	34.0	33.2
Loss as drip %	5.6	6.1
Fat in drip %	65.5	48.4
Cooking time min/kg	55.1	58.6
	Breast meat sensory score[3]	
Flavor	1.44	2.12
Tenderness	1.59	1.84
Juiciness	2.16	1.59

Notes
[1]Large male turkeys at 23 weeks of age.
[2]Cooking in a standard oven at 167°C from an internal breast temperature of 4 to 85°C.
[3]Preference estimates in log scale, with higher values denoting better quality.

Selected data from Moran *et al.* (1973).

Table 3.6   Effect of dietary beef tallow and soybean oil on fat content of turkey[1] breast meat, its fatty-acid profile and changes with cooking

Analyses	Soybean oil		Beef tallow	
	raw	cooked[2]	raw	cooked[2]
Petrol ether extract % total	5.0	5.0	4.4	4.0
Fatty-acid type	Fatty acid % total			
16:0	22.6	20.9	26.8	25.3
16:1	1.2	1.9	4.3	4.1
18:0	9.8	8.4	12.2	11.5
18:1	25.9	26.2	33.7	37.6
18:2	33.3	37.8	15.7	17.6
18:3	2.6	1.4	trace	trace

Notes
[1]Small-type male turkeys reared to 16 weeks of age and receiving 5% added fat as either soybean oil or beef tallow.
[2]Cooked in an oven at 157°C from an internal breast temperature of 4 to 85°C.

Selected data from Nelson (1976).

barrier. These unsaturated fatty acids are particularly subject to oxidative peroxidation, because of their extensive exposure to water and oxygen at both surfaces. Membrane disruption on cooking greatly accentuates this exposure and deterioration occurs, leading to a 'warmed-over' flavor within a short period of time. The rapidity of deterioration generally increases with increasing unsaturation of dietary fat, its amount in the feed and duration of feeding. The highly unsaturated fatty acids in fish oil represent an extreme situation that may be further aggravated by amines resulting from microbiological deterioration of raw fish prior to processing. The resultant 'fishy' taste is attributed to large arrays and amounts of peroxides and aldehydes that are formed on cooking. Although these degradation products may also be associated with the fat consumed, detoxification mechanisms exist to minimize any threats to poly-unsaturates already present in membranes and depots. Crawford and Kretsch (1976) avoided the development of fishy flavor in the breast meat of turkeys fed tuna oil by cooking under nitrogen and preventing access to air.

3.3.6   Grain and concentrated protein sources

As such, these are not usually responsible for quality changes in either carcasses or meat, but circumstances of use may lead to secondary changes. Providing whole grains as a free choice, separately from protein and minerals as a concentrate, leads to different intakes of each that would not occur if the two were combined in a complete feed. Possible alterations in the relationship between energy and protein may lead to changes in carcass fat and meat. Protein concentrates from meat meals and full-fat oilseeds may secondarily provide a variety of fats. Feedstuffs that provide omega-3 fatty acids in quantity, such as full-fat flaxseed, can create 'off' flavors, as do fish oils, but not to the same extent. The overall availability and balance of amino acids, together with the digestibility of carbohydrate in each feedstuff can potentially alter the energy–protein relationship to foster changes in carcass fatness and yield of skinless, boneless breast meat. Rapeseed meal is the only protein source feedstuff used on a broad basis where 'fishy taint' of the meat, but not the fat, was suspected. Sinapine is present at a high level in rapeseed meal and would normally be degraded to trimethylamine before further transformation to innocuous products. However, glucosinolates that are also found in rapeseed would complicate amine degradation, creating accumulations thought to cause an 'off' flavor. It has since been shown that trimethylamine does not accumulate in meat-type fowl, and use of glucosinolate-free varieties (Canola) avoids potential problems completely.

3.3.7   Phosphorus

Phosphorus is the primary mineral of concern in relation to poultry-meat quality. The high cost of inorganic sources and pollution threats from phosphorus in excreta lead to sub-marginal amounts in the feed, particularly during the last few

days, when diets omit medicants. Small inadequacies are unlikely to have an adverse effect on live-bird performance, but can reduce skeletal integrity. Not only is body weight unaffected, but a generalized lack of mobility may be of advantage to feed conversion and mortality. Although calcium is usually plentiful, as is vitamin D, crystallization of bone matrix is neither normal nor extensive without the corresponding involvement of phosphorus. Thus, problems with carcasses and meat associated with distinctly low phosphorus

Table 3.7 Effect of removing dicalcium phosphate from the final feed at six to seven weeks on live-bird performance, carcass quality and skeletal integrity

Feed treatment[1]	Phase of investigation		
	Live-bird performance		
	Week 7	6–7 weeks	0–7 weeks
	Bird weight	Bird weight gain (g)	Feed : Gain (g)	Feed : Gain (g)
Control	2926	572	2.10	1.85
w/o Dical	2876	523	2.27	1.88
	P < 0.01	P < 0.01	P < 0.05	P > 0.05
	Chilled carcass yield[2]		
	Pre-slaughter loss (g)	Abdominal fat (g)	Carcass w/o abdominal fat weight (g)	pre-slaughter (%)
Control	186	50	1852	67.5
w/o Dical	167	50	1827	67.5
	P < 0.05	P > 0.05	P > 0.05	P > 0.05
	Carcass defects		
	Broken drumsticks (%)	Broken clavicle (%)	Breast trim (%)	Back bruised (%)
Control	0.5	21.3	28.9	21.3
w/o Dical	3.0	29.0	18.4	14.4
	P < 0.05	P < 0.05	P < 0.05	P < 0.01
	Upper femur head after cone-deboning		
	Remain intact (%)	Epiphysis cap off (%)	Broken shaft (%)	Meat[3] Hunter 'a'
Control	33.8	62.7	3.0	12.8
w/o Dical	51.3	29.2	19.4	13.1
	P <0.001	P <0.001	P <0.001	P > 0.05

Notes
[1]Control feed from 6–7 weeks provided 0.82% calcium and 0.57% total phosphorus that decreased to 0.54 and 0.34%, respectively, with the omission of 1.20% dicalcium phosphate (Dical).
[2]Carcass without neck and giblets after four hours static slush-ice chilling.
[3]Light reflectance of thigh meat in contact with the femur shaft. Increasing '+a' values correspond to increasing redness.

Selected data from Moran (1994).

levels occur prior to slaughter. Immobility during live-bird production, reduced resistance to preslaughter handling and the lack of skeletal integrity to withstand automated processing lead to an array of effects (Table 3.7). Most obvious are the skeletal failures of drumsticks, clavicle and femur.

Structural growth and strengthening by calcification are not uniformly distributed throughout the skeleton, but favor the long bones and other areas experiencing stress that are in need of support. Given that long bones actively lengthen from their ends, epiphyses generally experience more problems than shafts. An excessive rate of tibial development, associated with the best nutrition, increases the frequency of defects in the upper epiphysis, and these become more accentuated with increasing body weight. Widening of the growth zone that is apparent with complete nutrition and rapid development also favors wing dislocations at either end of the humerus, during the violence of plucking, as well as removal of the cartilage cap from the upper femur during separation of thighs from the back, using cone deboning. Although sub-marginal levels of phosphorus narrow the growth zone, a lack of stability persists due to a pervasive softening of the bone, whereupon the whole head and shaft offer reduced resistance to breakage.

Loss of skeletal integrity only affects carcass and meat quality when resistance is exceeded at the site of stress. Stresses in pre-slaughter handling result mainly in breakage of leg and wing bones, together with bruising. Additional breakage of weakened clavicles, wings and rib cages occurs during plucking, evisceration and other processing steps, but without associated bruising. Breakage of clavicles attributed to electric stunning often causes vascular rupture and results in 'blood splash' of breast meat. Blood splash is not usually apparent until further processing has been carried out to obtain skinless, boneless meat, particularly thigh meat. Accentuated bleeding in the upper femoral area, due to diets with marginal phosphorus levels, almost exclusively occurs from abuses in live-bird handling. Additional breakage of the upper femoral head without blood splash, as mentioned earlier, is also evident during deboning, when thighs are forcibly dislocated from the back. Imposing marginal amounts of dietary phosphorus to minimize the cost of farm production and reduce pollution is of questionable value given the threats to carcass and meat quality from live-bird handling and processing.

3.4   The influence of non-nutrient feed additives on the quality of poultry meat

Additives are included in feed beyond the absolute needs of nutrition. Of primary importance in this respect are medicants providing protection from the continual microbial threats that escalate in intensive production. Other feed additives that may be used are those intended to preserve nutrient levels, relieve their costs and/or improve the quality of the resultant meat.

3.4.1   Medicants

These are the most frequently employed of all feed additives. For all fowl reared intensively on the floor, control of coccidial infections of the gastrointestinal tract is a necessity. Although inappropriate use of coccidiocides and coccidiostats can impair live-bird performance, no adverse effects on product quality are known to occur, apart from reduced yield. One exception is halofuginonone that interferes with connective-tissue formation and weakens the skin, thus favoring skin tearing during processing.

Inclusion of antibiotics that have broad-spectrum activity is optional; however, they have been used widely to improve live-bird performance. Intensive production unavoidably increases the concentration of microbes that the bird encounters in its environment, particularly during consumption of feed and water. Lumenal microbes create complications for the small intestine in many respects, especially by competition for nutrients and insults to the mucosa. Relief due to a broad-based microbial suppression is generally of more advantage to feed efficiency than body weight or yield. As a result, antibiotics are not considered to affect the quality of the resultant meat directly, as much as improving efficiency in producing the final amount of meat.

Concentrated bacterial populations that exist naturally within the large intestine provide for a supplementary digestion of material from the small intestine. The introduction of broad-spectrum antibiotics to these extremely diverse populations is expected to alter the nature and extent of their composition, as well as modifying the products of fermentation. Normally, volatile fatty acids are the primary end-products that can be absorbed rapidly through the mucosa. Increasing volatile fatty-acid concentrations in the ceca, particularly propionic acid, is helpful in decreasing pH and discouraging the establishment of any salmonellas or other foodborne pathogens. The potential adverse effects of antibiotics in altering population dynamics and volatile fatty-acid production, thus impairing suppression of pathogens, have been considered highly likely. Mucosal absorption of volatile fatty acids and evacuation of spent waste occur before certain other microbial metabolites appear. Evisceration of the bird shortly after death avoids these metabolites, when luminal and mucosal activities cease. Should a static situation persist in the gut, then by-products from extended fermentation will accrue and infiltrate the carcass. Marketing the plucked, uneviscerated carcass is common in some countries, and organic acids, amines and other metabolites acquired from the gut are presumed to be the basis of its developing 'gamey flavor'. Whether population changes caused by antibiotics would alter the extent and nature of this flavor is an open question.

3.4.2   Antioxidants

These compounds are particularly important to meat quality. Those added to feed are largely intended to minimize the oxidative rancidity of added fat and fat associated with feedstuffs, and for the protection of sensitive nutrients. Such nutrients relate almost exclusively to the fat-soluble vitamins. As double bonds

in carbon chains of fatty acids and other nutrients increase, then a progressive sensitivity to oxidative deterioration occurs. Access to water improves the ease with which oxygen reacts and generates peroxides, particularly with the catalytic help of transition-series elements, such as iron, copper, manganese, etc. Aldehydes are formed subsequently from peroxide cleavage, and browning products may develop rapidly, if amino groups are available and the reaction is aided by heat. Transitions from fatty acids to aldehydes result in a progression from hydrophobic to hydrophilic structures; in turn, the effectiveness of antioxidants at interrupting this cascading deterioration depends on their solubility characteristics and the redox potential.

Butylated hydroxytoluene and similar phenolic antioxidants are normally added to feed fats to minimize their peroxidation during storage. Ethoxyquin is a further supplement that largely provides protection for double bonds associated with the fat-soluble vitamins and prevents losses from lipid peroxides generated elsewhere. Tocopherols (vitamin E) are antioxidants normally associated with feedstuffs of plant origin that are absorbed and used by the animal to protect its body lipids from peroxidative degeneration. Alpha-tocopherol is the usual form added to ensure dietary adequacy and provide for improved meat quality, when feedstuff sources are insufficient. Safeguarding the tocopherols in feed from losses during manufacture and storage prior to consumption depends on the composite of aforementioned antioxidants.

Tocopherols absorbed from the feed are transferred to depots and membranes in the bird in proportion to the amounts provided by the feed. Restriction of water and oxygen to the periphery of triglyceride droplets within adipocytes minimizes the peroxidative threat to depots, in contrast to the ready accessibility of water and oxygen to both surfaces of all membranes. Tocopherol in membranes accrues most effectively on a gradual basis with myofiber development and cannot be inserted in quantity by large-scale supplementation of the final feed. Structural adjacency of tocopherol to phospholipid fatty acids and cholesterol within membranes provides direct protection by preferential peroxidation during the continual traffic of substrates and oxygen. As the degree of unsaturation in dietary fat increases, so also does its expression in membranes, and the need for an increasing concentration of tocopherols follows. Supplementary alpha-tocopherol, in excess of nutritional need, for decreasing thiobarbituric acid-reactive substances (TBARS) and 'warmed-over' flavor' is readily apparent, when dietary fats have a minimal degree of unsaturation (Table 3.8). TBARS largely correspond to malondialdehyde that arises from cleavage of hydroperoxides originating from two or more double-bond fatty acids. TBARS measurement provides a quantitative estimation of lipid deterioration beyond hydroperoxide formation. Fishy, 'warmed-over', and other 'off' flavors generally correlate with the level of TBARS. Because these aldehydes are water-soluble, ensuring adequate selenium nutrition is believed to maintain glutathionine peroxidase activity and address peroxidative escalation from within the aqueous network, while tocopherols are acting in a complementary manner from within hydrophobic networks.

Table 3.8   Quality of thigh meat patties made from broilers fed dietary tallow or olive oil and the benefit of increased alpha-tocopherol supplementation

Feed treatment[1]		Thigh meat composition[2]		Meat after 10 wk at 20°C	
Fat (6%)	Tocopherol (mg/kg)	Tocopherol (mg/g)	Fat (%) 18:1	TBARS[3]	WOF[4]
Tallow	30	7.2	39.4	3.92	8.27
	200	23.6	not tested	1.31	2.80
Olive oil	30	8.0	57.7	3.20	8.54
	200	30.6	not tested	1.41	2.27

[1] Feed treatment for broiler males to eight weeks of age.
[2] Composition of thigh meat after processing and before patty formation.
[3] Thiobarbituric acid-reactive substances: mg of malonaldehyde/kg of thigh meat after thawing and mincing to form patties.
[4] 'Warmed-over' flavor, scored on the basis of a 10 cm line scale, where 0 = no WOF and 10 = extreme WOF. Patties cooked to 75°C.

Selected data from O'Neill *et al*. (1998).

3.4.3   Pigments

Those added to feed are intended to intensify the yellow to orange color of poultry products for certain markets. Large concentrations of pigments are found naturally in yellow corn and various dried forage meals, while their levels in specialized feed additives like marigold meal is especially high. Lutein and zeaxanthine are the dominant carotenoids and are particularly desirable for coloring poultry products. All dietary pigments that are effective at altering the yellow-orange color of poultry products are fat-soluble and structurally related to vitamin A. These compounds have multiple double bonds and are subject to oxidative deterioration in parallel with the polyunsaturated fatty acids. Unsaturated dietary fat facilitates pigment absorption from the small intestine, because of the co-inclusion of pigments in lipid-digestion micelles and subsequent circulating lipoproteins, together with tocopherols, for final deposition. Although pigmentation appears most intense in the skin cuticle, accumulations in fat depots and membranes follow with the tocopherols. Antioxidants in feed protect pigments, as they do tocopherol, while tocopherol protects pigment from oxidative deterioration *in vivo*, as it does polyunsaturated fatty acids. Pigmentation of poultry products can be critical to visual acceptance; however, any influence on other sensory aspects of meat quality has yet to be established.

Other pigments and aspects of pigmentation associated with feed are minor, not intentional, and aqueous in character. Inorganic sources of nitrate-nitrite form pinkish complexes with the various forms of heme in muscle. While direct application of these inorganic cations in preparing cured meats is common practice, inadvertent contamination of feed and water accomplishes the same end, but is to be avoided.

3.4.4   Flavoring compounds

Such substances may occur in feed and are either added purposely to improve consumer value or inadvertently from corruption of feedstuffs. Regardless of source, flavorings in feed do not seem to provide either any distinct advantage or threat to quality. First, flavoring must be provided in 'reasonable' quantity, then absorption must follow and finally deposition must occur in the edible part of the bird, without intervening alteration in its character or changes due to subsequent cooking. Cooking is the essential facet of sensory evaluation, with more than 250 different chemicals being associated with cooked chicken (Ramaswamy and Richards, 1982). Water-soluble feed additives seem less likely to be influential than fat-soluble ones. Monosodium glutamate and various nucleotides are well known for their enhancement of flavor, when added directly to meat during its preparation; however, any evidence of effectiveness by inclusion in feed is lacking. Direct application of rosemary water extract can effectively inhibit peroxidative changes in cooked, turkey breast meat and delay loss of color (Yu *et al.*, 2002); however, employing feed as a vehicle to obtain high tissue concentrations would seem to be difficult, given all the obstacles. On the other hand, 'En-hance' is an approved, commercial flavor additive of unknown composition that has been shown to be effective, when employed in broiler withdrawal feed (Wabeck and Heath, 1982).

Oils associated with spices have unique flavors that relate substantially to their lipid and fatty-acid structure. Ready absorption of these flavorful oils from the bird's intestine, together with other fats, then transport and transfer to depots is a reasonable basis for detection. Heath *et al.* (1983) fed garlic-contaminated wheat to broilers and reported that up to 33 bulblets per kg are needed before a garlic taste can be detected in thigh and breast meat after oven roasting. Use of excessive amounts could be rectified, when a garlic-free feed was provided for at least 10 days before slaughter. Similar effects occur, but to varying extents, with caraway, almonds, thyme, mace, cayenne pepper and black pepper, but their sensory impact is minimal (Vogt *et al.*, 1989). Nevertheless, consumption of food sources having these oils by game birds in the wild cannot be ignored as a possible part of their distinctive meat flavor.

3.5   Husbandry and society: animal welfare and environmental concerns

Acceptance of poultry meat sold to the general public is closely allied to society's view of the care of the birds during production. Such a view of poultry husbandry is not fixed, but appears to be related to personal security and affluence. Verbeke and Viaene (2000) examined ethical challenges to livestock production in Belgium, where criticism of the poultry and pork industries was particularly evident. While meat safety had to be guaranteed, improvements in husbandry were also necessary, such that a minimum level of welfare was always being provided. Kratz *et al.* (2000) communicated concerns about the

environment in Germany relative to problems created by intensive broiler production. Application of excessive amounts of nitrogen and phosphorus to soil from excreta was considered a likely cause of pollution, while contamination of the air from litter emissions was another issue. The definition of 'adequate', as it relates to the welfare of commercial fowl and 'satisfactory' in relation to the environment, is generally a matter of perception by the individual and can be expected to vary considerably from country to country.

3.5.1   Animal welfare

In the present context, welfare essentially concerns the care provided to fowl by their husbandry. Free-range and organic production systems have become synonymous with adequate welfare and a favorable environment. Each system differs fundamentally from the other in its aims. Free-range systems invariably improve the amount of space per bird and may provide various forms of environmental 'enrichment' in addition to 'outside' access. Organic production systems focus on using 'natural' ingredients in feeds and all other aspects of production attempt to be more natural. Avoidance of antibiotics, medicants, pesticides, genetically modified (GM) materials and other synthetically derived products is necessary in order to comply with the term 'organic'. Free-range production need not include all requirements implicit in organic production and vice versa; however, both systems may be employed concurrently.

Free-range access, improved animal welfare and the restrictive requirements of organic production result in a myriad of variables in live-bird production. Attempts to understand the resultant effects on carcasses and meat are limited to a few controlled experiments published in scientific journals. According to Hahn and Berk (1999), offering turkeys perches above their litter and free-range access had little effect on live-bird performance or carcass quality, other than increasing breast blister-like problems from frequent contact with the perch. Castellini *et al.* (2002) compared broilers reared under 'organic' conditions and given additional space in the form of a grass paddock, with controls having no paddock, while both groups received a common feed regime to 56 days of age (Table 3.9). The organic, free-range treatment adversely affected overall live-bird performance, but carcass fatness decreased and the proportion of breast meat increased. The improvement in breast meat yield was accompanied by typical PSE-like quality problems that were further aggravated by increased TBARS. However, sensory evaluation indicated that the organic breast meat was more acceptable and juicier than the control meat, although TBARS and shear values suggested the reverse. Dunn *et al.* (1993) could find little difference in ultimate pH, sarcomere length and cooking characteristics of breast meat between female broilers reared free-range to 60 days and males approaching the same weight at 45 days, when grown under standard conditions. Mead *et al.* (1983) observed substantial changes in populations of *Escherichia coli*, streptococci (enterococci) and lactobacilli within the gastrointestinal tract of broilers given fresh green matter similar to that possible with free-range access,

Table 3.9   Effect of 'organic' production for broiler males at 56 days of age on live-bird production, carcass quality and breast-meat characteristics[1]

Measurement	Control	Organic
	Live-bird performance	
Live weight (g)	3291	2861
Feed conversion	2.31	2.75
	Carcass yield	
Carcass weight (g)	2263	2011
Yield (%)	70.3	70.3
Breast meat (%)	22.0	25.2
	Breast meat	
Moisture (%)	75.54	76.28
Lipid (%)	1.46	0.72
Ultimate pH value	5.96	5.75
Water-holding capacity (%)	52.02	51.82
Light reflectance L*	59.23	60.74
a*	4.96	4.59
b*	5.16	6.01
Raw TBARS (mg MDA/kg)	1.82	2.14
Shear value (kg/cm^2)	2.39	3.09
Cooking loss (%)	32.65	35.17
Cooked TBARS (mg MDA/kg)	3.28	3.82

Notes
[1]Controls had the same feed, stocking density, environmental temperatures and lighting as the organic group, except that a grass paddock provided an additional 4 m^2/bird for the latter. TBARS, see key to Table 3.8.

Selected data from Castellini *et al*. (2002).

compared to those reared intensively. Furthermore, a trained panel could detect a small improvement in the flavor of breast meat from birds given greens that was characterized as 'richer, meatier and sweeter' than meat from birds given conventional feed.

Stocking density is probably the single issue of which consumers are most critical. Decreasing the stocking density in intensive systems will usually improve live-bird performance and carcass quality in all respects. These improvements not only have advantages for bird welfare, but marketing a product having an 'acceptable' origin is likely to be well received from the consumer perspective. Any advantage in superimposing free-range/organic conditions on conventional poultry production, other than personal satisfaction, is far from resolved.

3.5.2   Environmental protection
For the general public, this can be accomplished partly by altering poultry husbandry. Litter represents a facet of production open to rapid, subjective

assessment. Litter treatments that either decrease the pH or bind ammonia improve immediate and distant air quality. Changes can also be made to feed that reduce both the burden of nitrogen and phosphorus in excreta and subsequent pollution. Feed strategies are multifaceted and may involve minimization of nutrients in the formulation, use of additives to improve their utilization and feedstuffs having nutrients of improved digestibility. Formulations that minimize crude protein content, while maintaining expected levels of all essential amino acids, lead to reduced nitrogen in excreta; however, extreme reductions in crude protein, as mentioned earlier, can adversely affect carcass fatness and meat yield. Again, minimizing the phosphorus content also decreases its presence in excreta, but excessive reductions impair the ability of the bird's skeletal system to resist traumas.

Use of broad-spectrum antibiotics is believed to reduce their effectiveness for humans and should cease. Omission of broad-spectrum antibiotics from feed is likely to impair nutrient utilization and the effectiveness of low crude protein and low phosphorus feeds; however, addition of a commercially available enzyme preparation appears to improve nutrient availability and more than compensates for the change. Crude enzyme complexes are capable of reacting with fiber, starch and phytin, and substantially improve nitrogen and phosphorus utilization (Bedford, 2000). The fiber-degrading enzymes not only appear to improve access to encapsulated nutrients, but the subsequent array of soluble carbohydrate by-products appears to improve microbial dynamics in the large intestine and creates an adverse environment for any foodborne pathogens. Genetic modification of nutrient forms to improve their total availability can complement enzyme use, particularly in the case of phytase. Phytin phosphorus is not readily digestible; however, genetic changes enable some of the grain's normal content to be substituted for more available forms. Unfortunately, accomplishing such genetic changes often necessitates 'GM procedures' that, in turn, create problems of their own. Undoubtedly, poultry production will be amended to satisfy the welfare and environmental concerns of the general public, while providing satisfactory economic returns.

3.6   Sources of further information and advice

Early research on poultry husbandry concentrated almost exclusively on measuring alterations to live-bird performance, with little concern for the quality of carcasses or meat, until integrated marketing evolved. Similarly, research on the food science aspects of poultry meat largely ignored the bulk of experimental data until background variation in quality became an issue in relation to further processing. Thereafter, the inclusion of measurements on carcass fatness, amount of meat and characteristics of the meat relevant to consumer requirements became commonplace. At present, poultry science journals are publishing husbandry research that now includes measurements central to the ultimate purpose of the birds, while research in food science, at the

opposite end of the spectrum, makes efforts to define and source the meats being studied. This chapter has relied on both sources of information. Therefore, the references cited here are central to both husbandry and meat quality. These citations are not complete, but are intended to provide a basis for cross-referencing of earlier research. Summarizing research on poultry husbandry, as it relates to all facets of carcass and meat quality, necessitates brutal generalizations. In this respect, the author has generously employed 'poetic licence' to provide context and brevity. As the reader encounters differences of opinion from the author and inadequate information, the references provided should enable limited cross-referencing to expand personal knowledge and opinion.

3.7   References

BASKER D, ANGEL S, BARTOV I and WEINBERG Z (1987), 'The effect of dietary energy-to-protein ratio variation on the taste and quality of broiler chicken meat', *Journal of Food Quality,* 10, 299–310.

BEDFORD M (2000), 'Removal of antibiotic growth promoters from poultry diets: Implications and strategies to minimize subsequent problems', *World's Poultry Science Journal*, 56, 347–365.

BILGILI S F, REVINGTON W H, MORAN E T Jr and BUSHONG R D (1991), 'The influence of diet and stocking density on carcass quality of broilers processed under soft- and hard-scald conditions', *Proceedings of the Tenth European Symposium on the Quality of Poultry Meat*, Beekbergen, The Netherlands, 263–271.

CASTELLINI C, MUGNAI C and DAL BOSCO A (2002), 'Effect of organic production system on broiler carcass and meat quality', *Meat Science,* 60, 219–225.

CRAWFORD L and KRETSCH M J (1976), 'Effects of cooking in air or in nitrogen on the development of fishy flavor in the breast meat of turkeys fed tuna oil with and without alpha-tocopherol supplement or injection', *Fishery Bulletin* 74, 89–92.

DOZIER W A and MORAN E T JR (2001), 'Response of early- and late-developing broilers to nutritionally adequate and restrictive feeding regimens during the summer', *Journal of Applied Poultry Research,* 10, 92–98.

DUNN A A, KILPATRICK D J and GAULT N F S (1993), 'Influence of ultimate pH, sarcomere length, and cooking loss on the textural variation of cooked *M. pectoralis major* from free range and standard broilers', *British Poultry Science,* 34, 663–675.

ELWINGER K (1995), 'Broiler production under varying population densities – a field study', *Archiv für Geflügelkunde,* 59, 209–215.

ELSON A (1989), 'Drinker design affects litter quality', *Poultry-Misset*, Feb/March, 8–9.

GWARTNEY B L, JONES S J and CALKINS C R (1992), 'Response time of broiler chickens to cimaterol: meat tenderness, muscle composition, fiber size, and carcass characteristics', *Journal of Animal Science*, 70, 2144–2150.

HAHN G and BERK J (1999), 'The influence of modified husbandry on carcass quality of heavy fattening turkeys', *Fleischwirtschaft,* September, 129–132.

HAMMERSHOJ M (1997), 'Effect of dietary fat and lighting programme on broiler skin strength and elasticity related to skin tearing', *Acta Agriculturae Scandinavica,* Section A, Animal Science, 47, 197–205.

HEATH J L, THOMAS O P, OWENS S L, NICHOLSON J L and BROSSARD E O, (1983), 'Effects of wheat contaminated with garlic and given to broilers', *Proceedings of the Maryland Nutrition Conference,* Washington, DC, USA, 2–7.

KRANEN R W, SCHEELE C W, VEERKAMP C H, LAMBOOY E, VAN KUPPEVELT T H and VEERKAMP J H (1998), 'Susceptibility of broiler chickens to hemorrhages in muscles: the effect of stock and rearing temperature regimen', *Poultry Science*, 77, 334–341.

KRATZ A, ROGASIK J and SCHNUG E (2000), 'Environmental impact of broiler production a review', *Landbauforschung Volkenrode,* 154, 3–14.

LAND D G, GEE M G, GEE J M and SPINKS C A (1975), '2, 4, 6-Trichloroanisole in broiler house litter: a further cause of musty taint in chickens', *Journal of the Science of Food and Agriculture,* 26, 1585–1591.

MARTLAND M F (1985), 'Ulcerative dermatitis in broiler chickens: the effects of wet litter', *Avian Pathology*, 14, 153–164.

MAY J D, MALONE G W, CHALOUPKA G W, MERKLEY J W and HUFF W E (1982), 'The effect of floor type on the development of breast blisters and feather follicle infections in broilers', *Poultry Science,* 61, 250–254.

MAYES F J (1980a), 'The incidence of bruising in broiler flocks', *British Poultry Science,* 21, 505–509.

MAYES F J (1980b), 'The incidence of breast blister down-grading in broiler chickens', *British Poultry Science,* 21, 497–504.

MCKEE S R and SAMS A R (1997), 'The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey meat', *Poultry Science*, 76, 1616–1620.

MEAD G C, GRIFFITHS N M, IMPY C S and COPLESTONE J C (1983), 'Influence of diet on the intestinal microflora and meat flavour of intensively reared broiler chickens', *British Poultry Science*, 24, 261–272.

MORAN E T Jr (1980), 'Impact of reducing finishing feed energy-protein level on performance, carcass yield, and grade of broiler chickens', *Poultry Science,* 59, 1304–1310.

MORAN E T Jr (1986), 'Manipulation of fat characteristics in animal products', *Proceedings of the Nottingham Nutrition Conference for Feed Manufacturers*, Loughborough, UK, 31–45.

MORAN E T Jr (1994), 'Significance of yield transportation losses and removal of dicalcium phosphate from the withdrawal feed', *Proceedings of the Twenty-Ninth National Marketing, Poultry Health and Processing Conference*, Ocean City, Maryland, USA, 79–84.

MORAN E T Jr and BUSHONG R D (1992), 'Effects of dietary crude protein to relieve litter nitrogen on broiler performance', *Proceedings of the Nineteenth World Poultry Congress,* Amsterdam, The Netherlands, 466–470.

MORAN E T Jr, LARMOND E and SOMERS J D (1973), 'Full-fat soybeans for growing and finishing large white turkeys 2. Effect on tissue fatty acids and organoleptic evaluation', *Poultry Science,* 52, 1942–1948.

NATIONAL RESEARCH COUNCIL (1994), *Nutrient Requirements of Poultry*, Ninth Edition, Washington, DC, USA, National Academy Press.

NELSON J R (1976), Carcass Quality of Broiler Turkeys as Influenced by Dietary Fat Type, Sex and Cooking, PhD Dissertation, University of Guelph, Ontario, Canada.

O'NEILL L M, GALVIN K, MORRISSEY P A and BUCKLEY D J (1998), 'Comparison of effects of dietary olive oil, tallow, and vitamin E on the quality of broiler meat and meat products', *British Poultry Science*, 39, 365–371.

RAMASWAMY H S and RICHARDS J F (1982), 'Flavor of poultry meat: a review', *Canadian*

Institute of Food Technology Journal, 15, 7–18.

RENDEN J A, BILGILI J F and KINCAID S A (1993), 'Research note: comparison of restricted and increased light programs for male broiler performance and carcass yield', *Poultry Science*, 72, 378–382.

SKINNER J T, WALDROUP A L and WALDROUP P W (1992), 'Effects of dietary nutrient density on performance and carcass quality of broilers 42 to 49 days of age', *Journal of Applied Poultry Research,* 1, 367–372.

TEMIN S, CHAGNEAU A-M, PERESSON R and TESSERAUD S (2000), 'Chronic heat exposure alters protein turnover of three different skeletal muscles in finishing broiler chickens fed 20 or 25% protein diets', *Journal of Nutrition,* 130, 813–819.

VERBEKE W A J and VIAENE J (2000), 'Ethical challenges for livestock production: Meeting consumer concerns about meat safety and animal welfare', *Journal of Agricultural and Environmental Ethics*, 12, 141–151.

VOGT H, HARNISCH S, RAUCH H W and HEILG (1989), 'Dried natural spices in broiler rations', *Archiv für Geflügelkunde,* 53, 144–150.

WABECK C J and HEATH J L (1982), 'Sensory changes of meat from broilers fed the feed additive En-hance', *Poultry Science* 61, 719–725.

YU L, SCANLIN L, WILSON J and SCHMIDT G (2002), 'Rosemary extracts as inhibitors of lipid oxidation and color change in cooked turkey products during refrigerated storage', *Journal of Food Science,* 67, 582–585.

4

Stunning and slaughter of poultry

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4.1 Introduction

Poultry meat production and consumption are predicted by the United Nations Food and Agriculture Organisation (FAO) to increase by more than 20% over the next six years, with an average annual growth rate of 2.5%. Most of the increase will occur in developing countries. This trend will be driven by the low production cost and price of poultry meat (relative to beef and pork), rising income and standard of living, and changing consumer preferences on health (low in fat) or social (convenient, fast food) grounds. However, issues concerning the origin, safety and quality of meat, bird welfare and environmental impact of poultry production and processing are likely to play important roles in world trade. The World Organisation for Animal Health (Office International des Epizooties, OIE) has been actively involved in debating animal welfare within the context of animal health and consumer safety. Evidently, farm animal welfare, in general, has become an issue of increasing concern to consumers, producers, governments and non-governmental organisations. Welfare issues that need to be addressed by the poultry industry are found in breeding, rearing, catching, transport and slaughter (Duncan, 2001).

Although, centralisation and mechanisation of poultry processing will improve process control, it will inevitably lead to transport of live birds for longer distances, sometimes in adverse weather and under poor transport conditions. The impact of this is likely to be larger numbers of birds becoming dead on arrival (DOA) at the processing plant (Warriss *et al*., 1992). Besides the complete economic loss to the industry, these birds, prior to their death, will have contributed significantly to the impact of the industry on the environment

(e.g. waste of energy and feed, excretion of nitrogen and heavy metals and emission of dust and odour). Needless to say, the environmental impact of livestock farming and meat production, which is becoming a major issue in Europe, will soon become a global concern. Therefore, improving infrastructure, careful planning of expansion and reducing waste will be critical to the success of the poultry industry, especially in developing countries.

The effect of pre-slaughter handling of poultry on carcass and meat quality has been reviewed previously (Warriss *et al*., 1999). The main objective of this chapter is to raise awareness and understanding of the complexity and difficulties associated with the stunning and slaughter of poultry, so that the industry will be encouraged to alleviate welfare problems or move away from methods that are known to be stressful to the birds.

4.2   Legislative and religious requirements for the slaughter of poultry

In most developed countries, except the United States of America (USA), animal welfare regulations require that poultry are stunned or stun/killed immediately prior to slaughter (neck cutting). Within Europe, the European Union Treaty of Amsterdam acknowledges that animals are sentient beings, rather than being agricultural products or commodities. Therefore, stunning before slaughter is mandatory and is performed to induce unconsciousness in the animals, so that death can occur through bleeding, without pain, suffering or distress. It is also a statutory requirement that no further carcass processing (e.g. electrical stimulation or scalding) begins until death has occurred or bleeding ceased. Stunning methods induce transient loss of consciousness and sensibility, and they rely solely on slaughter to cause death. Therefore, humane slaughter regulations require that the duration of unconsciousness induced by a particular stunning method should be longer than the sum of the time intervals between the end of stun and neck cutting, and the time it takes for bleeding to cause death. Stun/kill methods, on the other hand, induce unconsciousness and humane death either at the moment or within minutes of application, and therefore any delay in neck cutting or poor bleeding would not lead to compromises in animal welfare at slaughter.

Research has shown that blood volume in chickens has a curvilinear relationship with body weight. For example, blood volumes of chickens weighing 1.0, 1.5, 2.0, 2.5 and 3.0 kg were estimated to be 11.6, 8.9, 7.3, 7.3 and 7.4% of body weight, respectively (Kotula and Helbacka, 1966). It was also found that about 50% of total blood volume is retained in the carcasses and is not bled out at slaughter. It is well known that the intensive selection pressures applied during the past three decades in breeding broiler chickens have significantly improved feed conversion ratio, increased muscle mass and reduced the age at slaughter. However, the blood volume per kg body weight of today's commercial poultry is unlikely to have changed drastically. Severing all

the major blood vessels in the neck at slaughter results in the most rapid blood loss, and a minimum of 25 s bleed-out time is required to give a loss of blood equivalent to at least 2.5% of body weight (Gregory and Wilkins, 1989a; Raj and Gregory, 1991a; Raj and Johnson, 1997). This amount of blood loss in poultry may induce physiological shock and brain ischemia, such that return of consciousness could be prevented. Under this circumstance, a proportion of circulating blood volume may be retained in the visceral organs (e.g. liver and spleen) and will be removed at the time of evisceration (Kotula and Helbacka, 1966). Under commercial processing conditions, a bleed-out time of 90 s is commonly used. Poor neck-cutting practices will lead to prolonged bleeding and hence accumulation of blood in scald tanks. This will increase the microbial load on the carcass and the burden of effluent-treatment cost to the industry. Poor bleed-out will also increase the incidence of carcass downgrading conditions (see meat quality) and adversely affect the colour of breast meat (Table 4.1).

Religious slaughter is usually exempted from any statutory requirement for pre-slaughter stunning; in the UK, however, it should only take place in licensed or approved slaughterhouses. There are two main religious slaughter methods, Jewish and Islamic, practised throughout the world. Jewish slaughter (Shechita) must be performed by a religious person (Shochet or Shoket), who must obtain a licence from the Rabbinical Commission. Jewish law demands that animals must be conscious, healthy and have suffered no injury at the time of slaughter. Human consumption of blood is prohibited, and therefore, poorly bled and bruised carcasses are rejected from the food chain. Shechita must be made with a knife that is razor-sharp and free of blemishes, and the cut must be deep, severing the major blood vessels in the neck that carry blood to and from the brain (Levinger, 1996). In some countries, red-meat animals are stunned within seconds after their throats have been cut (NAWAC, 2001) but, for some reason, this requirement does not apply to poultry. The Muslim method of slaughter, known as Halal, is not controlled by a central board but is overseen by local Islamic authorities (HSA, 1993). The religious requirements are that animals are alive at the time of slaughter, God's name must be invoked during neck cutting and blood must be thoroughly drained from the carcasses after slaughter. The act of slaughter is by rapid cuts, severing the major blood vessels in the neck. Unlike Jewish slaughter, people who are neither trained nor licensed by religious authorities can perform Halal slaughter. However, some Muslim authorities accept that pre-slaughter stunning is not contrary to their beliefs, provided the

Table 4.1 Effect of amount of blood loss at slaughter on the severity of blood engorgement in chicken *pectoralis major* muscles

Bleed-out (% body weight)	Severity of engorgement (subjective score)
3.0	none
2.7	mild
2.0	severe

stunning method does not cause death. Under high-throughput conditions, neck cutting is also performed on previously stunned birds, using machines. This clearly reflects the trend that some religious authorities respond more favourably than others to the animal welfare concerns of the wider community.

4.3   Electrical stunning methods

Stunning methods used for poultry are electrical and gas stunning. Stun/kill methods include induction of cardiac arrest at stunning in a water-bath stunner, exposure to gas mixtures until the birds are dead, and penetrating or non-penetrating captive bolts (Raj and Tserveni-Gousi, 2000).

Electrical stunning of poultry is performed by passing an electric current either across the head (head-only stunning) or through the whole body using an electrified water bath (water-bath stunning) supplied with high-frequency currents (usually above 200 Hz) that do not induce death via cardiac arrest or ventricular fibrillation at stunning. The amount of current (mA) applied during electrical stunning must be sufficient to induce immediate loss of consciousness, typically in less than one second. Satisfactory electrical stunning will induce generalised epilepsy in the brain, particularly *grand mal*, which is normally associated with unconsciousness and insensibility in both humans and animals. In red-meat species, the occurrence of *grand mal* is recognised by the occurrence of highly synchronised electrical activity (amplitude $>100\,\mu V$ with frequency of 8 to 13 Hz) in the electroencephalogram (EEG) (Hoenderken, 1978; Lambooy, 1981). However, research has shown that electrical stunning of poultry seldom produces *grand mal* epilepsy in the brain. Instead, only a small proportion of birds develop epileptiform activity in the EEG following stunning, and about 90 per cent of birds that develop epileptiform activity show low frequency (<3 Hz) polyspike or spike and wave activity (Gregory and Wotton, 1986, 1987). These kinds of low-frequency polyspike activities in the EEG are not indicative of generalised epilepsy in the brain and therefore not always associated with unconsciousness in mammals, including humans. However, generalised epilepsy in the brain is always followed by a profoundly suppressed neuronal inhibition, as indicated by the occurrence of a profoundly suppressed EEG. Therefore, a profoundly suppressed EEG should also occur in electrically stunned chicken, if these EEG waveforms are indicative of generalised epilepsy (Raj, 2003).

The impact of electrical stunning in poultry has been determined on the basis of induction of epileptiform activity followed by a profoundly suppressed EEG for at least 30 s (Schutt-Abraham *et al*., 1983). The somatosensory evoked potentials (SEPs) in the brain, which occur in response to painful stimuli, are also abolished during the occurrence of a profoundly suppressed EEG (Gregory and Wotton, 1986, 1989, 1990a, 1990b, 1991). Since the depth of uncon-sciousness cannot be measured directly, these quantitative parameters provide indirect means for the setting of minimum electrical stunning currents, and such

standards, set on the basis of clearly defined criteria and sound scientific evidence, should ensure consumer confidence in the process.

Under commercial processing conditions, electrical stunning of poultry is performed using a variety of current waveforms and frequencies (Hz) (Wilkins *et al.*, 1998). The equipment (e.g. volt or current meter) used to set the stunners must be appropriate to these variables and be calibrated prior to use. The voltage used to deliver a sine-wave alternating current (AC) for stunning is expressed technically as root mean square (RMS) voltage, because it flows in both positive and negative polarity. The amount of current delivered using a sine-wave AC is also expressed as RMS current. The sine-wave has been modified to produce clipped waveforms resembling a saw tooth pattern, but the proportion of edges clipped varies widely. Owing to the clippings, the peak or peak-to-peak voltage necessary to deliver a fixed amount of RMS current with these waveforms is greater than that required with a full sine-wave (Gregory *et al.*, 1995). The depth and duration of unconsciousness induced by electrical stunning seem to be determined by the duration for which the current stays at the maximum level within each cycle, otherwise known as the period (period = 1000/frequency). For example, electric currents of 50, 400 and 1500 Hz sine-wave AC have periods of 20, 2.5 and 0.67 milliseconds, respectively. At a given RMS current level, the effectiveness of electrical stunning depends upon the period of current used and it decreases markedly when the period is below the threshold limit necessary to induce epileptiform activity followed by a quiescent EEG. This effect could be due to the electrical frequency-dependent nature of the neurotransmitter release responses occurring in the brain. There are two pools of synaptic vesicles, a readily releasable pool at the plasma membrane and a reserve pool. Electrical stimulation of the mouse-brain auditory neurones with 100 or 300 Hz showed that the synapse can sustain high-frequency-induced neurotransmitter release for many seconds, without depleting the vesicle pool, while high-frequency stimulation also enhanced significantly the rate of neurotransmitter replenishment (Wang and Kaczmarek, 1998).

When using a pulsed direct current (DC), the voltage employed to stun is expressed as the peak or average, since it flows from zero to a peak voltage (unipolar). The amount of current delivered using a pulsed DC is also expressed as the peak or average current. The period of a pulsed DC consists of mark (current ON time), otherwise known as pulse width of a DC or duty cycle, and space (current OFF time). The mark : space ratio determines the relationship between the peak and average currents of a DC at any given frequency, according to the formula peak current = average current × period in milliseconds/mark in milliseconds. Therefore, the peak current used to deliver an average current of 130 mA of a 50 Hz pulsed DC, which has a period of 20 milliseconds, will be 520 mA at 1 : 3 (130 × 20/5), 260 mA at 1 : 1 (130 × 20/10), and 173 mA at 3 : 1 (130 × 20/15) mark : space ratios. Theoretically, the peak voltage necessary to deliver an average current of 130 mA will also decrease with increasing mark or pulse width for a DC. However, despite the decreasing peak current and peak voltage necessary to deliver the same average

current, stunning should be more effective with a mark : space ratio of 3 : 1 than that achievable with a ratio of 1 : 3 for a pulsed DC. In other words, the current ON time within each cycle would determine the depth and duration of unconsciousness. Based on existing knowledge, it is suggested that, when using a pulsed DC, the mark : space ratio should be restricted to 1: 1. In addition, the frequency of pulsed DC would also determine the effectiveness of stunning, as in AC.

Most of the electrical stunners used under commercial conditions supply a constant voltage. In these stunners, the current starts to rise from zero to the maximum, depending on the supply voltage and the time it takes for the voltage to break down the total electrical resistance or impedance in the pathway. Owing to this, there will be a delay between the start of the application of stun and passage of the recommended current through the brain, that is, the latency to deliver the recommended current and induction of unconsciousness. On the other hand, a variable-voltage/constant-current stunner would operate on the basis of infinite impedance in the pathway, and therefore start with the maximum available voltage (e.g. > 600 V peak). In this situation, the recommended current would flow through the birds within 0.25 s from the start of the stun (Sparrey *et. al*., 1993). The voltage would also be modulated according to changes in impedance in the pathway during stun.

4.3.1   Head-only electrical stunning

Head-only electrical stunning involves application of a current across the head of the bird and is used commonly to stun poultry on the farm or as a back-up method in commercial slaughterhouses. Head-only stunning induces wing flapping from the moment the current starts to flow across the head (initiation of proper stun). The wing flapping must always lead to a distinct period of tetanus, as indicated by stiffening and arching of the neck, rigidly extended legs, wings folded tightly around the breast and constant body movements. Neck cutting should be performed as soon as possible after this type of stunning to prevent return of consciousness.

The minimum RMS current of a sine-wave AC necessary to stun chickens effectively was found to be 240 mA, when using a pair of conventional stunning electrodes made of three pins (Gregory and Wotton, 1990a). However, this study involved prolonged administration of currents (minimum of 5 s) using a constant-voltage stunner supplied with 110 V. Nevertheless, when neck cutting was performed within 10 to 15 s from the end of stun, it prevented the return of consciousness in the birds. Recent research has indicated that a RMS current of 100 mA, delivered using a 50 Hz sine-wave AC, would be sufficient to stun chickens by head-only, when using a pair of tongs fitted with low impedance electrodes (300 ohms) and stunning with a variable-voltage/constant-current stunner delivering >600V peak. By contrast, stunning broilers with 400 Hz and 1500 Hz AC would require minimum currents of 150 and 200 mA to achieve satisfactory depth and duration of unconsciousness (Raj, unpublished). Another

study indicated that, at 130 mA average current of a 50 Hz pulsed DC, increasing pulse width from 5 to 10 or 15 ms improved the effect of head-only stunning in chickens, as determined from the number of birds showing epileptiform activity and the magnitude of EEG suppression occurring in the EEG. However, at this average current level, the three pulse widths failed to induce unequivocal changes in the EEG that are normally associated with unconsciousness and insensibility following electrical stunning (Raj, unpublished). These results also imply that an average current of 130 mA, applied using 50 Hz pulsed DC, is less effective than a 100 mA RMS current delivered using a 50 Hz sine-wave AC. The waveform of a stunning current seems to affect the depth and duration of unconsciousness in poultry.

4.3.2   Water-bath electrical stunning

Water-bath stunning is commonly used under commercial conditions where large throughput rates are required. In this system, conscious birds are hung upside down on a moving, metal-shackle line (shackling) and passed through an electrified water bath, such that the current flows through the whole body towards the shackle, which serves as the earth. The water-bath stunners used under commercial conditions are all supplied with constant voltages. The duration of stunning depends upon the processing-line speed and the amount of current delivered to the birds, which in turn determines the length of the water bath. For example, application of low currents in water-bath stunning requires a long stun duration to induce unconsciousness and hence involves a very long water-bath stunner. Since poultry are highly likely to suffer cardiac arrest, even at low current levels, when stunning is performed with a current frequency of 50 to 60 Hz AC, water-bath stunning is normally carried out using frequencies between 400 and 1500 Hz of sine-wave AC and pulsed DC. Electrical water-bath stunning facilities have to be well designed and constructed to maintain high bird-welfare standards and product quality. The issues listed in the following paragraphs are intended to provide background knowledge in areas of concern and indicate possible measures to achieve good welfare standards at slaughter.

Under commercial conditions, the duration between shackling and stunning varies according to the system used for live-bird transport and the layout of the processing plant. Investigations have revealed that up to 90% of birds hung on moving shackles flap their wings (Kannan *et al*., 1997a; Parker *et al*., 1997). While most birds stop flapping within a few seconds of shackling, many subsequently resume if they are suddenly exposed to sunlight, jolting or pre-stun electric shocks at the entrance to the water-bath stunner (Gregory and Bell, 1987). Wing flapping was found to be violent and prolonged if the shackles were tight fitting (Parker *et al*., 1997). Provision of plastic curtains or sheets running along the line (known as a breast comforting plate) had a quietening effect (Gregory and Bell, 1987). Wing flapping was found to be significantly lower when the intensity of light in the shackling area was 5 lux or less in comparison with 50 or 200 lux (Jones *et al*., 1998). The use of blue or ultraviolet light in the

lairage, live-bird handling and shackling areas tends to have a calming effect on the birds. Wing flapping in live birds will lead to a very high prevalence of red wing tips in the carcasses, which will subsequently be downgraded (Gregory *et al.*, 1989). Therefore, properly designed and constructed shackle lines are essential to long-term welfare and economic benefits. Nevertheless, shackling of live poultry results in a physiologically abnormal posture, and compression of metatarsal bones by the metal shackle, which is reported to be extremely painful (Gentle and Tilston, 2000). It has been calculated that the force on each leg of a broiler could be $180\,N$ applied over an area of $1\,cm^2$ (Sparrey, 1994). The shackle size is important because broilers show variable leg sizes, with males having legs of larger diameter than females. The pressure applied during shackling increases exponentially with deformation of legs (Gentle and Tilston, 2000). Shackling of live poultry causes bruising on the surface of leg muscles and the magnitude of this problem will increase with the force applied during shackling. Bruised, skinless leg muscles will be downgraded or rejected and, therefore, selecting shackles that are appropriate to the size of the birds to be processed and suspending them gently will help to improve bird welfare and reduce meat quality problems. Modern shackles are designed to accommodate birds of different sizes and selecting the most appropriate type at the outset is always advisable (Sparrey, 1994). The pain and suffering during shackling is likely to be worse in birds with diseases or abnormalities of leg joints/bones (Danbury *et al.*, 2000). In this regard, the prevalence of extreme lameness in broiler chickens has been reported to be up to 15 per cent in Denmark and about 1 per cent in the UK (see Butterworth, 1999). The pain associated with shackling is also significant in birds suffering from dislocation of joints and/or fracture of bones induced by rough handling. The occurrence of dislocated joints and broken bones in carcasses will lead to downgrading or condemnation (Gregory and Wilkins, 1990). Therefore, affected birds and any runts that are likely to miss the water-bath stunner should not be shackled. Instead, they should be killed humanely, using an emergency slaughter procedure (for example, captive-bolt stunning).

A potentially painful, pre-stun electric shock will occur during water-bath stunning, when the bird's leading wing makes contact with the water bath before the head is fully immersed. Wing flapping at the entrance to the stunner predisposes poultry to receiving pre-stun electric shocks. Birds should be allowed to settle down on the shackles before they enter the stunner, in order to minimise this problem. Shackle lines between the point of shackling and the stunner should not have bends or sudden dips, because these can induce or exacerbate wing flapping, and hence reduce the efficiency of stunning (Sparrey *et al.*, 1992, 1993). Wing flapping at the entrance to the stunner can also lead to inadequate stunning due to delayed or interrupted contact with the electrified water bath and, at worst, the head may not even come into contact with the water. Such birds will remain conscious when they reach the neck cutter, thus posing an animal-welfare problem. The incidence of pre-stun shocks can be reduced by implementing certain measures:

(1) water-bath stunners should not overflow at the entrance
(2) the stunners should be fitted with an electrically isolated 'entry ramp' that slopes upwards toward the bath. These entry ramps are fitted so as to facilitate gentle swinging of the head of each bird into the stunner. In some instances, shackle lines are constructed with a slope to ensure that the head is dipped in the water bath.

Modern electrical water-bath stunners may contain up to 20 chickens at any one moment and, as birds enter a stunner supplied with a constant voltage, they form a continuously changing parallel electrical circuit (Sparrey *et al*., 1993). The voltage necessary to deliver a pre-set current seems to vary according to the depth of immersion of birds in the water bath. Shallow immersion needs a higher voltage than deeper immersion to deliver a pre-set, constant current. Working on geese, Schutt-Abraham *et al*. (1992a) suggested that such variations are due to

(1) the distance between the bird and the live electrode in the bath
(2) an increase in contact area between bird and electrified water
(3) a reduction in body mass between the live and earth electrodes (shackle).

It is recommended that each bird should be immersed in a water-bath stunner up to the base of its wings (Shutt-Abraham *et al*., 1983). Most of the electrical impedance in the pathway between the electrified water bath and the earth is attributed to poor contact between the legs and the metal shackle. According to Ohm's law, each bird in a multiple-bird water-bath stunner will receive a current inversely proportional to the electrical resistance or impedance in the pathway (Sparrey *et al*., 1992). The effective electrical impedance can vary between birds, usually 1000 to 2600 ohms in broilers and 1900 to 7000 ohms in layer hens (Schutt-Abraham *et al*., 1987; Schutt-Abraham and Wormuth, 1991). Thinner metatarsal bones fitting loosely on a wider shackle and dry scales on the legs could be associated with a relatively higher impedance in females than in males, especially in turkeys. The electrical impedance could be reduced significantly by wetting the leg-shackle contact area with a water spray. The electrical conductivity of water used in the stunner bath may vary depending upon its content of naturally-occurring minerals. The conductivity improves with operating time. This is because minerals will be inadvertently added to the water through the accumulation of either dirt or faecal material, since poultry are known to defaecate during water-bath stunning. However, addition of cooking salt even at a concentration of only 0.1%, particularly at the beginning of the day, helps to overcome any deficiency in the conductivity of the water (Bilgili, 1992).

Owing to differences in electrical resistance for various tissues in the pathway, only a small proportion of the current applied in a water bath may flow through the brain, with the majority flowing through the carcass (Wooley *et al*., 1986a, 1986b). The amount of current flowing through the body probably contributes to certain carcass and meat quality defects associated with water-bath stunning systems (Raj, 1999). The complexity of multiple-bird water-bath

stunning makes process control extremely difficult, if not impossible. However, it is recommended that the electrode in the stunner should extend to the full length of the water bath. This is particularly important, because the amount of current and the voltage decrease as the measuring device is moved 5 cm or more away from the live electrode, the source of current in a water bath (Schutt-Abraham *et al*., 1991). Therefore, not only should the electrode extend to the full length of the water bath, but the birds must be immersed up to the base of their wings, such that the heads are always held close to the electrodes in the bath, where the current density is high.

The variation in electrical impedance in the pathway, and hence the variation in amount of current delivered to each bird during multiple-bird water-bath stunning, can be overcome by the installation of a constant-current stunner to ensure delivery of a pre-set current to each bird (Sparrey *et al*., 1993). During stunning with a variable-voltage/constant-current stunner, each bird is electrically isolated and the stunner modulates the voltage required to deliver a pre-set current by continuously monitoring the impedance in the pathway. A fundamental requirement for implementing constant-current stunning is that each metal shackle carrying birds into the water bath must be electrically isolated. However, considering that the birds are suspended on shackles 15 cm apart and the processing line is operating at a speed of up to 220 chickens per minute, it may not be possible to isolate each bird for long enough to measure electrical resistance in the pathway and deliver the pre-set current. A poorly designed and constructed constant-current water-bath stunner could lead to carcass and meat quality problems (Wilkins *et al*., 1999).

With a water-bath system, Schutt-Abraham *et al*. (1983) concluded that a minimum of 120 mA per chicken is necessary to achieve humane stunning, when using a 50 Hz sine-wave AC. Subsequent research showed that a minimum current of 120 mA per chicken, delivered using either a 50 Hz sine-wave AC or a 350 Hz pulsed DC, will be necessary to abolish SEPs following water-bath stunning (Gregory and Wotton, 1989, 1991). Therefore, it may be safe to assume that a current (RMS or average) of 120 mA per bird, delivered using a sine-wave AC or a pulsed DC of up to 350 Hz would be adequate to stun chickens. However, there are some possible problems associated with the use of a 50 Hz sine-wave AC to deliver this amount of current in water-bath stunners. Firstly, since a sine-wave AC is efficient in inducing cardiac arrest, its use in water-bath stunners will be more appropriate to stun/killing than stunning. Secondly, a commercial disadvantage of using 50 Hz AC is that, at current levels greater than 105 mA per chicken, about 90% of birds will suffer cardiac arrest. There are also significant increases in the incidence of haemorrhaging in breast and leg muscles, broken bones and other carcass-downgrading conditions (Gregory and Wilkins, 1989b, 1989c).

It is doubtful whether a single current could be recommended for stunning poultry effectively, using frequencies of up to 1500 Hz of sine-wave AC or pulsed DC (see head-only electrical stunning). This follows from a recent study that investigated the effectiveness of water-bath electrical stunning of chickens

with a constant RMS current of 100 mA per bird, delivered for three seconds and using 100, 200, 400, 800 and 1500 Hz sine-wave AC, respectively. The changes occurring in the spontaneous EEGs and SEPs were used to determine the effectiveness of stunning. Stunning was applied using a variable-voltage/constant-current stunner. The results indicated that stunning of chickens with a constant RMS current of 100 mA per bird, delivered for three seconds using 100 or 200 Hz, induced epileptiform activity immediately followed by a profoundly suppressed EEG. It was suggested, therefore, that stunning of chickens with an RMS current of 100 mA per bird, using 100 or 200 Hz, induced a satisfactory depth and duration of unconsciousness. However, both the carotid arteries in the neck must be severed at slaughter to prevent the return of consciousness. By contrast, stunning with an RMS current of 100 mA per bird delivered for three seconds using 400, 800 or 1500 Hz failed to induce epileptiform activity and EEG suppression and the SEPs were also retained in the majority of chickens. Therefore, on humanitarian and bird-welfare grounds, an RMS current of 150 mA per bird should be applied when using frequencies of up to 400 Hz, and a minimum RMS current of 200 mA per bird should be applied when using 800 Hz or more (Raj, unpublished).

A possible consumer safety concern is that electrical water-bath stunning results in inhalation of stunner water by the birds, which has been estimated to be 0.5 ml per chicken (Gregory and Whittington, 1992). Considering that the majority of birds defaecate into the water during the application of stunning and faeces are a potential source of foodborne pathogens, contamination of internal tissue may occur, following inhalation. A similar problem is associated with the scalding of carcasses from adequately stunned and slaughtered birds (European Integrated Pollution Prevention and Control Bureau, www.eippcb.jrc.es). The consequent risk to consumers needs to be addressed and quantified.

Another concern associated with electrical stunning is the occurrence of birds entering the scald tank alive. Live birds can enter the scald tank under two scenarios. Firstly, inadequately stunned birds and those that have missed the stunner, due to wing flapping or being runts, avoid the neck cutter by holding their heads up. Occasionally, effectively stunned birds also miss the neck-cutting blades due to the fact that they do not engage the rails that guide the neck towards the blade(s). Therefore, if these birds were not slaughtered manually, they would enter the scald tank live and conscious. Secondly, adequately stunned birds could have a poor neck cut and therefore enter the scald tank alive but unconscious. Owing to fast throughput rates, manual back-up alone is not sufficient to prevent this potential welfare problem. These birds may inhale scald water, thereby causing internal contamination with microbes.

The most significant disadvantage of water-bath stunning is the detrimental effect on carcass and meat quality. The amount, frequency and waveform of a current have been reported to affect carcass and meat quality (Gregory and Wilkins, 1989b, 1990; Gregory et al., 1995; Wilkins et al., 1998; Kranen et al., 2000). The prevalence of some quality defects seems to increase with body weight (Wilkins et al., 1998). This is probably due to the fact that, the higher the

proportion of breast muscle, the greater is the amount of current flowing through it, and this, in turn, increases the force of muscle contraction that occurs during stunning (Raj, 1999).

4.3.3   Electrical stun/kill using a water bath

The only difference between stunning and stun/killing in a water bath is the frequency of the electric current employed. Therefore, the various welfare concerns and technical details listed under water-bath stunning are also relevant to this method.

A 50 Hz sine-wave (full or clipped) AC has been shown to be effective in inducing cardiac arrest at stunning in a water bath (Gregory *et al*., 1995). Inducing cardiac arrest at the point of electrical stunning has welfare advantages, since any delay between the end of stunning and neck cutting, and the efficiency of neck cutting, then become less important (Schutt-Abraham and Wormuth, 1988). When a 50Hz AC is used, the current necessary in a water bath to induce cardiac arrest in 99% of chickens is 148 mA per bird (Gregory and Wotton, 1987; Gregory and Wilkins, 1989b, 1989c). Since this amount of current is in excess of the 120 mA required to induce immediate unconsciousness, as determined using EEGs or SEPs, there are no perceived welfare concerns. However, the carcass and meat quality problems associated with water-bath stunning could be exacerbated by the water-bath electrical stun/kill method, especially when poor bleeding occurs (Gregory and Wilkins, 1989c).

4.3.4   Electrical stun/kill using dry electrodes

Since head-only stunning induces severe wing flapping, which impedes prompt neck cutting and is also detrimental to carcass and meat quality, Lambooij (1992) proposed an electrical stun/kill method for poultry. The initial research carried out in the Netherlands was aimed at eliminating or reducing the severity of wing flapping after head-only electrical stunning. This research has shown that the severity of wing flapping following head-only electrical stunning can be reduced by the application of a high-frequency current through the spinal cord (Hillebrand *et al.,* 1996). Free-standing chickens were stunned using a pair of tongs with either 50 Hz AC, 100 V for four seconds or 200 Hz AC, 100V for one second, followed by the application of a 'relaxation current' of 100 000 Hz, 200 V for four seconds through the whole body. It was found that the two head-only stunning treatments resulted in mild to severe wing flapping and the application of a 'relaxation current' reduced its severity. However, carcass and meat quality defects still occurred. Since the relaxation current would mask any signs of consciousness in poultry, the humanitarian aspects of such a procedure can be questioned.

Another approach to solving these problems is first to head-only stun the birds using a pair of tongs, and then kill them immediately by passing an electric current across the body, such that the electrical field spans the heart. Such an

electrical stun/kill method appears to be more humane than the induction of cardiac arrest in a water-bath stunner. Firstly, the stunning current is applied focally to the head in order to span the brain, before the induction of cardiac arrest. This will enable the amount of current found to be necessary for any one species of bird on welfare grounds to be applied without compromising carcass and meat quality, an inherent problem with the water-bath systems. Secondly, it is envisaged that this method could be applied to birds that are restrained in a sitting posture, using a pair of conveyors, thereby enabling freshly-killed birds to be shackled. This would certainly eliminate the stress and pain associated with the shackling of conscious birds under the water-bath system. The results of a study involving a prototype stun/kill device indicated that the technique can be better on carcass and meat quality grounds than electrical stun/kill in a water bath (Raj *et al.*, 2001). Further research should be carried out to exploit the bird-welfare and commercial benefits of this system, which will be ideally suited for stunning/killing poultry in small and medium-sized processing plants.

4.4   Gas stunning methods and use of captive bolts

Gas stunning of poultry in transport containers, as they arrive at the processing plant, eliminates the need for live-bird handling and the problems associated with electrical stunning. Gas stunning poultry on a conveyor would eliminate the problems associated with electrical water-bath stunning.

4.4.1   Stunning with gas mixtures

Poultry can be stunned by exposing them to either an anoxic (< 2% oxygen by volume) atmosphere created with nitrogen, argon or other inert gases, a minimum of 30% by volume of carbon dioxide in air, or a mixture of a low concentration of carbon dioxide (maximum of 30% by volume) with nitrogen or argon, leaving a maximum of 2% residual oxygen. Some systems involve a mixture of carbon dioxide, oxygen and nitrogen and certain others have increasing concentrations of carbon dioxide in air. However, research has shown that, during exposure to carbon dioxide, it would be difficult to effectively stun all the birds without inducing death in some, while the duration of unconsciousness induced with the stun can be very short in some cases (Zeller *et al.*, 1988). The changes occurring in the EEG and the time to abolition of SEPs during exposure to gas mixtures have been used to determine the time to loss of consciousness (Wooley and Gentle, 1988; Raj *et al.*, 1990a, 1991a, 1992a, 1998). These seem to vary according to the oxygen and carbon dioxide levels in the mixture. Therefore, abolition of SEPs has been used as an unequivocal indicator of loss of consciousness, during exposure of chickens to various gas mixtures.

Since the induction of unconsciousness with gas mixtures is a gradual process, the mixture should be non-aversive and the induction process should

not be distressing to the birds. It is known that carbon dioxide is an acidic gas and is pungent when inhaled in high concentrations. It is also a potent respiratory stimulant, which could cause breathlessness before the loss of consciousness (Gregory *et al.*, 1990). The welfare implications of these effects are that birds could experience distress, either on initial exposure to carbon dioxide, or during the induction phase. It was found that three out of eight hens and six out of 12 turkeys tested showed aversion to entering a chamber to obtain food and water, when it contained 47 and 72% carbon dioxide respectively in the atmosphere (Raj, 1996). Human experience suggests that 40% or more by volume of carbon dioxide in air is pungent to inhale and rapidly induces a sense of breathlessness (Gregory *et al.*, 1990).

Exposure of chickens to anoxia created with 2% oxygen in argon results in loss of SEPs, on average in 29 s (Raj *et al.*, 1991a). However, the duration of unconsciousness provided by the anoxia may not always be long enough to allow uncrating, shackling and bleeding of the birds. In this regard, it has been reported that exposure of chickens to 2% oxygen in argon for 2 min resulted in the death of most of the birds, while survivors regained consciousness as early as 15 s after returning to air (Raj and Gregory, 1990a). It has been reported that exposure of chickens to 45% carbon dioxide in air results in loss of SEPs, on average, after 30 s (Raj *et al.*, 1990a). Increasing the concentration of carbon dioxide in the stunning atmosphere does not appear to reduce the time taken to lose consciousness, as determined by loss of posture in the birds (Raj and Gregory 1990b).

It is not known how long birds need to be exposed to any particular concentration of carbon dioxide to induce a sustained period of unconsciousness that will be sufficient to ensure their welfare at slaughter. Considering that exposure of chickens to 45% carbon dioxide in air for two minutes resulted in the death of the majority of the birds, while survivors responded to comb-pinching as early as 26 s after returning to atmospheric air (Raj and Gregory, 1990a), it is doubtful whether any concentration of carbon dioxide (including gradients) would provide an adequate depth and duration of unconsciousness in all the birds without killing a proportion. It has been suggested that addition of oxygen to carbon dioxide may not be beneficial to bird welfare (Raj *et al.*, 1998). This is based on the observation that, during the induction phase, birds that were exposed to a mixture of 50% carbon dioxide and 50% oxygen showed signs of respiratory distress that were similar to those in birds exposed to 50% carbon dioxide in air (Zeller *et al.,* 1988). In addition, the inclusion of oxygen in a carbon dioxide atmosphere can prolong the time to loss of brain responsiveness and thus unequivocal loss of consciousness. The average time taken for broilers to lose SEPs was found to be longer than two minutes when exposed to a mixture of 40% carbon dioxide, 30% nitrogen and 30% oxygen in air; in these birds, the time to return of response to comb-pinching was 30 s after returning to air (Raj *et al.,* 1998). Therefore, if this gas mixture is to be used for stunning, the birds should be exposed for longer than two minutes and both the carotid arteries severed within five seconds of birds leaving the gas mixture to avoid resumption of consciousness.

However, convulsions (wing flapping), occurring after the loss of consciousness, can be aesthetically unpleasant. Ernsting (1965) reported that, under anoxic conditions, depression of activity in the mammalian brain extends progressively from the telencephalon to the diencephalon and then to the mesencephalon. Anoxic convulsions result from the release of the caudal reticular formation from the suppression by higher centres, particularly the cerebral cortex and rostral reticular formation (Dell *et al.,* 1961; Ernsting, 1965). The implication of this is that the onset of anoxic convulsions themselves can be used as an indicator of the loss of consciousness. Based on the occurrence of slow waves in the EEGs of chickens, Woolley and Gentle (1988) reported that the birds were unconscious during wing flapping, when anoxia was induced gradually. Raj *et al.* (1991a) also reported that acute exposure of chickens to anoxia resulted in EEG suppression at 17 s with convulsions beginning at 22 s. Since one of the objectives of gas stunning is to alleviate the pain and suffering associated with shackling of conscious poultry, followed by water-bath stunning or stun/killing, gas stunning must be limited to birds contained in crates or on conveyors.

4.4.2 Stun/kill with gas mixtures

The only difference between stunning and stun/killing with a gas mixture is that, in the latter case, the birds are exposed to the gas mixture until they are dead. Therefore, any delay in neck cutting or the nature of the blood vessels cut becomes irrelevant. Since the birds are shackled *post mortem* with this method, shackling can be performed in well-lit conditions without compromising bird welfare or heath and safety of the personnel. Owing to the lack of wing flapping, emission of dust to the environment is largely eliminated. Also eliminated is the risk of internal carcass contamination from water-bath stunning and scalding, due to faecally contaminated water.

At present, two gas mixtures are being used in Europe for killing chickens and turkeys:

1. Argon, nitrogen or other inert gases, or any mixture of these gases, in atmospheric air, with a maximum of 2% oxygen by volume;
2. Any mixture of argon, nitrogen, or other inert gases in atmospheric air plus carbon dioxide, provided that the carbon dioxide concentration does not exceed 30% by volume and the oxygen concentration does not exceed 2% by volume.

In both mixtures, a residual oxygen level of less than 2% by volume is maintained and birds are exposed for a minimum of two minutes. With this system, crates containing the birds are carried through a gas tunnel. Another gas stun/kill system being used involves two stages. Under this system, broilers on a conveyor are exposed to a mixture of 40% carbon dioxide, 30% oxygen and 30% nitrogen for one minute and, subsequently, exposed to 80% carbon dioxide in air for two minutes.

The time between the end of exposure to gas mixtures and neck cutting is longer than the corresponding time for electrical stunning or stun/kill systems. However, research has shown that stun/kill with gas mixtures and the delay between the end of exposure and neck cutting do not impede blood loss at slaughter, provided neck cutting is performed within three minutes of birds leaving the gas mixture (Raj and Gregory, 1991a; Raj and Johnson, 1997). Research has also shown that, in comparison with electrical stun/kill in a water-bath, stun/killing of chickens in transport crates using anoxia produces superior carcass and meat quality, which has a significant economic benefit to the industry (Raj and Gregory, 1991b; Raj et al., 1990b, 1990c, 1991b, 1992b, 1997). These studies have indicated that the incidence of broken bones in carcasses, haemorrhaging in muscles and other downgrading conditions are eliminated or significantly reduced. The environmental benefits include more efficient utilisation of resources and reduced emission of odour and volume of waste (carcass trimming and rejection) for disposal. In addition, research under commercial conditions has shown that stun/killing with anoxia accelerates the rate of rigor development and hence maturation of the meat. Therefore, poultry carcasses can be portioned or muscles removed (filleted) soon after slaughter, without inducing toughness in the meat. The commercial benefits include a significant reduction in the need for refrigeration space and cost. However, a consumer safety concern with gas stun/kill systems is the efficient removal of DOA birds. A study in the UK involving *post mortem* examination of DOA birds has revealed that trauma is the principal cause of death (Gregory and Austin, 1992). Nevertheless, consumer safety has to be ensured by a system for removing DOA birds prior to immersion of crates into gas mixtures, to avoid the processing of birds that have died from disease (Fig. 4.1).

4.4.3   The use of captive bolts

There are penetrating or non-penetrating captive bolt devices that are fired using either cartridges or compressed air (Humane Slaughter Association, UK, www.has.org.uk; Raj and O'Callaghan, 2001). Captive bolts induce immediate and severe structural damage to the brain, leading to death. The impact has been determined on the basis of the induction of slow waves (high amplitude, low frequency activity) followed by a profoundly suppressed EEG. The visually evoked potentials (VEPs) are abolished during the occurrence of a suppressed EEG (Raj and O'Callaghan, 2001). Spring-loaded captive bolts have also been used to stun/kill poultry (Shutt-Abraham et al., 1992b). However, severe wing flapping due to captive-bolt shooting is not conducive to operative safety, effective neck cutting or good carcass and meat quality (Hillebrand et al., 1996; Lambooij et al., 1999). Research carried out in the Netherlands, involving broiler chickens and a penetrating bolt with a diameter of 5 mm and a length of 25 mm (Hillebrand et al., 1996), showed that captive-bolt shooting can be effective in inducing unconsciousness in the birds. The results of another study indicated that the bolt must be fired in a direction perpendicular to the frontal bone. The ideal conditions should be a minimum of 6 mm bolt diameter,
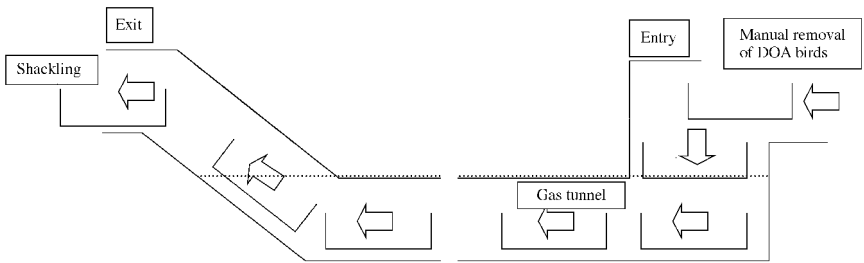
Fig. 4.1   An illustration of equipment used for stun/killing poultry in transport crates.

delivering an impact energy of not less than 21 joules, with a penetration depth of 10 mm (Raj and O'Callaghan, 2001). In these broilers, suppressed EEGs and loss of VEPs occurred immediately after shooting. A captive bolt fitted with a plastic head is being used effectively for emergency slaughter of poultry in the UK. Owing to the nature of the head, the velocity of this bolt is high and it causes severe structural damage to the skull and brain. The bolt can be fired by means of compressed air or cartridges, and can be used for disease-control purposes as well (www.has.org.uk).

4.5   The effects of pre-slaughter stress and stunning methods on meat quality

The effect of stunning or stun/kill methods *per se* on carcass and meat quality has been reviewed previously (Raj, 1999). Studies have shown that the colour of fresh breast meat, sampled from retail outlets in the USA and UK, varies widely (Fletcher, 1999; Wilkins *et al*., 2000). Although dark breast fillets usually have an elevated ultimate pH (Allen *et al*., 1997; Wilkins *et al*., 2000), the causes of variation in the colour of breast meat have not been clearly elucidated. On the other hand, pre-slaughter stress levels have been reported to influence the colour of thigh meat (Kannan *et al*., 1997b). Literature concerning breast meat colour reveals that the anterior (cranial or thicker) end is darker (lower L* and higher a* values) than the caudal (posterior or thinner) end. One possible explanation for this difference could be that, since poultry carcasses are hung on shackles during chilling and maturation, the residual blood (or blood pigment) in the breast muscle gravitates towards the cranial end of the fillet. For example, the data presented in Table 4.1 suggest that the severity of darkening in breast muscles due to engorgement is worst when the amount of blood loss is only about 2.0% or less of the body weight. Further research should reveal any direct correlation between the amount of residual blood and the severity of discolouration in breast meat. Ideally, poultry should always be slaughtered promptly by severing all the major blood vessels in the neck to achieve a satisfactory bleed-out. The effect of poor bleeding can be differentiated from electrical stunning-induced haemorrhaging. The latter occurs mainly on the

medial side of the fillet due to the rupture of blood vessels, with or without the occurrence of broken pectoral bones (furculum or clavicle). The severity of haemorrhaging depends upon the frequency and amount of current flowing through the breast muscles (Raj, 1999).

The tenderness of breast meat is affected by the period *post mortem* up to the time of filleting, rather than the stunning or stun/kill method *per se*. Stunning is known to have a significant effect on the rate of rigor development and maturation of meat, which, in turn, may influence the time to filleting (Raj, 1999). Stunning or stun/killing of poultry with an electric current or carbon dioxide gas can retard the rate of rigor development. The effect is probably due to the depletion of intra-cellular free calcium levels. Stunning or stun/killing of poultry with anoxia induced by nitrogen or argon accelerates the rate of rigor and hence maturation of the meat.

4.6   Methods of neck cutting, dislocation and decapitation

Mechanical neck cutting is the preferred method of slaughter under high-throughput conditions. The neck-cutting machines have one or two circular blades, which can be set to achieve the desired results. Stunning must always be followed by severance of all the major blood vessels in the neck, which can be performed ideally using a twin-bladed machine (Fig. 4.2a). The chance of a return to consciousness in adequately-stunned poultry is increased when a single-bladed machine is used for cutting only one carotid artery and one jugular vein (Fig. 4.2b), and the situation can be worse when a dorsal cut severing vertebral arteries is made (Fig. 4.2c). A single-bladed machine can be set to make a ventral cut in the neck, severing both the carotid arteries and jugular veins.

Gregory and Wotton (1986), using anaesthetised and mechanically-ventilated chickens, investigated the time to loss of spontaneous EEG activity in order to determine the state of consciousness following decapitation, induction of cardiac arrest and various neck-cutting methods that are commonly used under humane slaughter conditions. In that study, the time to reach 5% of the pre-slaughter integrated EEG activity was used, and the results are summarised in Table 4.2. A similar criterion (reduction in the total power (V^2) content of EEG signals to less than 10% of the pre-stun value) has been used as an indicator of quiescent EEG (unconsciousness and insensibility) in red-meat species (Bager *et al.*, 1992). Gregory and Wotton (1986) found that decapitation and induction of cardiac arrest, followed by cutting both the carotid arteries, were the most rapid slaughtering methods in terms of the time to loss of consciousness and onset of death. All the other slaughter methods tested in that study required significantly longer times to reach a similar end-point. These results clearly highlight the need for cutting of carotid arteries, which supply oxygenated blood to the brain.

Decapitation and dislocation of the neck are used as back-up methods to kill poultry showing signs of returning to consciousness after stunning. The scientific
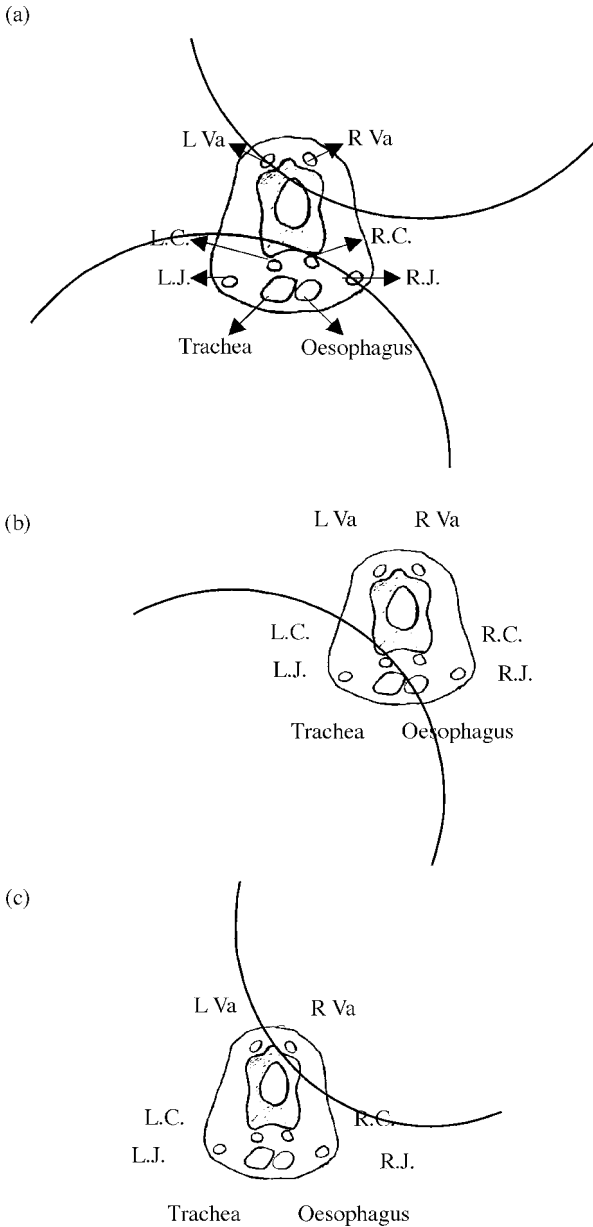
(a)

(b)

(c)

Fig. 4.2   (a) Example of a twin-bladed neck cutter set to sever all the blood vessels in the neck; (b) Example of a single-bladed neck cutter set to make a ventral cut severing at least one carotid artery and one jugular vein; (c) Example of a single-bladed neck cutter set to make a dorsal cut severing a vertebral artery.
L Va = left vertebral artery, R Va = right vertebral artery. L C = left carotid artery, R C = right carotid artery, L J = left jugular vein, R J = right jugular vein.

Table 4.2   Effect of slaughter methods on times to loss of VEPs in chickens

Treatment	Average time (seconds)	Standard error
Cardiac arrest	23	2
Decapitation	32	2
2 carotid arteries cut	60	8
1 carotid artery and 1 jugular vein cut	122	22
2 jugular veins cut	185	25
1 jugular vein cut	233	58

literature suggests that these methods do not always induce immediate loss of consciousness. For example, electrical activity indicative of consciousness can persist in the brain of chickens for on average 32 s after decapitation (Gregory and Wotton, 1986). In addition, neck dislocation raises concerns because VEPs in the brain have been demonstrated in chickens for up to four minutes after dislocation, depending on the method used (Gregory and Wotton, 1990c). In this regard, neck dislocation by manual stretching of the neck causes more rapid loss of VEPs than crushing the neck with a pair of pliers. It has been suggested that dislocation caused by manual stretching induces concussion of the brain. However, for practical purposes, neck dislocation should be limited to small numbers of birds, and it must achieve severance of the spinal cord from the brain (to prevent neural transmission) and all the major blood vessels in the neck (to prevent any blood supply to the brain). As an alternative, many retailers in the UK are recommending captive-bolt stunning as a back-up method (visit: www.hsa.org.uk). A practical problem under commercial conditions that needs to be addressed is that birds showing signs of consciousness during bleeding are inaccessible to the back-up operatives, that is, they cannot be reached safely and easily. Proper design and layout of the shackle line and blood-collection troughs (or vats) will help to overcome this problem.

4.7   Future trends: improving poultry meat quality

Mobile slaughter facilities designed for on-farm use would be more appropriate for countries lacking infrastructure or centralised slaughter and processing facilities. A number of systems are being used in the USA and France to produce high-quality carcasses for sale through co-operatives or farm shops. A portable gas stun/kill system is also manufactured in the UK (www.aaflow.com).

It is to be expected that mechanised and integrated bird catching and crating machines will become more common, and successful use of these will not only improve bird welfare and the quality of carcasses and meat, but reduce labour, cost and waste. Stun/killing of poultry in crates or conveyors using gas mixtures should be the ideal solution to many of the existing welfare and quality problems at the processing plant. The opportunity to portion carcasses within two hours of

slaughter, thus reducing refrigeration space and costs, and the environmental benefits of stun/killing poultry while contained in transport crates must be tested under high-throughput processing conditions. Because of these benefits, it is hardly surprising to note that the European Integrated Pollution Prevention and Control Bureau (EIPPCB) has considered stun/killing of poultry with nitrogen as the best practice. On the other hand, electrical water-bath stunning or stun/kill method would still be the preferred method for small- and medium-sized processing facilities around the world. In such situations, use of constant-current stunners should become mandatory to protect bird welfare at slaughter. For this purpose, it may be possible to install multiple shackle lines, with appropriate space between the shackles, so that individual birds can be electrically isolated in water-bath stunners, prior to converging as one high-speed processing line.

4.8   Sources of further information and advice

http://www.eippcb.jrc.es
http://www.wto.org
http://www.maf.gov.nz/AnimalWelfare
http://www.rspca.org.uk
http://www.grandin.com
http://www.fao.org
http://www.defra.gov.uk
http://www.amif.org
http://www.oie.int
http://europa.eu.int/
http://www.hsa.org.uk
http://www.awtraining.com

4.9   References

ALLEN C D, RUSSELL S M and FLETCHER D L (1997), 'The relationship of broiler breast meat colour and pH to shelf life and odour development', *Poultry Science*, 76, 1042–1046.

BAGER F, BRAGGINS T J, DEVINE C E, GRAAFHUIS A E, MELLOR D J, TAVENER A and UPSDELL M P (1992), 'Onset of insensibility at slaughter in calves: effects of electroplectic seizure and exsanguination on spontaneous electrocortical activity and indices of cerebral metabolism', *Research in Veterinary Science*, 52, 162–173.

BILGILI S F (1992), 'Electrical stunning of broilers – basic concepts and carcass quality implications: a review', *Journal of Applied Poultry Science*, 1, 135–146.

BUTTERWORTH A (1999), 'Infectious components of broiler lameness: a review', *World's Poultry Science Journal*, 55, 327–352.

DANBURY T C, WEEKS C A, CHAMBERS J.P, WATERMAN-PEARSON A E and KESTIN S C (2000), 'Self-selection of the analgesic drug carprofen by lame broiler chickens', *Veterinary Record*, 146, 307–311.

DELL P, HUGELIN A and BONVALLET M (1961), 'Effects of hypoxia on the reticulo-cortico-reticular system and on motor excitability', in Gustaut H and Meyer J S, *Cerebral Anoxia and the Electroencephalogram*, Charles C Thomas, Springfield, IL., 46–57.

DUNCAN I J H (2001), 'Animal welfare issues in the poultry industry: is there a lesson to be learned?', *Journal of Applied Animal Welfare Science*, 4, 207–221.

ERNSTING J (1965), 'The effect of anoxia on the central nervous system', in Gillies J A, *A Text Book of Aviation Physiology*, Pergamon Press, Oxford, 271–289.

FLETCHER D L (1999), 'Colour variation in commercially packaged broiler breast fillets', *Journal of Applied Poultry Science*, 8, 67–69.

GENTLE M J and TILSTON V L (2000), 'Nociceptors in the legs of poultry: Implications for potential pain in preslaughter shackling', *Animal Welfare*, 9, 227–236.

GREGORY N G and AUSTIN S D (1992), 'Causes of trauma in broilers arriving dead at poultry processing plants', *Veterinary Record*, 131, 501–503.

GREGORY N G and BELL J C (1987), 'Duration of wing flapping in chickens shackled before slaughter', *Veterinary Record*, 121, 567–569.

GREGORY N G and WHITTINGTON P E (1992), 'Inhalation of water during electrical stunning in chickens', *Research in Veterinary Science*, 53, 360–362.

GREGORY N G and WILKINS L J (1989a), 'Effect of slaughter on bleeding efficiency in chickens', *Journal of Science of Food and Agriculture*, 47, 13–20.

GREGORY N G and WILKINS L J (1989b), 'Effect of stunning current on carcase quality in chickens', *Veterinary Record*, 124, 530–532.

GREGORY N G and WILKINS L J (1989c), 'Effect of ventricular fibrillation at stunning and ineffective bleeding on carcase quality defects in broiler chickens', *British Poultry Science*, 30, 825–829.

GREGORY N G and WILKINS L J (1990), 'Broken bones in chickens: effects of stunning and processing in broilers', British *Poultry Science*, 31, 53–58.

GREGORY N G and WOTTON S B (1986), 'Effect of slaughter on the spontaneous and evoked activity of the brain', *British Poultry Science*, 27, 195–205.

GREGORY N G and WOTTON S B (1987), 'Effect of electrical stunning on the electroencephalogram in chickens', *British Veterinary Journal*, 143, 175–183.

GREGORY N G and WOTTON S B (1989), 'Effect of electrical stunning on somatosensory evoked potentials in chickens', *British Veterinary Journal*, 145, 159–164.

GREGORY N G and WOTTON S B (1990a), 'An evaluation of the effectiveness of handheld stunners for stunning chickens', *Veterinary Record*, 126, 290–291.

GREGORY N G and WOTTON S B (1990b), 'Effect of stunning on spontaneous physical activity and evoked activity in the brain', *British Poultry Science*, 31, 215–220.

GREGORY N G and WOTTON S B (1990c), 'Comparison of neck dislocation and percussion of the head on visual evoked responses in the chicken's brain', *Veterinary Record*, 126, 570–572.

GREGORY N G and WOTTON S B (1991), 'Effect of a 350 Hz DC stunning current on evoked responses in the chicken's brain', *Research in Veterinary Science*, 50, 250–251.

GREGORY N G, AUSTIN S D and WILKINS L J (1989), 'Relationship between wing flapping at shackling and red wingtips in chicken carcasses', *Veterinary Record*, 124, 62.

GREGORY N G, RAJ A B M, AUDSLEY A R S and DALY CC (1990) 'Effects of carbon dioxide on man', The use of carbon dioxide for the stunning of slaughter pigs, Report of a meeting of experts held in Heeze on 26–27 January 1990, *Fleischwirtschaft*, 70, 1173–1174.

GREGORY N G, WILKINS L J, WOTTON S B and MIDDLETON A L V (1995), 'Effects of current and waveform on the incidence of breast meat haemorrhages in electrically

stunned broiler chicken carcasses', *Veterinary Record*, 137, 263–265.

HILLEBRAND S J W, LAMBOOY E and VEERKAMP C H (1996), 'The effects of alternative electrical and mechanical stunning methods on haemorrhaging and meat quality of broiler breast and thigh muscles', *Poultry Science*, 75, 664–671.

HOENDERKEN R (1978), 'Electrical stunning of slaughter pigs', PhD Thesis, University of Utrecht, The Netherlands.

HUMANE SLAUGHTER ASSOCIATION (HSA) UK (1993), *Slaughter by Religious Methods.*

JONES R B, SATTERLEE D G and CADD G G (1998), 'Struggling responses of broilers shackled in groups on a moving line: effects of light intensity, hoods, and "curtains"', *Applied Animal Behaviour Science*, 58, 341–352.

KANNAN G, HEATH J L, WABECK C J and MENCH J A (1997a), 'Shackling of broilers: effects on stress responses and breast meat quality', British *Poultry Science*, 38, 323–332.

KANNAN G, HEATH J L, WABECK C J, SOUZA M C P and MENCH J A (1997b), 'Effects of crating and transport on stress and meat quality characteristics in broilers', *Poultry Science*, 76, 523–529.

KOTULA A W and HELBACKA N V (1966), 'Blood volume of live chickens and influence of slaughter technique on blood loss', *Poultry Science*, 45, 684–688.

KRANEN R W, LAMBOOIJ E, VEERKAMP C H, VAN KEPPEVELT T H and VEERKAMP J H (2000), 'Haemorrhages in muscles of broiler chickens', *World's Poultry Science Journal*, 56, 93–126.

LAMBOOIJ E (1981), 'Some neural and physiological aspects of electrical and mechanical stunning in ruminants', PhD Thesis, University of Utrecht, The Netherlands.

LAMBOOIJ E (1992), 'General aspects of electrical stunning', Proceedings of EC workshop on pre-slaughter handling and stunning of poultry, Brussels, November 9–11, 17–25.

LAMBOOIJ E, PIETERSE C, HILLEBRAND S J W and DIJKSTERHUIS G B (1999), 'The effects of captive bolt and electrical stunning, and restraining methods on broiler meat quality', *Poultry Science*, 78, 600–607.

LEVINGER I M (1996), 'Shechita im Lichte des Jahres 2000. Kritische Betrachtung der wissenschaftlichen Aspekte der Schlachtmethoden und des Schächtens', *Zentralrat der Juden in Deutschland*, Bonn, Machon Maskil L'David, Jerusalem.

NAWAC (2001), 'Discussion paper on the animal welfare standards to apply when animals are commercially slaughtered in accordance with religious requirements', National Animal Welfare Advisory Committee, New Zealand.

PARKER L J, BAJOIE K C, CATILLE S, CADD G G, SATTERLEE D G and JONES R B (1997), 'Sex and shank diameter affect struggling behaviour of shackled broilers', *Poultry Science*, 76 (Suppl. 1), 88.

RAJ A B M (1996), 'Aversive reactions of turkeys to argon, carbon dioxide, and a mixture of carbon dioxide and argon', *Veterinary Record*, 138, 592–593.

RAJ A B M (1999), 'Effect of stunning and slaughter methods on carcass and meat quality', in Richardson R I and Mead G C (eds), *Poultry Meat Science,* Carfax, Abingdon, Vol. 25, 231–254.

RAJ A B M (2003), 'A critical appraisal of electrical stunning in chickens', *World's Poultry Science Journal*, 59, 87–96.

RAJ A B M and GREGORY N G (1990a), 'Investigation into the batch stunning/killing of chickens using carbon dioxide or argon-induced hypoxia', *Research in Veterinary Science*, 49, 364–366.

RAJ A B M and GREGORY N G (1990b), 'Effect of rate of induction of carbon dioxide anaesthesia on the time of onset of unconsciousness and convulsions', *Research in*

Veterinary Science, 49, 360–363.

RAJ A B M and GREGORY N G (1991a), 'Efficiency of bleeding of broilers after gaseous or electrical stunning', *Veterinary Record*, 128, 127–128.

RAJ A B M and GREGORY N G (1991b), 'Effect of argon stunning, rapid chilling and early filleting on texture of broiler breast meat', *British Poultry Science*, 32, 741–746.

RAJ A B M and JOHNSON S P (1997), 'Effect of the method of killing, interval between killing and neck cutting and blood vessels cut on the blood loss in broilers', *British Poultry Science*, 38, 190–194.

RAJ A B M and O'CALLAGHAN M (2001), 'Evaluation of a pneumatically operated captive bolt for stunning/killing broiler chickens', *British Poultry Science*, 42, 295–299.

RAJ A B M and TSERVENI-GOUSI A (2000), 'Stunning methods for poultry', *World's Poultry Science Journal*, 56, 291–304.

RAJ A B M, GREGORY N G and WOTTON S B (1990a), 'Effects of carbon dioxide stunning on somatosensory evoked potentials in hens', *Research in Veterinary Science*, 49, 355–359.

RAJ A B M, GREGORY N G and AUSTIN S D (1990b), 'Prevalence of broken bones in broilers killed by different stunning methods', *Veterinary Record*, 127, 285–287.

RAJ A B M, GREY T C, AUDSLEY A R S and GREGORY N G (1990c), 'Effect of electrical and gaseous stunning on the carcase and meat quality of broilers', *British Poultry Science*, 31, 725–733.

RAJ A B M, GREGORY N G and WOTTON S B (1991a), 'Changes in the somatosensory evoked potentials and spontaneous electroencephalogram of hens during stunning in argon-induced anoxia', *British Veterinary Journal*, 147, 322–330.

RAJ A B M, GREY T C and GREGORY N G (1991b), 'Effect of early filleting on the texture of breast muscle of broilers stunned with argon-induce anoxia', *British Poultry Science*, 32, 319–325.

RAJ A B M, GREGORY N G and WOTTON S B (1992a), 'Changes in the somatosensory evoked potentials and spontaneous electroencephalogram of hens during stunning with a carbon dioxide and argon mixture', *British Veterinary Journal*, 148, 147–156.

RAJ A B M, NUTE G R, WOTTON S B and BAKER A (1992b), 'Sensory evaluation of breast fillets from argon-stunned and electrically stimulated broiler carcases processed under commercial conditions', *British Poultry Science*, 33, 963–971.

RAJ A B M, WILKINS L J, RICHARDSON R I, JOHNSON S P and WOTTON S B (1997), 'Carcase and meat quality in broilers either killed with a gas mixture or stunned with an electric current under commercial processing conditions', *British Poultry Science*, 38, 169–174.

RAJ A B M, WOTTON S B, MCKINSTRY J L, HILLEBRAND S J W and PIETERSE C (1998), 'Changes in the somatosensory evoked potentials and spontaneous electroencephalogram of broiler chickens during exposure to gas mixtures', *British Poultry Science*, 39, 686–695.

RAJ A B M, WILKINS L J, O'CALLAGHAN M and PHILLIPS A J (2001), 'Effect of electrical stun/ kill method, interval between killing and neck cutting and blood vessels cut on blood loss and meat quality in broilers', *British Poultry Science*, 42, 51–56.

SCHUTT-ABRAHAM I and WORMUTH H-J (1988), 'Cardiac arrest stunning in poultry', *Proceedings of the 34th International Conference of Meat Science and Technology*, Brisbane, Australia, August 29–September 2, 106–108.

SCHUTT-ABRAHAM I and WORMUTH H-J (1991), 'Anforderungen an eine Tierschutzgerechte elektrische Betäubung von Schlachtegeflügel', *Rundeschau für Fleischhygiene und Lebensmittelüberwachung*, 43, 7–8.

SCHUTT-ABRAHAM I, WORMUTH H-J, FESSEL J and KNAPP J (1983), 'Electrical stunning of poultry in view of animal welfare and meat production', in Eikelenboom G (ed.), *Stunning of Animals for Slaughter*, The Hague, Martinus Nijhoff, 187–196.

SCHUTT-ABRAHAM I, WORMUTH H-J and FESSEL J (1987), 'Vergleichende Untersuchungen zur Tierschutzgerechten Elektrobetaubung verschiedener Schlachtgeflügelarten', *Berliner und Münchener Tierarztliche Wochenschrift*, 100, 332–340.

SCHUTT-ABRAHAM I, KNAUER-KRAETZL K, WORMUTH H-J and GREGORY N G (1991), 'Effect of salinity in a waterbath stunner on the amperage obtained during electrical stunning of poultry', *Fleischwirtschaft*, 71, 1309–1310.

SCHUTT-ABRAHAM I, KNAUER-KRAETZL B and WORMUTH H-J (1992a), 'Effects of some stunning conditions on the currents obtained during the electrical stunning of geese', *Fleischwirtschaft*, 72, 298–300.

SCHUTT-ABRAHAM I, KNAUER-KRAETZEL B and WORMUTH H-J (1992b), 'Beobachtungen bei der Bolzenschussbetaubung von Kaninchen', *Berliner und Münchener Tierarztliche Wochenschrift*, 105, 10–15.

SPARREY J (1994), 'Aspects of the design and operation of shackle lines for the slaughter of poultry', MPhil thesis, University of Newcastle upon Tyne, UK.

SPARREY J M, KETTLEWELL P J and PAICE M E (1992), 'A model of current pathways in electrical waterbath stunners used for poultry', *British Poultry Science*, 33, 907–916.

SPARREY J M, KETTLEWELL P J, PAICE M E R and WHETLOR W C (1993), 'Development of a constant current water bath stunner for poultry processing', *Journal of Agricultural Engineering Research*, 56, 267–274.

WANG L-Y and KACZMAREK L K (1998), 'High frequency firing helps replenish readily releasable pool of synaptic vesicles', *Nature*, 394, 384–388.

WARRISS P D, BEVIS E A, BROWN S N and EDWARDS J E (1992), 'Longer journeys to processing plants are associated with higher mortality in broiler chickens', *British Poultry Science*, 33, 201–206.

WARRISS P D, WILKINS L J and KNOWLES T G (1999), 'The influence of ante-mortem handling on poultry meat quality', in in Richardson R I and Mead G C (eds), *Poultry Meat Science*, Carfax, Abingdon, Vol. 25, 217–230.

WILKINS L J, GREGORY N G, WOTTON S B and PARKMAN I D (1998), 'Effectiveness of electrical stunning applied using a variety of waveform-frequency combinations and consequences for carcass quality in broilers', *British Poultry Science*, 39, 511–518.

WILKINS L J, WOTTON S B, PARKMAN I D, KETTLEWELL P J and GRIFFITHS P (1999), 'Constant current stunning effects on bird welfare and carcass quality', *Journal of Applied Poultry Research*, 8, 465–471.

WILKINS L J, BROWN S N, PHILLIPS A J and WARRISS P D (2000), 'Variation in the colour of broiler breast fillets in the UK', *British Poultry Science*, 41, 308–312.

WOOLEY S C and GENTLE M (1988), 'Physiological and behavioural responses of the domestic hen to hypoxia', *Research in Veterinary Science*, 45, 377–382.

WOOLEY S A, BROTHWICK F J W and GENTLE M J (1986a), 'Flow routes of electric currents in domestic hens during pre-slaughter stunning', *British Poultry Science*, 27, 403–408.

WOOLEY S A, BROTHWICK F J W and GENTLE M J (1986b), 'Tissue resistivities and current pathways and their importance in pre-slaughter stunning of chickens', *British Poultry Science,* 27, 301–306.

ZELLER W, METTLER D and SCHATZMANN U (1988), 'Studies into the stunning of slaughter poultry with carbon dioxide', *Fleischwirtschaft*, 68, 1308–1312.

5

Primary processing of poultry

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5.1   Introduction

The purpose of this chapter is to describe the different stages of processing and the equipment commonly used in preparing oven-ready carcasses and cut portions. Although there are still many plants, largely in lesser developed markets, which process birds largely by hand using individual machines to which carcasses are fed manually, most higher volume plants now use processing systems based on a moving overhead conveyor. In all cases, the level of automation will depend on hourly throughputs and the availability and cost of labour. Regardless of the level of automation, the process will usually be split into the following individual departments:

- live-bird supply
- stunning, killing, scalding and plucking
- evisceration and giblet handling
- chilling
- whole bird selection by weight and quality
- whole bird packing
- cut-up, deboning and the packaging of cut and deboned product
- freezing and/or chilled storage.

Line capacities go from 500 to over 10 000 birds per hour. The process description which follows starts with live-bird supply and ends with carcass deboning.

5.2   Live-bird supply

Processing begins once birds are ready to be caught and transported to the processing plant. Rough handling during catching and poor transport conditions will result in a high count of birds 'dead on arrival' (DOA) at the processing plant and in substantial downgrading and loss of yield. It is therefore important that animal welfare and optimum working conditions for catching personnel are taken fully into consideration, when choosing transport units, working practices and transport vehicles.

5.2.1   Containers and crates

Birds can be caught and loaded into a number of different transport units. Most common are:

- plastic crates
- modular steel frames with removable open-top plastic drawers
- modular multi-tier steel containers.

Plastic crates have either solid or perforated floors. While crates with solid floors are cheaper to buy and prevent droppings from one layer of birds from contaminating birds in the layer below, there are several reasons why perforated floors are often preferred. These are:

- there is better ventilation of the birds
- temperature conditions are more favourable, especially in summer, and
- respiratory moisture from the birds is discharged, so that the birds can remain dry throughout the journey.

These feature help to maintain bird quality and reduce the incidence of DOAs at the processing plant.

Plastic crates are mostly, but not always, used in lower capacity plants. These are filled manually and loaded individually on to the transport vehicle. Modular transport units such as steel frames with removable open top plastic drawers and multi-tier steel containers can be filled either manually or automatically and are loaded by forklift truck onto the transport vehicle. Although plastic crates are still widely used in many countries, modular systems are becoming increasingly prominent. They save labour, improve animal welfare by reducing the risk of damage to birds during catching, improve working conditions for catching personnel and, because the job is done more quickly, ensure that birds reach the processing plant as speedily as possible. Modular systems give fewer DOAs and fewer costly downgrades.

Although most birds worldwide are still caught and placed into the transport units by hand (Fig. 5.1), labour saving automatic catching machines are becoming ever more common. EU legislation requires that the space allowance is at least $160 \, cm^2$/kg of live bird. In hot climates, it is advisable to increase this to $170 \, cm^2$/kg.

Fig. 5.1   Loading steel containers by hand.

5.2.2   Transport vehicles

Optimum conditions during transport from the growing shed to the processing plant are of vital importance in ensuring that birds arrive at the processing plant in good shape. Birds are grown commercially in all climates and in extremes of heat and cold. Transport module and vehicle design must allow good ventilation and therefore dissipation of heat from the birds during transport. Care must also be taken to protect birds during inclement weather. In this context transport vehicles must be provided with suitable curtains or even solid panels. Vehicle design must also ensure that transport modules can be loaded quickly and stowed safely.

5.2.3   Arrival at the plant and live-bird lairage

No matter how well these activities are carried out, catching and transport cause stress for birds. It is therefore important that they should have time to settle down in comfortable conditions before being hung on the processing line. Stressed birds process badly and processing yields will suffer. The live-bird store at the processing plant, the lairage, should be big enough to store at least two hours production. It should allow birds to be protected from the weather in a well-ventilated environment with subdued lighting.

5.2.4   Hanging of live-birds on the processing line

The next step is to hang the birds on the first of several processing lines, the killing line (Fig. 5.2). Full plastic crates are destacked either manually or automatically and are placed onto a conveyor system, which takes them to the

Fig. 5.2   Hanging of live birds.

operatives, who will remove birds from the crates and hang them on shackles. Full and empty crates are weighed to determine live-bird weight and the empty crates given a thorough wash before being restacked either manually or automatically. Crate washing can be done either manually or automatically.

Modular systems introduce a degree of mechanisation into this process. These systems now predominate in high-capacity processing plants. With modular frames with removable open top drawers, the full drawers are pushed automatically one by one out of the frame onto a conveyor system, which takes them to the operatives, who will remove birds from the open top drawers and shackle them. Full and empty drawers are weighed to determine bird weight and both drawers and frames given a thorough automatic wash. The washed drawers are then put back into the washed frame.

Full multi-tier containers are placed by a forklift truck onto a conveyor system, which takes them to an automatic unloading device. The doors on each tier are opened automatically and the container tilted. The birds exit the container via sliding plates onto an enclosed trampoline conveyor system, which takes them to a rotating carousel onto which they are shackled by the hang-on operatives. Empty containers are washed and, if necessary, disinfected automatically. Full and empty crates are weighed. A dust extraction system ensures that hang-on operatives work in a dust-free environment.

Clean crates or containers are stored separately from full crates or containers. In this case the lairage or live-bird arrival area can be divided into 'dirty' and 'clean' areas. Transport vehicles will have been washed down before being loaded with clean crates or containers for another run.

5.3   Stunning, killing, scalding and plucking

5.3.1   Stunning

Except where slaughter is performed ritually, regulations insist that birds must be stunned before application of the bleeding cut.[1] Stunning renders birds insensitive to pain allowing them to be killed humanely. Until relatively recently stunning was always carried out electrically in a water-bath stunner using a 50 Hz/60 Hz supply. However, demands in Europe from veterinarians, super-markets and animal welfare lobbies have, however, led to an increase in the amperage received by each bird. Higher amperages at 50 Hz/60 Hz will often result in an increased incidence of broken bones and in unacceptable blood spots in valuable breast and thigh fillet. To combat these undesirable side effects, processors now commonly use either high-frequency electrical stunners operating at 300 Hz and above or modified atmosphere stunning systems using a variety of gas mixtures. High-frequency electrical stunning can reduce the incidence of broken bones and blood spots by up to a third and are now a common sight in high-capacity poultry processing plants. Modified atmosphere stunning is now in use in many European Union markets. Both single stage anoxic and two-stage anaesthetic systems are in everyday use. In single-stage anoxic systems birds enter a mixture, which will typically contain argon and either carbon dioxide or nitrogen. In two-stage systems birds are anaesthetised in the first stage by an atmosphere rich in oxygen and carbon dioxide and then rendered irreversibly unconscious in a separate atmosphere high in carbon dioxide.

Modified atmosphere stunning has many benefits. From the animal welfare point of view, birds are no longer hung fully conscious to the killing line and there is no chance of any bird entering the scalding process still alive. For hang-on operatives an unconscious bird is far easier to shackle than a struggling live animal. Modified atmosphere stunning virtually eliminates the bone breakage and blood spots seen with electrical stunning. Quality and yield benefit as a result. Modified atmosphere stunning can also help with maturation.[2,3]

5.3.2   Neck cutting and bleeding

After birds have been stunned, a cut is applied to the neck to allow birds to bleed out. European Union legislation dictates that birds must die from exsanguination. The bleed cut can be applied either manually or automatically. Manual cutting is obligatory in ritual slaughter when no stunning is applied, where the carotid veins and arteries on both sides of the neck must be cut through. In all higher capacity processing plants the bleed cut is applied automatically. Automatic cutting will usually sever the carotid vein and artery on one side of the neck only. This procedure does not damage the oesophagus or trachea, allowing these to be removed later in the process during evisceration.

Automatic cutting machines which open up the carotid veins and arteries on both sides of the neck are also used. All automatic machines must be followed by a back-up operative. Blood drains from the bird into a bleeding trough. Bleed

times will vary from 90 seconds for birds killed ritually or by automatic machines that cut the carotid vein and artery on both sides of the neck, to some 150 seconds when the bleed cut is applied automatically to one side of the neck only. No other activity, such as electrostimulation, is carried out during the first 90 seconds of bleed out. Blood is pumped from the bleed trough to a storage tank.

5.3.3   Scalding

In this process turbulent hot water is used to transfer heat to the feather follicles, which then relax allowing feathers to be removed mechanically in the pluckers. Carcasses are conveyed through one or more scalding tanks filled with hot water at a preset temperature. The temperature of the scald water and the dwell time in the scalding system and therefore its size will depend on whether carcasses are to be soft (50–51ºC for 2.5–3 min), medium or hard scalded (58–60ºC for 1.5–2 min) for sale fresh or frozen. Soft scalding leaves the epidermis intact allowing soft scalded birds to be chilled by air alone. Medium and hard scalding will tend to loosen the outer layer of the epidermis, which is then partially removed during plucking. Such carcasses will usually have to be wet chilled and subsequently frozen to safeguard their appearance.

The scald water can be heated by direct steam injection or by low pressure steam or hot water circulated through integral heating panels mounted in the scald tank. The temperature of the scald water is monitored and controlled electronically. In most modern scalders turbulence is induced by introducing air into the scald water through nozzles mounted in the bottom of the tank (Fig. 5.3). There are,
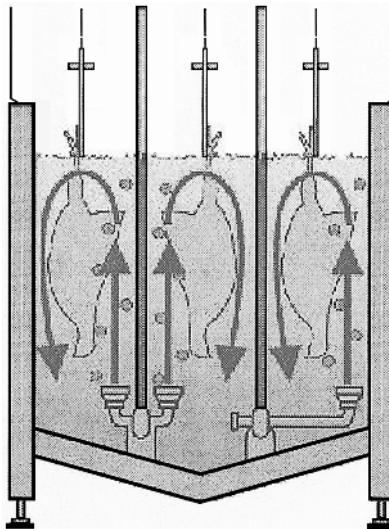

Fig. 5.3   Cross-section scalding tank with air nozzles.

however, many older scalders still in everyday operation, where turbulence is induced mechanically by electrically or hydraulically driven impellers.

Recent developments have concentrated on reducing running costs, making scald tanks easier to clean and, most importantly, on reducing microbial contamination of carcasses. To this end many processors have installed multi-bath scalding systems with birds moving into ever cleaner water. Research is also being carried out into hot air scalding systems.

5.3.4   Plucking

Feathers are removed in electrically or hydraulically driven automatic pluckers by rubber fingers mounted on either belt or gear driven contra-rotating discs. Pluckers are installed immediately after the scalding process so that carcasses remain warm during feather removal. When religious requirements dictate that scalding cannot be used, automatic plucking is not satisfactory and then the feathers must be removed manually.

Different plucking machines are available for the removal of tail feathers, and for the rough plucking and finishing of a wide range of bird weights. The type and number of automatic pluckers in a plucking system will depend on bird weight, scald temperature and hourly throughput. More plucking capacity is needed for soft scalded birds than for medium or hard scalded birds. Depending on the desired quality of the end product, birds may have to be finished by hand by one or more operatives called 'pinners'.

Feathers are washed down from the pluckers into a channel running underneath the machines and are then pumped over a separation screen, from which they fall into a container to await removal. Wet feathers are often fed to a feather press where much water is removed, thereby reducing both the volume of feathers to be transported and the cost of transporting them. Recent developments in plucking machines have concentrated on making them easier to set, maintain and clean and on reducing cost of ownership.

5.3.5   Electrostimulation

In some markets birds have to be matured before being portioned and filleted. This is because consumers prefer tender meat. In most instances this process is done off-line by holding birds in a cold store for a set period of time. This method of maturing carcasses does, however, have its drawbacks. It needs a lot of space, is labour intensive and can compromise yield in that carcasses will dry out. The time needed to mature carcasses also reduces available shelf-life. Electro-stimulation is part of a cocktail of measures, which will allow birds to be matured in-line (Fig. 5.4). These measures are referred to in greater detail in Section 5.9.2. Electrostimulation, which is carried out immediately after plucking, can give the equivalent of some four hours maturation off-line. By pulsing electricity through the birds for a period of some 90 seconds, residual energy in the muscles is removed more quickly. In some plants electrostimulation is also carried out

Fig. 5.4   In-line maturation.

during bleed out and before scalding and plucking. In this instance, however, electrostimulation cannot legally begin until birds have bled for at least 90 seconds. Since electrostimulation accelerates the onset of *rigor mortis*, it makes plucking more difficult if carried out before scalding.

5.3.6   Other killing line activities
After the carcass has been plucked and, if appropriate, electrostimulated, heads, oesophagus and trachea are removed automatically and feet or legs cut off. Feet or legs can be cut off in a dedicated foot or leg cutter. This activity can, however, be combined in an automatic carcass-transfer device, which transfers carcasses birds automatically from the killing line to the evisceration line. Heads and feet are usually taken by vacuum to a storage container for subsequent removal from site. Empty shackles are washed and return to the hang-on area.

5.4   Evisceration and giblet harvesting

5.4.1   Evisceration
Plucked birds will have been rehung either manually or automatically on the evisceration line. They then pass through a number of automatic carousel
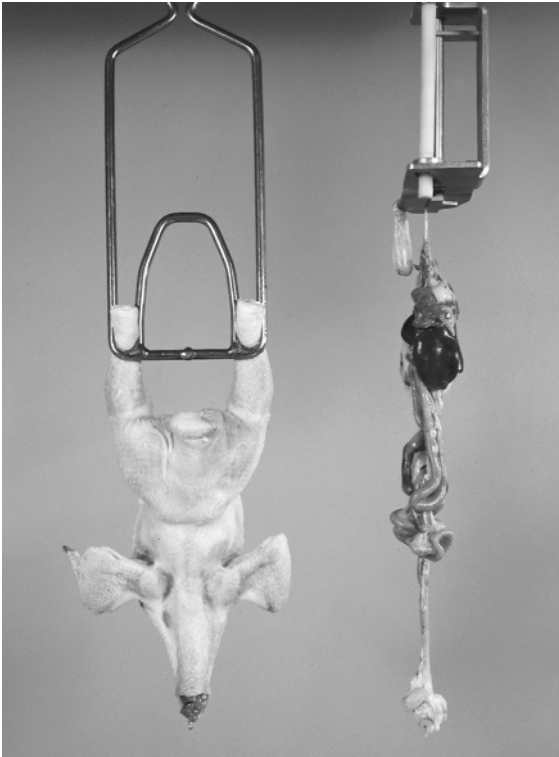
Fig. 5.5   Presentation bird and viscera pack.

machines, which will perform the operations necessary to eviscerate the bird and present a clean carcass to the chilling process. In sequence these operations are venting and opening to open up the bird for evisceration, evisceration itself during which the viscera pack and all edible and inedible offal are removed, neck flap cleaning to ensure that the trachea and oesophagus have been removed from the neck skin, automatic neck removal and the removal by vacuum of any loose debris still remaining in the carcass. Once all these operations have been completed, the carcass is given a thorough wash both inside and out.

Until some ten years ago eviscerating machines drew out the viscera 'pack' and laid it over the back of the bird, from where all edible giblets were harvested. This process can still be seen in many smaller plants. New evisceration systems were then launched, which drew out the viscera pack and then transferred it automatically to an entirely separate giblet harvesting process (Fig. 5.5). These newer systems saved labour and improved hygiene in that the viscera pack no longer came into contact with the back of the bird thus reducing contamination with gut contents. They also made veterinary inspection of both bird and viscera pack easier.

5.4.2   Giblet harvesting and transport

In many markets edible giblets such as hearts, livers and gizzards remain valuable whether for sale for human consumption or for the manufacture of pet food. It is therefore important that as many giblets as possible are harvested. In some cases the neck is packed with the giblets.

Modern evisceration systems separate the viscera pack completely from the bird and either deposit it into a synchronised pan conveyor for semi or fully automatic giblet harvesting, or transfer it to a synchronised overhead conveyor system, where individual machines cut off the intestines and gall bladder, harvest the liver, deposit the gizzard into a gizzard processing system and drop the heart and lungs into a heart and lung separating machine. Advantages of the new process are substantial labour savings, increased giblet yield and vastly improved hygiene.

Giblets can be chilled by cold air or by immersion in counterflow water chillers. They can be pumped either before or after chilling to a separate area in the processing plant for further handling and packing. Alternatively they can be packed into crates in the evisceration department and then air chilled. A new technique involves giblets being deposited automatically onto a belt conveyor system, which takes them through the same air chiller as that used for carcasses. Once chilled these giblets are packed for sale, retail or bulk. Inedible offal such as intestines, lungs and waste from the gizzard harvesting process is usually sucked away in a fully enclosed vacuum transport system, which deposits the material into storage containers for subsequent removal from site.

5.5   Chilling

Once evisceration is complete, birds must be chilled to slow the growth of harmful bacteria. How carcasses will be sold, whether in whole carcass, portioned or deboned meat form, will determine the chilling process to be used. If carcasses are to be sold dry and fresh, they will have been soft scalded and will be chilled using air alone. If they are to be sold wet fresh or frozen, they will have been medium or hard scalded and must be wet chilled. Medium or hard scalding removes most or all of the outer epidermis. If such carcasses were air chilled, they would emerge from the process unacceptably discoloured.

5.5.1   Air chilling

This involves circulating cold air around and inside the carcasses, taking care, however, not to freeze wing tips and neck flaps. Most higher capacity plants producing dry fresh product will have an air chilling tunnel, through which birds are transported by shackles on an overhead conveyor system, which can be up to four tiers high (Fig. 5.6). Cold air is blown either down onto or across the carcasses. Such tunnels are known as 'downflow' or 'crossflow' tunnels. Some tunnels also have a system of ducts, which direct cold air into the cavity of the carcass and over the thickest part of the breast. This method shortens the chill

Fig. 5.6   Air chilling.

time needed. In all cases birds are chilled to a maximum of 4ºC, a process that takes 1.5–2.0 hours for a 1.5–2.0 kg carcass. Birds can be transferred automatically to and from the air chilling line. Air chilling techniques are also used in maturation chill tunnels, more information on which is given in Section 5.9.2. One disadvantage of air chilling is that carcasses can dry out resulting in yield loss. Moistening techniques are now available, which largely prevent carcasses drying out and which have no negative effect on shelf-life.

5.5.2   Wet chilling

The two most common methods of wet chilling are water-immersion chilling which is usually carried out in a counterflow screw chiller and spray chilling. Whilst water-immersion chilling has disappeared from most European Union countries, it is still common practice in many other markets in the world. The process involves dropping carcasses into a one- or two-bath system, through which they are transported by an Archimedes screw into ever colder and cleaner water. Agitation of the chill water allows carcasses to pick up water to the maximum allowed by national legislation. In the EU, the process must meet requirements relating to water usage and temperature and carcass residence time. Immersion chilling is more labour intensive than systems using an overhead conveyor, as automatic line-to-line transfers cannot be installed.

Spray chilling is common in the European Union. In essence this technique involves adding a system of water sprays to an air chilling tunnel as described

above. Carcasses are chilled 'individually' on a shackle. Evaporation of the water film on the carcass surface may assist the cooling process, while wetting the carcass avoids excessive moisture loss. Water pick-up is, however, less than with an immersion chill.

5.5.3   Combination chilling

In some markets wet and dry processes are combined to give a composite system. An example of this is a shortened immersion or drag through wet chill system followed by a shortened air chill tunnel. Medium or hard scalded carcasses remain wet but do not have the same amount of free water as birds chilled completely by immersion.

5.6   Whole-bird selection by weight and quality

Once carcasses have been chilled, they are now ready for packing as whole carcasses, portions or deboned meat. Each individual carcass must now be graded by weight and quality, so that it can be allocated to the correct process as dictated by the marketplace. The correct allocation of carcasses is essential, if a processing plant is to operate profitably. In most higher capacity processing plants in the European Union, carcasses are transferred either manually or automatically to an overhead conveyor system usually called a preselection line, on which they are graded by weight and quality and from which they are released automatically by individual weight and quality at a number of automatic unloading stations.

5.6.1   Quality grading

Carcasses can be graded for quality by specially trained personnel. Grading can be carried out before or after carcasses are hung to the preselection line. Various devices are available for registering the quality grade allocated to each carcass. These pass this information to a computerised control unit, which will also receive and process data on the weight of each carcass. Some plants now use computer-controlled vision systems, which assess quality automatically. More information on these systems is given in Section 5.9.1.

5.6.2   Weight grading

Carcasses are weighed electronically either in the rehang unit, which transfers them from the chill line to the preselection line, or in a weigh station installed in the preselection line itself. This information is passed to a computerised control unit.

5.6.3   Information processing

Information on weight and quality is processed in the computerised control unit and each carcass allocated by weight and quality grade to a number of automatically activated unloading stations or to one or more automatic portioning systems. Modern control systems allow individual customer orders to be met in the most cost-effective way and will integrate easily into higher computer systems.

5.7   Whole-carcass packaging

How whole-carcasses will be packed will depend largely on whether they are to be sold fresh or frozen. Wet chilled carcasses to be sold frozen are usually packed into pre-printed polythene bags. This can be done manually using bagging chutes or either semi or fully automatically using a range of bagging and closing machines. Dry chilled birds to be sold fresh are usually placed onto trays and overwrapped with film. They are then weighed and labelled. Bags or other leak-proof packaging systems can be an alternative. Carcasses to be further processed or sold wholesale are usually packed in bulk into cartons or returnable plastic crates.

5.8   Secondary chilling

All products that will be sold fresh rather than frozen require further chilling to slow the growth of cold-tolerant spoilage organisms. This is usually acheived by holding the wrapped product in a chill room until the deep-muscle temperature reaches 0–1ºC.

5.9   Portioning and deboning operations

5.9.1   Portioning

In high volume markets, a large percentage of carcasses is cut into portions for retail sale, for use in canteen and catering outlets and as a raw material for an increasingly wide range of fast-food products. In low throughput plants carcasses can still be cut manually. In most medium and high throughput plants, however, birds are cut automatically by modular systems able to operate at hourly throughputs of 5000 carcasses or more.

Most automatic cut-up systems are now installed on overhead conveyors, which allow cutting modules to be sited at any point on the conveyor. This makes for optimum layout flexibility helping to ensure the best possible logistics in the cut-up and deboning area. It is, of course, vitally important that the product is packed as quickly as possible and transferred to the chill store or freezer. Automatic cut-up systems are now able to replicate with great accuracy virtually all portion cuts currently in everyday circulation. They are also able to

Fig. 5.7   Breastcap cutter with by-pass.

weigh and size in-line whole and half carcasses, rear quarters, anatomic legs and drumsticks.

A relatively recent innovation is the ability to track carcasses electronically through the cut-up system and to by-pass individual cutting modules (Fig. 5.7). When combined with weight information from the preselection line or from one or more weighing modules in the cut-up system itself, this ability allows carcasses to be cut selectively and extremely cost-efficiently according to weight and to orders received by the processing plant from its customers. The same technique allows legs, for example, to be sized into whole leg portions, cut into thigh and drumstick portions, or transferred automatically to an automatic leg deboning line.

5.9.2   Deboning
More and more carcasses are being deboned to satisfy the rapidly increasing demand for deboned meat for use both at home and in the preparation of an ever wider range of further processed convenience and catering products. Whilst many lower volume plants still debone by hand, labour cost and availability will often dictate that deboning is done automatically. In many markets breast fillet is the premium product. The first machines to debone these automatically were launched in the early 1980s. Modern modular systems can now handle in excess of 3000 breast caps or front halves per hour and can process these into a wide

Fig. 5.8   Leg meat harvesting.

variety of breast fillet products both with and without skin. The systems, which can be integrated seamlessly with downstream weighing and packing activities, give excellent yields with minimal residual bone and can be switched quickly from one fillet product to another.

Whole legs, thighs and drumsticks can now also be deskinned and deboned automatically (Fig. 5.8). These activities can either be carried out in stand-alone machines or in modular overhead conveyor based systems, to which pre-sized legs are transferred automatically from the automatic cut-up system. Leg deboning can be performed at speeds of up to 7200 legs per hour.

5.9.3   Packaging of portions and deboned meat

Product for sale retail can be packed in a number of ways. Portions to be sold frozen will usually have been individually quick frozen in a spiral freezer. These are then often packed by weight into pre-printed polythene bags. Portions, including breast and thigh fillets to be sold fresh will usually be packed on trays, overwrapped, weighed and labelled. In some markets, however, where packs are sold by weight and count, sophisticated weighing systems will assemble the required pack weights automatically and with a minimum of give-away, before the product is packed.

In recent years large supermarket groups are attaching increasing importance to modified atmosphere packaging techniques. Packing portions of deboned

meat in a modified atmosphere environment prolongs shelf-life and gives both processor and retailer increased operating flexibility.

5.10   Future trends

5.10.1   Vision systems

Grading carcasses and portions for quality has always been a key activity. Until relatively recently this was performed by eye. Some ten years ago the first in-line computer controlled vision systems began to come onto the market. Although initial progress was slow, vision systems have now become commonplace in today's high volume processing plants (Fig. 5.9). The first systems were installed to grade fresh birds in-line after air chilling. Advantages were labour savings and, perhaps even more importantly, more consistent grading. Accurate grading is essential if the best use is to be made of each individual carcass. The latest systems are now able to grade birds in-line immediately after plucking and either before or during automatic portioning to grade individual parts of the carcass such as wings, breast, thighs and drumsticks. Grading birds after plucking pinpoints the exact reasons for any downgrading and will reject unfit carcasses. Grading individual parts of the bird saves labour and allows the best use to be made of each individual portion. Work is also being carried out on using vision systems to detect disease on both the killing and evisceration lines.
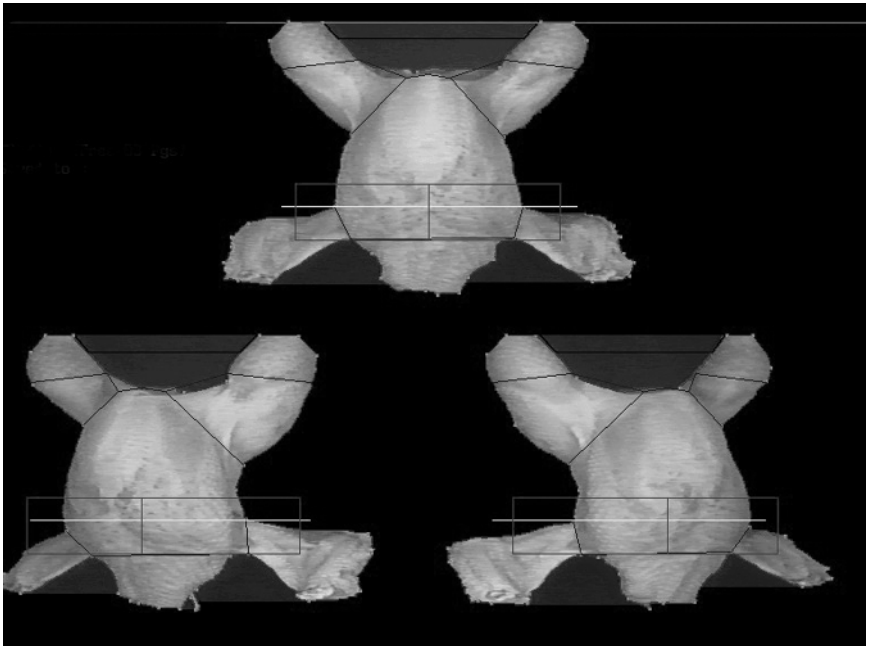

Fig. 5.9   Grading birds with in-line vision system.

5.10.2   In-line tenderness management versus off-line maturation

Maturation off-line in a maturation store has a number of disadvantages. These have already been listed in Section 5.3.5. A process or combination of processes was therefore needed, which would allow birds to mature in-line to give the tender breast meat which consumers want. A process is now available, which allows the same levels of tenderness to be achieved in-line in some three hours as were formerly only possible by storing birds off-line for at least six to eight hours. This process comprises a cocktail of measures to accelerate both *rigor mortis* and the breakdown of proteins:

- controlled atmosphere stunning
- electrostimulation
- maturation chilling.

Controlled atmosphere stunning has been shown to help the tenderising process. In-line maturation is, however, also possible with high frequency electrical stunning. Electrostimulation, which accelerates *rigor mortis*, has already been referred to above and can give in just 90 seconds the same tenderising effect as maturing carcasses off-line for some four hours.[4]

The final element in the process is in-line maturation chilling in a maturation chill tunnel briefly referred to in Section 5.5. The maturation chill tunnel is a variant of a standard air chilling tunnel, where the chilling process is carried out in two phases. In the first, shorter phase all exterior and interior surfaces of the carcass are chilled rapidly using very cold air at high velocities. The application

Fig. 5.10   Central control system for traceability.

of a thin water film prevents birds drying out and helps the chill process. In the second, longer phase birds are subjected to less cold air at much lower velocities. This promotes maximum enzyme activity to break down proteins.

Maturation in-line gives the following benefits:

- saves labour as it eliminates double handling
- improved hygiene as product is touched less
- saves space and improves logistics
- reduces weight loss
- helps traceability
- prolongs in-store shelf-life

5.10.3 Tracking and tracing

In recent years food safety has become a hot topic. Many retailers and fast food chains now insist on complete traceability for their products. In those plants where birds are kept on-line from live-bird hang-on to their release as sized whole-birds or portions, and where transfer between the individual processing lines is carried out automatically, it is now possible to track each individual bird through the entire process and thereby to guarantee traceability.

Birds are tracked by counters linked to a central control system (Fig. 5.10), which will also interface with in-line weigh heads, quality grading devices and vision systems. This allows a complete 'file' to be kept on each bird with full information on which growing farm it came from, how much it weighed after processing, what quality grade was assigned to it, for what type of end product it was used and to which customer it was despatched.

5.11 References

1. Council Directive 93/119/EC on the protection of animals at the time of slaughter or killing.
2. GADE P B, VON HOLLEBEN K and VON WENZLAWOWICZ M (2001), 'Animal welfare and Controlled Atmosphere Stunning (CAS) of poultry using mixtures of carbon dioxide and oxygen, Report of a Symposium held in Oldenburg, Germany on 4th December 2000, *World's Poultry Science Journal*, 57, 189–200.
3. COENEN A M L, LANKHAAR J A C and VAN LUIJTELAAT E L J M (2003), 'Controlled Atmosphere Stunning of chickens with a carbon dioxide-oxygen mix is preferable to a carbon dioxide-argon mix', *XVI European Symposium on the Quality of Poultry Meat*, 659–665.
4. KRANEN R W (2003), RapidRigor: The way to accelerate in/line poultry processing, *XVI European Symposium on the Quality of Poultry Meat*, 666–671.

6

Further processing of poultry

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6.1 Introduction: poultry consumption and the evolution of the poultry industry

Over the past 40 years, more than a dozen textbooks, technical reviews and numerous trade magazine articles have been published, with information on the further processing of poultry. Since most further-processed poultry products are aimed specifically at selected markets, the evolution and changes in these products on a worldwide basis have been numerous and highly variable from country to country or between regions within a country. Although some further-processed items have had relatively long product lives (e.g. canned soups, potpies, and frozen TV dinners), other products have been trendy, short-lived or of limited distribution. The whole area of product development and further processing is highly dynamic in terms of technical development and response to changing food-purchasing habits, markets and consumer demands and expectations. It is an interesting paradox that, in a world increasingly dominated by globalization of markets, information and consumer goods, there are still major differences in national, regional, ethnic and religious preferences for the foods we eat.

The development of further-processed poultry products depends heavily on three major inputs: technical capabilities, market demands and, most importantly, economics. Technical issues are more related to the appearance of new equipment, process control, scientific limitations (such as water- and fat-binding capacity, oxidative and microbial stability, and food safety), production expertise and the development of proprietary systems to produce specific products. Market demands are highly variable and based on national, ethnic, religious and traditional values, and are also highly dependent on marketing and

product advertising, as well as governmental regulations. However, the most important issues are economic.

Further-processed products are often referred to as 'value-added' items, with the expectation of enhanced profit margins. The technical ability to produce such products has always taken second place to the realities of the marketing and economic viability of new foods. Although we may have the scientific knowledge and technical capability to produce a 'silk purse out of a sow's ear', there are not necessarily any marketing or economic incentives to do so.

There is an inherent enigma in writing a chapter on further processing. There may be only a few hundred individuals in the world with real technical knowledge about the further processing of poultry. These individuals wish to see highly scientific and technical answers to current problems, but a work providing the answers would rapidly become dated and end up as an historical document. To those with little knowledge of poultry processing, such a scientific treatise would be little more than meaningless technobabble. To the novice, simple explanations with lots of pictures and diagrams are the norm. Previous works have attempted to cover the basic technical areas in a traditional, scientific manner and include the use of pictures to show products and equipment. Instead of duplicating the historical development that these earlier works provide, this chapter is intended to offer a more systematic approach to the basic concepts of further processing. In place of pictures and 'how-to' formulations, interested readers are encouraged to attend a poultry or food-manufacturing equipment trade show to see the actual state-of-the-art technologies, to visit a further processor (if possible) or, at the very least, to visit both large-scale and traditional food markets to see the products available locally. Hopefully, the information gained will offer a glimpse into the complexity and scale of further poultry processing and how the products in question have reached the various markets. Recent editions of an *International Poultry Exposition Guide* and a *Who's Who in the Egg & Poultry Industries in the USA & Canada* are listed in Section 6.8 as resource guides for buyers as well as reference guides to equipment, supplies and statistical data for the poultry industry.

6.1.1   Historical perspective on poultry consumption

Numerous poultry-based food products have traditionally been prepared and consumed since the first domestication of the fowl over 5000 years ago. Because poultry, and especially chickens, are relatively small (often less than 2 kg live weight), animals slaughtered for consumption were generally eaten immediately and by-products, such as feathers, head, feet and edible viscera (giblets), were used to make speciality products. The feathers were often washed and used to insulate clothing or bedding, the larger quills of the major flight feathers were used to make pens, the head, feet and bones often boiled down for soup stock (rich in collagen) and the edible viscera (heart, gizzard, and liver) were either consumed with the bird or used to make speciality products, gravies and meat

pies. As with many traditional livestock species, very little of the carcass went unused. However, since a single bird would offer little more product than could be consumed at one sitting, little effort was devoted to developing preserved poultry products (such as salted or dried meat, sausages, etc.). For this reason, although we may have a rich history of recipes that utilize poultry-meat, there are few traditional further-processed products. Red meat and fish often demanded some form of further processing to preserve excess quantities arising from the size of the animal (beef and pork), or because of a large fish harvest. In agrarian-based societies, the keeping of live poultry was much more practical than the preservation of food products made from poultry.

Poultry was also different in another way from other, traditional meats or fish. In early societies, the bird was a valuable farm animal for the production of eggs and feathers. It was also used for entertainment (cock fighting) and as a barn-yard scavenger (being omnivores the birds were valuable for keeping weeds and insects under control). Some birds were used as show animals and, perhaps least importantly, as a source of meat. Since many of the birds were kept primarily for eggs and their fighting qualities, little effort was made to increase meat production. Up until the last 60 years or so, poultry were extremely widespread, but flock sizes tended to be relatively small (hundreds of birds at most). Many families, rural or urban, will have kept at least a few birds for egg production and meat for the occasional feast. For much of Western civilization, fowl generally had a higher prestige value than that of other sources of meat. Even today, poultry species are most closely associated with the more revered festival meals.

It was not until the last century that concerted efforts were made to increase the commercial production of both eggs and meat. As industrial cities began to grow, the production of many foodstuffs became more concentrated, with the sole purpose of supplying high-population centers with food. This shift from primarily agrarian to industrial societies depended on the intensification of food production, in which farms began to look more to the production of specific foods, as opposed to being self-contained units. Intensive farming manifested itself in orchards, vegetable farms, large dairies and specialized meat-producing farms. In relation to poultry, this intensification was first realized for egg production and later for meat. The intensive production systems demanded some degree of extended shelf-life and product diversification to allow reasonable time for distribution and marketing of more consumer-oriented foods, as opposed to mass quantities of basic commodities.

6.1.2   Evolution of the poultry-meat industry

During the first half of the twentieth century, poultry production followed the traditional agricultural pattern of other livestock. A farmer would buy chicks from a hatchery, feed from a feed mill, basic equipment from a farm-supply house (or even the Sears and Roebuck Catalog, which sold both birds and equipment), and grow the birds to market age. The farmer may then have taken

his birds to a traditional livestock market or sold them directly to a processor, who slaughtered and prepared the birds for sale to consumers. The processor would have sold directly to the public or to wholesalers, who then sent the carcasses to a number of small meat markets, grocery stores or restaurants in towns and cities.

During this period, there was considerable competition in producing the various poultry breeds and cross-breeds that yielded either the highest numbers of eggs, the meatiest birds or which were best at both (dual-purpose breeds). Because chicks are very small and precocial, and since they can usually survive for several days following hatch, due to the internal storage of excess yolk, they were easily transported by train over very long distances. Individuals were able to purchase almost any breed by mail. Since poultry could be effectively raised with a minimal amount of space and relatively inexpensive, specialized equipment, there was general interest in raising poultry in almost all sectors of society. Production was relatively cheap to initiate, it yielded edible products from both eggs and meat for the owner, provided excess product that was readily marketable, and created an almost universal acceptance of poultry as a popular meat option. Around the time of World War II, poultry supplies were adequate to meet market demand, but poultry-meat prices were similar to or higher than those of mutton, pork, or beef.

In the late 1940s and early 1950s, poultry producers began to integrate vertically the many aspects of poultry production, as well as take advantage of scientific breakthroughs in nutrition, genetics and disease control. Vertical integration is simply bringing the various aspects of poultry production, including breeding, incubation, husbandry, processing and marketing under one business structure. With the application of intensive breeding programs, better nutrition, disease control, management improvements and vertical integration, there was an improvement in the economy of production that was unparalleled in agriculture. Around the time of World War II, it took about 16 weeks to produce a 1.5 kg bird, using 6 kg of feed. A bird of the same market weight can now be produced in approximately 6 weeks on 3 kg of feed. It is not uncommon to see poultry marketed today at an unadjusted price similar to that of 50 years ago!

A major consequence of this large increase in production efficiency has been an astronomical increase in the size of poultry companies and a concomitant decrease in the number of poultry producers. Before World War II, most flocks numbered less than 500 birds. A modern US poultry company is extremely large, with the top ten companies slaughtering between 7 and 70 million kg of broilers per week. Because of the extremely low fixed costs and the massive capital and labor costs of one of these major producers, small poultry companies have all but disappeared, except for highly specialized, niche-market producers (e.g. range-fed, organic or Label Rouge birds). Before World War II, almost anyone could afford to start a poultry operation; today, with increased efficiencies and low-cost production, the margins are so low that only massive operations can afford to exist, and it is estimated that approximately 100 million dollars or euros would be required to build an average-sized operation. The scale

of a modern processing plant, slaughtering 1–3 million birds a week, puts all poultry enterprises on a scale that is almost impossible to imagine by those not familiar with the industry. All the operations, from breeding farms, hatchery and growing farms, through processing, further processing and marketing of products are performed on a similar scale.

6.2   The development of further processing: market and consumer forces and scientific research

As mentioned earlier, poultry is consumed on a worldwide basis, in which differences in ethnic, religious and local customs have resulted in a multitude of ways that the meat and other edible parts can be prepared for consumption. In the industrialized nations, intensive agriculture was more involved initially in the high-volume production of chicken as a commodity. Prior to World War II, poultry was strictly a commodity in which almost all consumption was based on home preparation. Following the rapid growth of the poultry industry in the 1950s, more and more poultry products appeared in both the rapidly-growing fast-food market and grocery stores. However, since there were very few traditional food products that had been developed for preservation, such as cheese, sausages and dried meats and fish, there were also few further-processed products made from poultry. Early further processing is well covered in the textbooks written in the 1960s and is focused on the fact that poultry meat could be used effectively to make numerous meat products, such as frankfurters, bologna and sausages, that were not made traditionally from poultry.

Although there were no real technical problems, consumers were not used to buying poultry in such forms, and it took many years for these products to gain consumer acceptance. As inexpensive poultry meat and by-products, such as mechanically separated meat, became more available, and thus economically attractive for incorporation into traditional, further-processed, red-meat products, these poultry by-products began to be considered sub-standard in quality. Strict requirements for product identity relative to species (meat, fish or poultry) and labeling often resulted in products being identified in ways that were highly disadvantageous in the market. The need for products to be clearly labeled as being made from poultry, or having to use terms such as 'artificial' or 'made from' were stigmas indicating that the products were inferior to those from traditional meat sources. It was not until later, when consumers began to perceive poultry meat as healthy that many of these negative issues disappeared. Good examples today are the proliferation of popular chicken- and turkey-based deli products, such as poultry frankfurters, bologna, turkey ham, turkey bacon and other speciality meats, such as pastrami and luncheon meats, that now constitute a major market share.

In the 1970s there was a considerable shift in market form from whole birds, as a commodity, to brand-name products, available in both whole and cut-up, pre-packaged forms, as well as dramatic increases in fast-food, restaurant and

Table 6.1 Estimated changes in percentage market distribution and market forms between 1970 and 2001

	Market		Market form		
	Retail or grocery store	Food service or take-home	Whole birds	Cut-up	Further processed
1970	80	20	70	25	5
2001	48	52	10	50	40

institutional use. From the 1980s to today, there has been a steady increase in the use of boneless, skinless broiler and turkey meat, used as raw ingredients in a multitude of further-processed products that are available as fresh and frozen entrées. As with the concentration of primary production into a few but extremely large commercial operations, further processing is also conducted on an equally massive scale. Although limited further processing has been a reality for many years, the modern form has occurred primarily during the past 30 years. In previous times, dependable statistics were available on market channels and product profiles. However, in modern, ultra-high-volume processing plants, product distributions are almost impossible to document, although estimates can be made to illustrate this relatively recent phenomenon (Table 6.1).

The role of further processing and product development can be approached in a number of ways. Firstly, one could focus on specific products such as bologna, frankfurters, frozen fried chicken, canned soups, etc., paying attention to the products themselves, their formulations and marketing. Further processing can also be viewed as a dynamic concept, in which specific systems are the focus, such as chilling, packaging, forming, smoking, marinating and cooking. Further processing can also be approached from a strictly objective and scientific viewpoint relative to topics like protein-water-fat gel formation, water-holding capacity, oxidative stability, gas permeability of packaging materials, color reactions, flavor enhancement and optimization of other sensory properties. Equally, further processing can be viewed as a strictly marketing issue by studying niche markets and the development of products to compete in a wider market (moving historically marketed products from the fresh-meat case to the deli section, frozen foods, meal entrées and take-home, ready-to-eat foods). In truth, further processing involves all of these approaches, which are very important, but cause confusion to individuals new to further processing of poultry or more concerned with changes in consumer buying habits. Do consumers buy the products offered or do processors deliver products based on consumer demand?

In previous books (see Section 6.8) there have been clear distinctions in the way authors and editors chose to cover this complicated area. Earlier works tended to focus on the development of new chicken products, formulations and market expansions, while later books focused more on the scientific and

technical developments that led to the processes used to manufacture a wide range of further-processed products. These later works have sections on packaging, product development, shelf-life extension, food safety, commercial-scale marination, product-forming equipment and application of cooking and freezing technologies.

It is the purpose of this chapter to avoid concentrating on any single approach. The whole area of further processing is highly dynamic and products are constantly evolving. Examination of the earlier accounts shows that the growth in consumption of further-processed poultry products and the development of new technologies and equipment have expanded dramatically, even since publication of the more recent works. It should also be mentioned that much of modern product development and technology is carried out by private companies, who sell the equipment, supplies and ingredients, as well as the technical expertise to produce specialized products. Much of this information is proprietary and not readily available for public dissemination. Instead of poultry processors developing their own new products, this is done by equipment companies, ingredient suppliers, packaging companies and customers (such as fast-food companies) in order to increase demand for their product or food service.

Another aspect that should be considered is the role of scientific research in product development. One approach is to characterize a process scientifically and then apply it to the development of new products. Alternatively, new products and processes can be developed, to which science may be applied after the event to improve processing efficiency and problem solving. Over the years, it is clear that the second scenario has been more realistic – science has had less impact on the development of new products and, instead, new products and processes have driven scientific investigation. The desire to produce frozen foods, extend shelf-life and improve product uniformity have been a reaction to production requirements and market demand. Therefore, an examination of further processing from a solely scientific perspective would result in a highly distorted and unrepresentative picture. There is a marked contradiction between the direction of most scientific research in this field and the actual domination of product forms in the market place. For example, one can find entire books and hundreds of articles on materials or topics for which the scientific basis is established, such as mechanically deboned meat, gel properties, myofibrillar extractions and measurements of rancidity. However, these are not necessarily well represented by the actual products in the market place.

6.2.1   Definitions of further processing

Although widely used, the term 'further processing' is not well defined. In its simplest form, further processing can be defined as any step or process that goes beyond the normal production and marketing of a raw, agricultural commodity and attempts to add value to the product or increase market share. Within this context, in relation to traditional, live-bird markets, killing, scalding and picking

could be viewed as 'further processing', since they make the meal preparer's job easier. Later, as fully-eviscerated carcasses became more popular, it is hard to imagine that, in a little over 60 years, consumer expectations would have changed to an extent that almost no-one in the developed world would consider buying fresh poultry with the viscera still intact and inside the carcass. Thus, the definition of further processing changes over time, as consumer perceptions of market products evolve. These perceptions are by no means universal and vary widely between national and regional markets, and between companies, based on corporate structure, physical lay-out and management necessity.

During the last half century, further processing has taken on more specific meanings and has also evolved with the rapid growth of the industry itself, much of which was fueled by the development of these same further-processed products. The way in which we refer to further processing may be more a function of how a company's facilities are physically arranged, how it is organized and accounts for inter-product transfer, and how customers, such as restaurant chains, specify particular products. Within this concept, some terms are used rather commonly. It should be kept in mind that, although poultry-product development is not new, many canned, frozen, fully cooked and other further-processed, poultry-based foods were available in grocery stores in the 1950s, but they were a relatively small proportion of the total amount of poultry consumed. What we refer to today as further processing is more of a volume-related issue, reflecting changing market demands.

The first steps in modern processing are the slaughter, evisceration and chilling of carcasses. The traditional terminology used to describe the slaughterhouse or abattoir uses euphemistic terms such as 'processing plant,' 'packing plant,' 'packing house,' or more recently, 'primary processing' or 'first processing.' The cutting of the carcass into parts, packaging of raw consumer products, deboning and portioning are often referred to as 'secondary processing' or 'second processing.' The formulation of specific products (shaping, marination, coating, etc.), cooking, packaging and freezing are often referred to as 'third processing.' Very often, second and third processing are combined simply into 'further processing'. It must be understood that these are often arbitrary terms and will be used differently by different companies and in different countries. There are no distinct divisions between the above terms and many plants may simply distinguish the steps according to the physical layout of the plant or the management structure. Thus, one plant may encompass the complete process from slaughter through to a fully cooked and ready-to-eat product, whereas, in other circumstances, the same product may be handled by several companies, with specialized plants for each major function.

A differentiation between the concepts of preparation and processing also needs to be addressed. Preparation is how a product is handled, cooked and presented for immediate consumption or sale. In this context, preparation covers the culinary arts and kitchen practices used to prepare specific dishes. Processing is a more industrialized and centralized approach to the creation of 'pre-prepared' products. An example of the former would be the use of raw

chicken for the preparation of a specific dish, such as fried chicken, chicken casserole, or chicken cordon bleu. Each of these products can be prepared from basic commodities in a home or institutional kitchen. These very same products could also be mass-produced by a commercial further-processor for distribution to either a commercial kitchen or a home, for minimal preparation prior to consumption.

Further processing can be defined according to three basic criteria: processing (food technology), product form and product presentation. Food technology refers to the actual engineering and chemical processes, technologies and equipment used in operations such as portioning, marination, coating, cooking, product formulation, freezing and packaging. Product form refers to the nature of the product, when purchased and used by the customer or consumer. Product form also refers to how the technologies are applied to produce recognizable and acceptable products. Product forms would include whole birds, parts, fillets, patties, nuggets, deli meats and poultry-based entrées, including fresh, shelf-stable (canned or dry-packaged) and frozen products. Finally, there is product presentation, which is how the product is actually marketed. This would cover market niche (fresh, deli, frozen), retail outlets, restaurants, fast-food, take-out or take-home foods and frozen entrées. These three criteria could be used to develop a three-dimensional matrix to cover the entire spectrum of further processing. Within such a concept, a single product, such as a breaded and fried nugget, may be produced using different technologies, marketed fresh, frozen, or fully cooked, and could be presented to the consumer in a retail outlet or made available in restaurants and fast-food outlets.

6.3   Further processing methods and technologies

As stated, many of our modern further-processed products are the result of technological advance. Equipment development and new-product development are components of a circular process, which is constantly evolving. Anyone can obtain a very good 'snapshot' of the further-processed poultry products available today by simple observation of the products available in fast-food outlets, restaurants and at the major locations of grocery stores (fresh meat, prepackaged deli section, fresh deli, canned and shelf-stable products, baby foods, pet foods, prepared fresh and raw products, bulk frozen foods, frozen entrées, speciality foods and fully prepared and ready-to-eat, take-out foods). Since these markets only stock what sells, they accurately depict the current market, as dictated by consumer choice. What can be seen in six months or two years may be substantially different. There is also considerable variation between the different types of market. 'Upscale' grocery stores are likely to offer a greater variety and quantity of further-processed convenience foods, while more traditional grocery stores will carry a higher proportion of traditional poultry products, low-cost and in bulk, in both fresh and frozen form, and minimally processed products.

Manufacturers of further processing equipment and ingredient suppliers are also highly dynamic. Their goal is to produce ever more efficient machines and ingredients that improve yield, product quality and consistency, with machines that are simple to operate, easy to clean and can readily be shown to either save money or produce products yielding higher margins. These new technologies and products are constantly being highlighted in the many poultry-processing and food-technology trade magazines and at poultry, meat or food-technology trade shows. These are excellent sources of current, cutting-edge technologies and provide some idea of changing market trends.

The physical and chemical technologies of further processing range from the minimum of cutting and portioning the carcass through to the use of highly sophisticated technologies to formulate unique food products. These technologies include shaping, forming, emulsifying, marinating, coating, various methods of cooking and smoking, chilling and freezing systems and packaging. Much of modern further processing is a function of machinery design and ingredient formulation, for which the technologies are highly proprietary. Although the physico-chemical aspects of many of the processes used are well understood, overall, the industry relies heavily on the expertise of equipment manufacturers and ingredient suppliers to produce consistent products. Companies are more concerned with economic factors associated with production and marketing, and only raise scientific issues when these are needed to solve specific problems.

Further processing can be approached by examining the various processes that are used. The range of products that can be produced by various combinations of these processes is almost infinite. However, not all technologies are compatible with all other technologies. Some types of further-processed products may be suitable only for institutional markets, and would not be appropriate for direct consumer sales. Products are often developed in response to highly-focused markets and include institutional and consumer products formulated for specific groups, such as children or geriatrics, including health foods, ethnic products, ready-to-eat convenience items and pet foods.

6.3.1   Cutting, deboning and portioning

Since fresh or frozen whole birds now represent a minority of consumer sales (less than 10% in the USA), it is estimated that about 50% are cut up for direct consumer sale or use in fast-food, restaurant or institutional markets, and the remaining 40% are deboned and used to make numerous poultry-based products. In relation to the sheer volume of birds being processed, as well as the wide variety of potential uses, considerable options exist for both hand and machine cutting and deboning of carcasses. The earliest, intensive cut-up operations were designed to meet the growing demands of institutional and fast-food markets. The producers required a highly uniform bird-size and specialized cutting operations for both process and portion control. The uniformity of size was critical for cooking protocols, inventory control and consumer expectations.

Because of the highly specialized nature of the cuts involved, many of these processors relied, and still rely, on manual cutting. Institutional markets, as well as general consumers, demanded more and more product defined by specific cut, shape and weight. Consumers often preferred to buy whole birds pre-cut or to purchase only one specific cut, such as the white meat (front half) or dark meat (rear half). Since such demands were not as specific as those of large, fast-food customers, generic cutting was acceptable and more appropriate for mechanical cut-up systems. Automated cut-up systems have been available for at least 20 years, but are still the subject of research and development. Many of these specialized cut-up machines are designed for both specific cuts, such as removing the rear half of the bird (saddle) or the wings and legs, or for a cut-up and deboning system in which highly specialized cuts are made by individual machines placed in tandem, and integrated to allow the complete cutting and deboning of an entire carcass. The mix-and-match concept of using machines for specific marketing and sales demands varies from company to company, from plant to plant, and even between lines within a plant. Also, it is not uncommon to see both mechanical and manual cutting and deboning on one line.

Modern portioning machines are capable of cutting deboned meat portions to highly uniform shapes, thicknesses and weights, using computer-aided systems and high-pressure, water-jet cutting. These systems can produce thousands of highly uniform products per hour. Fast-food and restaurant customers for these products often demand specific and highly uniform products in relation to size, shape and weight, to guarantee uniform coverage on a sandwich bun ('bun coverage'). Such products are often subjected to other processes, such as marination or coating, and may be sold as fresh or frozen raw, partially-cooked or fully-cooked products. Most are sold to the large fast-food or institutional food chains, which demand very high standards for the above-mentioned criteria and for appearance and sensory properties.

Some meat and excess trim are stripped, diced and sized prior to being individually quick-frozen (IQF) and packaged. Diced meat may be used to make consumer products (e.g. for fajita or soup mixes) and is used in other further-processed products, such as potpies and a variety of frozen entrées. The use of larger birds that yield more breast meat has created some new opportunities. These birds, often slaughtered at 56 days of age and averaging almost 3 kg, yield larger breast fillets than are generally required for many product specifications. Trimming the large fillets to meet a standard portion specification, such as 110 g, results in a correspondingly large amount of lower-value trim meat. Machines have been developed to slice the large fillet laterally into two or more pieces of uniform thickness. This process is sometimes referred to as 'slittering.' There is interest in the performance of these sliced fillets in subsequent processes, such as marination and cooking, in view of the loss of muscle membranes on the cut surfaces, which must change the surface properties for both marinade uptake and cooking loss.

There is also some confusion concerning the term 'mechanical deboning.' Traditionally, mechanical deboning has referred to the recovery of edible tissue

from necks, bones and skeletal frames, following cut-up and hand removal of the meat. In this process, the skeletal frames and bone residues are coarsely ground and then forced through one of many types of machine which, under high pressure, force the more fluid fat, soft muscle tissue and moisture through a fine-mesh screen or series of plates, while the bones and less-fluid residue (some tendons and connective tissue) are retained and collected separately. The resulting mechanically deboned poultry meat (MDPM) has the texture of a fine paste and is high in fat and heme pigments from the bone marrow, which give the product a pink color. This product has been available for over 35 years, but it has compositional and textural problems, and a relatively short shelf-life due to auto-oxidation; it is, however, very inexpensive and often used as a cheap ingredient in such products as poultry frankfurters. The machines used to strip whole muscles from the carcass are sometimes referred to as 'mechanical deboners.' However, due to the different requirements for terminology and labeling of the more traditional MDPM, there may be some confusion between the two. Therefore, although the term mechanical deboning may be used to describe the automated machines that replace hand deboning, some caution needs to be exercised to be sure that the interpretation is correct.

6.3.2   Marination

Marination is an old process, used in preparing meat, either for immediate consumption or as a preliminary step in preservation. Marination is used to improve both sensory (flavor, color, moisture and texture) and functional properties of the meat (water-holding capacity, stability and cooked yield, for example). Marinades were primarily a mixture of salt, organic acids, nitrates and spices in a solution in which the meat was soaked, or with which it was injected prior to smoking and/or curing. Traditional preparations of ham and dried beef are good examples. In the last decade, there has been a large increase in the marination of poultry carcasses, parts and deboned meat. Whole birds and parts are often injected with a flavored salt or phosphate solution prior to manufacture of rotisserie, grilled, barbeque or fried chicken products. The marinade produces a more tender product, with more flavor, lower cooking losses and increased juiciness. Whole turkeys and turkey breasts are also commonly marinated to improve their sensory properties. Skinless and boneless meat are marinated in a tumbler (massager), operated in a static, vacuum or high-pressure environment to improve marinade absorption and uniformity. These products can then be sold directly to the consumer as pre-marinated, ready-to-cook meat, or they can be frozen for distribution to fast-food and restaurant outlets. For the institutional food industry, this type of product is extremely versatile, as it can be cooked rapidly and served as a whole, grilled fillet or stripped and used on grilled-chicken salads, fajitas and a wide variety of sandwiches.

Although marination is an old process, modern, high-capacity marination systems are relatively new. The major methods of marination are a static soak (not widely used commercially because it is too slow), injection and tumbling

under static conditions, vacuum or pressure. Static marination is primarily for small pieces of meat that are placed in the marinade and allowed to absorb the solution under chill conditions. This can occur in large vats or in small lots within packages. In some consumer packs, the meat and marinade are packaged together and absorption and stabilization of the product occurs during distribution.

Injection involves a series or grid of spring-loaded needles that penetrate the carcass and force the marinade into the tissue under pressure. Since the needles are often spring loaded, they will stop upon contact with bone surfaces. Also, the needles have multiple orifices to allow marinade to be injected at various depths. The marinade is then capable of diffusing into large pieces of meat, whole muscles, parts and whole birds much more rapidly. Injection is often done on high-speed belts, where the parts pass under the injection needles, are injected and then pass through the system. Injection systems are primarily used on whole carcasses, turkey breasts and broiler parts, where both skin and bone are still attached. The system is often run under chill conditions and any marinade not absorbed by the meat is collected, filtered and recycled. The major advantages of injection are that it is relatively fast, can accommodate a wide variety of product sizes and shapes, and leaves the skin and bone intact. It is ideal for whole birds, halves and large and small cut-up parts. Such products are often used for rotisserie, oven-cooked, smoked, barbeque, roasted and fried chicken products.

Tumbling or mechanical massaging was first shown to be of benefit for accelerating the absorption and diffusion of marinade in hams. Whole meat, such as breast fillets and tenders (*M. pectoralis minor* or *superficialis*), can be placed in a drum with a pre-determined amount of marinade, sealed and slowly turned to allow a 'massaging' or tumbling action to accelerate the uptake. Modern tumblers usually pull a partial vacuum and, in some systems, high pressure is being tested to accelerate and make the process more uniform. The major disadvantage of tumbling is that it is not suitable for skin-on products or meat susceptible to damage from the tumbling action. In fact, tumblers are designed to maximize physical massaging for optimal marinade uptake, while minimizing product damage. Although vacuum tumbling is widely used, there is actually very little information available to explain the scientific principles. Although the basic principles of meat science are well established, marination is more of an art associated with specific equipment, marinade formulations and product forms. It is well accepted that marination processes are not always consistent and what works on a laboratory or pilot scale may not be directly applicable to production-scale processing. Also, marination is highly equipment- and formulation-dependent, and often varies between batches of chicken. Recent research has focused on the effects of factors such as meat aging, fillet size, cut surfaces (from slicing), meat color (especially between extremes of light and dark fillets) and muscle pH on both total marinade uptake and uniformity of uptake between fillets in large batches. These issues are important in relation to both basic research, which seeks to provide better understanding of the

marination process, and the industry, which wants to produce more uniform products and control marinade uptake relative to possible regulations and labeling requirements.

6.3.3   Coating

The coating of poultry products can vary from minimal seasoning with salt and pepper, through sophisticated sauces to completely battered and breaded (enrobed) products. Coating is often used as a basic preparation technique to add flavor, seal the product so that moisture and juiciness are retained during cooking, and improve product appearance. It is often associated with specific dishes. Coatings are also important in further processing to increase cooked-product yield, both by helping to retain moisture and by the added weight of the coating material itself. Depending on the amount of added material, such as breading, it may be necessary for the product to be suitably labeled. The difference between a coated meat product, such as some types of nugget, and a 'fritter' may be due solely to the ratio of breading to meat.

Coatings can be dry, liquid or a combination of the two. Carcass parts and meat are often coated with a flour, starch or rice-based coating, containing salt and other flavorings. These products can then be cooked using a variety of techniques, but are mostly fried. Some products may be coated, using a sauce that acts as both a functional and flavoring agent (barbeque, for example). The most common methods of coating are breading and battering prior to frying. The normal process is to use cut-up or deboned meat portions, pre-dusted with a starch and/or a protein-based flour (wheat or rice) or dipped into an egg- or starch-based solution. This is followed by a wet or dry outer coating, just prior to immersion in a frying medium. The pre-dusting or dipping stage is used to provide an adhesive matrix that improves binding between the final coating and the underlying skin or meat surface. The breading and/or battering, sometimes followed by a second breading, involves a variety of wheat- and rice-based proteins, starches, sugars and flavorings to impart the desired final appearance, coating texture, color and flavor. There is an ever-changing and enormous variation in such products. All of these operations, including pre-dusting, dipping, breading and battering are highly automated and extremely consistent in their effects.

Some products are lightly coated with a protein or starch-based material that is salted and flavored. The process is sometimes referred to as a 'dry rub' or a 'dry marination.' The salt and phosphates present extract the surface protein, which helps to seal the surface during cooking and favors the retention of moisture and juiciness. A variety of glazes, variable-viscosity liquid coatings or marinades is also used to impart flavor and moisture to products. Many of these materials can be applied by tumbling, and the product is packaged raw for consumer preparation. Other products, such as the currently popular 'Buffalo wings', are often fried and then coated with a proprietary sauce. A common commercial product is one in which carcass parts, patties or preformed products

are pre-dusted, battered, breaded (or some combination thereof) and 'flash fried' merely to partially cook or 'set,' the coating. The products can then be cooked in other types of oven, such as a forced-air convection or steam oven, without drying the product or compromising the textural quality of the coating. Some products are fully cooked, with a combination of flash frying and a steam-convection oven to finish the cooking process. The products are often frozen and ready to 'heat and eat'.

With widespread consumer use of home microwave ovens, new types of coating have been developed, because traditional batter-breading technology does not create the most acceptable product. The coatings do not heat well in microwave ovens and heating in this way adversely affects their sensory properties, especially with regard to texture and mouth-feel. Different breading formulations and applications have helped to reduce the problem and there are now a number of breaded products available in microwaveable packages. The industry has been under pressure to lower the fat content of products used by institutions or sold directly to consumers. Coating mixes are used both in large-scale further processing and at consumer level to coat poultry products that can then be cooked in conventional ovens to simulate fried foods, but without the added fat.

The development of coated products will continue, since they allow an almost endless variety of products. The use of dry coatings, flavored marinades and glazes will continue to expand the serving options of further-processed products. Currently, there are numerous fresh and frozen entrées that use these technologies to constantly offer new dishes and variations on traditional ones. These products are most obvious in the frozen-food speciality entrées and meals that cater for calorie- and budget-conscious consumers, who wish to purchase foods that require minimal preparation. The frozen products, often sold as individual meal servings, with low total calories (often less than 300 kcal per meal), and which sell for a low unit price offer the modern, fast-paced, two-job family the opportunity to have individual meals that require only a minimal heating time prior to serving.

6.3.4   Emulsified and formed products

One of the oldest meat technologies is sausage making. The primary difference between traditionally-made, coarse-ground sausages and modern emulsified products, such as hot dogs and bologna, is the degree of particle reduction and the proportions of protein, fat and water used in producing a stable product. The ability of meat proteins to bind both water and fat are important properties. These functional properties, water-holding capacity and emulsification or oil-binding capacity, are critical to producing a wide variety of meat-based products. Meat proteins in intact, ground or macerated muscle, or in the extracted and purified form, are able to form complex and stable structures. These can range from the extreme of extracted myofibrillar protein, which can be used to form protein-based gels, to the partially-extracted surface proteins that can be used to bind meat pieces together.

One of the oldest and most common products of this kind is the frankfurter. Poultry meat can be finely ground or macerated and used to make a product with both high fat and water content. Frankfurters may contain up to 30% fat and a water content not exceeding four times the protein content plus 10% (thus, a frankfurter could be 30% fat, 12% protein and 58% water). The testing and listing of possible meat sources according to their 'emulsification capacity' was one of the earlier attempts to quantify the functional properties of meat. The formulation technology of frankfurter and deli-meat manufacture is very well established. Actual formulations will vary depending on the quality of the product, labeling demands (reduced or low fat, low sodium, etc.), and specific product niches, ranging from low-cost, pre-packaged luncheon meats to high-priced, fresh deli meats. Emulsified products (it should be noted that not all scientists or technologists agree that 'emulsified' is the correct term, although it is still widely used) have the distinct disadvantage of being homogenous, with almost no fibrous structure. Since most consumers prefer the fibrous nature of whole-muscle meat, these products, although very popular, are often viewed as having less prestige than whole-muscle products.

Formed products that utilize pieces of meat, trim or flaked material (very fine shavings of meat that retain some fibrous structure), may have meat-like characteristics. In these products, the meat is mixed with salt (and flavoring agents, if desired) formed into specific shapes and cooked. The salt solubilizes the surface proteins and, when pressed together and cooked, the pieces are effectively bound. Depending on the size of the meat pieces, the resulting product, although not completely like natural meat, has a more fibrous structure than an emulsified product.

An interesting market example of this technology is the large, shaped, deli turkey breast. Such products are all shaped in the same way, but may vary widely in their quality rating, according to the raw material used and method of processing. Superficially, these products appear very similar, since all are produced by the same shape-forming machinery. However, the product can be manufactured using emulsification technology to give a texture close to that of a frankfurter or bologna. Alternatively, trim and meat pieces may be bound together to more closely resemble natural meat, or the product can be made from whole breast lobes, in which case, it is clearly a whole-muscle product. Other formed products include meat patties (such as pre-formed hamburger patties) and variously shaped nuggets. The technology uses the materials mentioned above to produce any desired shape and weight (extremely high level of uniformity), with the aid of various dies. Formed products can be fresh or frozen, coated or breaded, and can be partially or fully cooked prior to sale. The products are very common in fast-food outlets (fried chicken patties and nuggets) as well as being sold as fresh, bulk-frozen and individually frozen entrée products. An interesting market application is the specialized formulation, shaping and breading of products specifically aimed at children (shaped nuggets in celestial or biological shapes).

The scientific basis for the above products is fairly well established, but it is the design of proprietary equipment and the associated product formulations that are the most critical issues. Because of the large volumes produced on high-speed lines, the economics of production is a major factor. The relative quality of such products varies widely and depends on specific markets (fast food, institutional food, children's foods, generic, high-volume, wholesale clubs) and quality of the raw materials.

6.3.5   Partial cooking, full cooking and smoking

In developed nations, modern food marketing has moved away from raw, agricultural commodities, used to prepare meals in the home, to the partially or fully-prepared foods requiring a minimum of additional preparation (the processor does everything but eat the product!). Many of the technologies described above are used to make a greatly expanded variety of products that, in some cases, require cooking to set the product, but, in other cases, are marketed as fully cooked, ready-to-eat products.

Many of the aforementioned portioned, marinated, coated and formed products are cooked in a 'smoke house' to produce the traditional items that are often marketed in the fresh or pre-packaged sections of deli outlets. Smoking, once a method of preservation, is almost exclusively done now to develop color and flavor in specific products. Smoking is a common practice for frankfurters, deli products, whole birds, roasted products and dried meats, such as jerky. Commercial smokers often use chemical smoke to add flavor, or burn sawdust or wood chips to supply a controlled amount of smoke in a high-humidity, temperature-controlled smoke house.

Many coated products need to be at least partially cooked or flash-fried to ensure that the coating adheres to the product and an ideal color and texture are obtained. Flash-frying, followed by oven cooking, also ensures longer oil life, less darkening due to over-use of the frying oil or over-cooking, and allows the product to be cooked finally in an oven that avoids excessive moisture loss and thereby improves final product yield. Many institutional and fast-food products are flash-fried, frozen and distributed to the establishment kitchen, where they are fully cooked on site, just prior to serving. Although, at first, such products were also offered directly to consumers, there is now a trend to reduce this market, since many consumers assume that the product is fully cooked and ready to eat (it has a fully-cooked appearance). Because of the potential for mishandling and subsequent liability issues, partially cooked products are becoming less available for direct consumer sales.

Fully-cooked fresh and frozen products are becoming more popular. These products may range from take-out (take-home) foods, which are fully prepared and ready to eat, to those that are fully cooked, whether chilled or frozen, and need only be reheated prior to consumption. The main advantage of these products is the short time necessary for preparation, especially if they are microwaveable. Successful marketing of such products also demands a constantly changing array

of items to avoid consumer fatigue from only a limited number of choices. There are many types of commercial cooking systems. Smoke houses, water cookers (to produce stock and bouillon) and retorts for thermal processing of canned meat all tend to be large-batch systems. However, most modern cooking systems are high-volume, continuous-line processes. These in-line cookers can be rapid flash-fryers, fryers for complete cooking, forced-air convection ovens, steam and combination ovens. They are built for high throughput, uniformity and consistency of heat transfer, flexibility, ease of cleaning (sanitation) and high cooked-product yield. The systems are often placed in-line immediately following marination, batter and breading or char marking (a system that burns lines onto a fillet or patty to give it the appearance of being cooked on a traditional grill), and are immediately followed by cooling, freezing and packaging equipment. Sanitation during this post-cooking process is critical to control contamination with organisms such as *Listeria*, which can be a major liability and/or recall issue, if found in fully-cooked products.

A constant requirement during cooking is the monitoring of internal product temperatures to meet cooking standards and regulations, and maintain high product yields and sensory quality. In general, there is an antagonistic relationship between cooking temperature and time, and yield. For this reason, combination cooking systems, such as flash-frying, followed by forced-air and steam cooking are often used to attain the correct final temperature and to minimize loss of weight during the cooking process.

6.3.6   Chilling and freezing

The predominant method of food preservation is cold-temperature storage. Depending on product form and type, either chilling or freezing is the method of choice. For example, in the United States, fresh broilers, either whole or as parts, are clearly the dominant market form. Frozen broilers are virtually non-existent, except for export markets. In contrast, frozen, whole turkeys or turkey breasts are dominant over the corresponding fresh meat. Very often, the only issue that determines whether a product is to be marketed fresh or frozen is the pattern of traditional consumer acceptance.

The relationship of 'chilled' and 'frozen' to 'fresh' is a complex issue. Fresh is a term often used to denote a non-frozen or non-further-processed product. However, the term 'fresh frozen' is not uncommon (meaning the product was fresh when it was frozen). For many foods, frozen implies a lower quality expectation than 'fresh' (chilled). However, some frozen products are viewed as the quality standard in relation to other marketing forms. It is interesting to note that, while traditional biases towards some products are well established, other products can be marketed successfully in both fresh and frozen form. There is no question that modern commercial freezing, storage and distribution technologies can deliver high-quality products. However, the past practice of slow freezing to 'save' products nearing the end of their shelf-life still has a negative impact on some commodities, such as whole poultry and fish. Retailers would sometimes

freeze slow-moving stock for later sale. These products were frozen and held under poor conditions, in packaging which allowed excessive surface-drying or freezer-burn. Also, they may have been approaching spoilage and were clearly recognized by consumers as sub-standard products.

Most regulatory standards require that poultry and poultry products are cooled rapidly and held at temperatures below 4.4ºC. The criterion to distinguish between fresh and frozen, although not scientifically-based, has, nonetheless, become a marketing and labeling standard. At the time of slaughter, poultry must be chilled rapidly and only minor variations are allowed in handling temperature following chilling. Improvements in plant sanitation, computer-assisted distribution systems, just-in-time marketing (where product is delivered for immediate display or use, as opposed to storage) and improved packaging conditions have made the distribution of fresh poultry a highly efficient and economically sound activity. Most case-ready (pre-packaged) and deli-meat products are also sold fresh.

Freezing is a highly advanced area of food technology. There is a wide variety of freezing systems all the way from slow, static freezing, through blast freezing to specialized, rapid-freezing tunnels or spiral systems that use liquid carbon dioxide or liquid nitrogen. The quality of frozen meat is dependent on both the rate of freezing and the temperature and consistency of frozen storage. Since the quality of frozen foods has been so variable over the past 50 years, many products carry a stigma of poor quality, even though modern freezing technology can produce first-class products. In any event, freezing is expensive, requires more costly packaging and demands sophisticated temperature control throughout storage, distribution and marketing. Therefore, most of the more sophisticated freezing systems are reserved for the more expensive value-added products. Small carcass parts, such as wings, deboned breast fillets and further-processed and coated products, such as patties and nuggets, are often IQF, using liquid carbon dioxide, liquid nitrogen, or in combination with high-velocity air (fluidized bed). The products can then be bagged, or packaged and held frozen in such a manner that the individual parts are easily recognizable. This is critical for institutional use, where the product goes directly from the frozen state into a cooker, or for home use, so that the consumer can remove only one item from a pack at a time. Some products, such as marinated and flattened breast fillets, must be cooked directly from the frozen state to prevent excessive moisture loss (thaw drip). These 'high-tech' products are very suitable for the sophisticated handling and control systems that are available in many fast-food and restaurant chains, but would not be appropriate for direct consumer sales, due to the potential for mishandling and consequent poor quality, if the product were allowed to thaw prior to cooking.

6.3.7   Packaging

One of the most important factors contributing to the increased consumption of poultry is the advances that have been made in packaging. Poultry was the first

large-scale meat commodity to be pre-packaged and case-ready upon arrival at a retail outlet. This allowed personnel to simply stock the meat display cases, instead of having meat cutters and wrappers handle the poultry beforehand. The packages were clean, attractive and presented the product in a highly favorable manner. Consumers were offered an array of products that were attractively packaged, had a good shelf-life and were clean to handle – as opposed to the traditional bagged bird, which was damp and often dripping when opened up.

Packaging developments very much paralleled the other further-processing technologies. Use of marination, product appearance, shelf-life, moisture retention and protection against freezer burn are all important factors that contribute to the success of modern products. The use of specialized films, with specific gas (oxygen, carbon dioxide and nitrogen) and water permeabilities, are critical to product appearance, surface drying, shelf-life and quality. Modified-atmosphere packaging systems were developed using selective, gas-permeable materials and the pack would be flushed with specific gases or gas mixtures. For chilled products, various combinations of gases could greatly extend the microbiological shelf-life and stabilize product appearance. For example, a pack with higher than normal concentrations of both oxygen and carbon dioxide could be used to suppress the growth of both aerobic and facultatively anaerobic bacteria, thus extending the shelf-life of the product.

Specialized packs have been developed that are not only attractive and present the product well at the point of sale, but also function in both preparation (cooking) and serving. Traditional TV dinners are packaged in an aluminum tray suitable for oven-cooking and serving. The newer packaging materials can be used in either conventional or microwave ovens, and the entrée can be served in its original container. Ready-to-eat chilled snacks and complete lunch packages are available. These products are sold 'ready-to-go' and are most often marketed for school lunches. The products generally have a meat-based entrée, a carbohydrate (bread or crackers), cheese, a drink and a dessert.

6.4   Categories of poultry products

As mentioned earlier, further processing can encompass the entire spectrum of poultry-meat products, from whole carcasses to formulated and fully-cooked items. As with the often-confusing terminology of further processing, there are numerous ways to categorize further-processed products. For example, there are fresh and frozen, dried, canned, whole-muscle items versus formed products, processed raw products and fully-cooked products, with a variety of packaging options and expanding market niches. Where poultry meat was almost exclusively a fresh or frozen meat-case commodity, with limited institutional and restaurant options, it is now available in deli cases, as canned and ready-to-prepare foods and frozen entrées, and is a major option on many restaurant menus and in fast-food outlets.

6.4.1   Traditional product forms

Traditional product forms are raw, whole birds, cut-up parts, deboned meat and commodity-based products. The product forms are normally marketed directly to consumers or customers, either as fresh chilled or frozen products. The marketing of traditional, fresh and frozen raw products is highly dependent on geographical and historical factors. Although frozen food is not a recent phenomenon, there are strong market biases towards either fresh or frozen poultry. In general, where fresh products are readily available, they dominate the market, since fresh is perceived as being higher quality and is actually less expensive than the corresponding frozen product. However, where poultry consumption is more seasonal (such as for turkey, goose and duck) and distribution systems are not highly sophisticated, or where fresh poultry is not readily available, frozen products are the norm. It is interesting that, although freezing is more expensive and greater demands are made on packaging, frozen poultry is often the dominant market form in the less developed nations, due to distribution and supply limitations.

6.4.2   Whole-bird product forms

The marketing of whole birds and their packaging and further processing are highly variable. Whole birds are sold in bulk for wholesale purposes, or can be individually pre-packaged, pre-labeled and weighed for retail consumer sales. Bulk sales are primarily for institutional markets, or for transfer to second or third processing, in which the birds may be injected, cooked and sold as ready-to-eat whole birds in either fresh or frozen form. The pre-packaging systems may use a plant (packer) label or a custom label (such as a particular grocery-store chain). Whole birds are now marketed with 'pop-up timers' that indicate when the product is fully cooked, thus avoiding either under- or over-cooking by the consumer. Whole, ready-to-eat rotisserie and smoked broilers, turkeys and speciality birds have been available for many years. Traditionally, these products have been sold frozen, but, in recent years, whole, fully-cooked broilers have been available as chilled products for retail, take-out and restaurant outlets.

6.4.3   Parts

A major market form is poultry parts. These can be as simple as halves, quarters or fully portioned carcasses. Parts can be sold mixed, by front or rear half (light meat versus dark meat) or as one specific part. They can be marketed in consumer packs or sold to further processors in bulk. Part definitions are regulated by label requirements for direct consumer sales or by contractual specification for further processing or restaurant-trade use. Certain parts, such as wings, drumsticks and breast fillets are often purchased in strictly defined weight categories for portion control. As bird sizes become more divergent, depending on market destination, more conflict arises in trying to develop a saleable product mix. For example, bigger birds are more suited to optimizing

breast meat yield, but also produce wings that are too large for the normal 'Buffalo' or hot-wing market. Consumers now find that they have less choice of carcass weight, for both whole chickens and turkeys, than in the past. In the USA, the dominant retail parts are breasts and wings. In other areas of the world, legs and dark meat have greater market appeal. Parts such as drumsticks, thighs, wings and breast portions are often further processed and marketed raw or as partially- or fully-cooked items. The products may be marinated, coated or sold as part of a specific meal entrée.

6.4.4 Boneless and skinless meat

The increase in poultry consumption in North America during the last 20 years has been largely due to the increased demand for products based on boneless, skinless breast fillets. The fillets have been marketed directly as fresh and IQF consumer products, as marinated fresh products (e.g. lemon pepper, barbeque, Italian, Mesquite, Teriyaki products), as the basis for a multitude of fast-food and restaurant dishes, and as a low-calorie, low-cost ingredient in frozen entrées. The fillets are perceived by both processors and consumers alike as having great value, being high in protein, low in fat and a highly versatile product. Whole-muscle strips and nuggets from the breast fillet and whole tenders are in great demand. Breast meat, having less than 2% fat, is the basis for many poultry-based, frozen dishes and entrées. Because of the need to market individual frozen entrées economically and with low-fat and low-calorie label claims, there has been a considerable advantage in using poultry meat for these types of consumer product. A similar trend is seen in both fast-food establishments and restaurants, which now carry many more poultry-based menu items than even ten years ago, both to cater for consumer demand for low-fat meat entrées and changing perceptions and acceptance of poultry meat as a 'center-of-the-plate' entrée. The tremendous demand for white meat and wings has put dark meat into a dramatic over-supply situation in North America. If one considers the ratio of white to dark meat and the total number of broilers produced, the dark meat alone would rank as the fourth largest meat commodity produced in the United States. Economically, depending on market form, rear half (saddle) or boneless, skinless dark meat has from a fifth to a third of the price potential of the front half of the carcass or boneless, skinless white meat. Although there are some successful dark-meat products, such as boneless, skinless leg meat and chunks and strips for fajita mixes, generally, the over-supply of dark meat is excessive. The turkey industry has been far more successful in utilizing dark meat for further-processed deli products, such as turkey ham, and for the production of ground turkey leg meat, a very successful product in its own right.

6.4.5 Formulated products

Product formulations can be as simple as the application of the most basic seasonings to an otherwise fresh breast fillet or as complex as emulsified deli

products. Although it is difficult to define the difference between a seasoned fillet and a formulated product, the concept may be more about how the final product is presented in the market place. For example, a consumer could buy fresh breast fillets and marinade or rub them to produce an Italian-style or Mesquite-flavored fillet at home. However, if the same operation was performed in a further-processing plant, with the product individually packaged and sold 'ready-to-cook', it would be viewed as a further-processed product.

Many of the products being supplied to fast-food chains and restaurants are being formulated to meet contractual specifications. These aim to provide product consistency and facilitate process control during preparation, while reducing the need for supplies and labor for on-site preparation. The processes used include marination to improve product juiciness and tenderness, battering, breading and pre-frying to improve product appearance, and the addition of grill marks. Many of these products are still distributed fresh, but, increasingly, are being sold to the food-service industry as frozen, pre-prepared products. In this form, they allow distribution flexibility, facilitate inventory control and reduce waste.

The success of many of these products in the fast-food market, most notably nuggets, fingers, patties, Buffalo wings and grilled products, has led to consumer acceptance and a willingness to purchase similar products for home consumption. This is a reversal of the trend for restaurants and fast-food companies to market foods that are already familiar and change to one in which they actually establish a new food that is not associated with traditional 'home' cooking. Although the products are similar in appearance, those produced for fast-food companies, school lunch programs, fresh retail marketing or frozen, ready-to-cook or heat-and-eat products, may all be formulated quite differently.

6.4.6   Entrées and ready-to-eat foods

Clearly the area of greatest penetration of poultry into new product niches has been the extensive development of frozen entrées based on poultry-meat. These range from the venerable chicken potpies to more modern and upscale products, such as chicken fettuccini, chicken fajitas and even chicken pizza. These entrées are extremely popular with sectors of society that want fast, flexible, high-quality meals that can be purchased, stored in the home freezer and then heated for consumption in a very short time. Such products also allow for individual servings, such that each person in a family can have a separate entrée. Poultry has been successful in this new niche, primarily because it is relatively inexpensive, low in fat and highly flexible for use in a wide variety of processed product forms and dishes. Companies can prepare speciality dishes that are economical, contain less than 300 to 400 kcal per serving, are low in fat and yet still have a sizeable portion of meat. However, the products are constantly changing to meet greater consumer demand for variety.

Another product form that has been gaining market share as a new concept is the ready-to-prepare type of dish ('kit' foods). These have been available in both Europe and North America in varying forms. Basically, they are pre-packaged

assortments of items that can be used to make specific dishes. The package may include some diced meat, beans and vegetables to make a soup. Alternatively, there are strips of seasoned meat and oriental-style vegetables, with a seasoning pack and directions for use. The dish can be cooked on a griddle or in a wok for a 'freshly' prepared stir-fry. Frozen packs are available that contain tortillas, seasoning and 'fajita' spiced meat for making 'home cooked' fajitas. Stuffed pasta is available, with the sauce contained in a separate pack for combining with the pasta immediately prior to serving. As more and more of these complete, ready-to-prepare foods become available, there is a trend for consumers to keep less and less of the basic ingredients in their home kitchens. Although the mark-up on prepared foods, such as pizza, is high, because all the ingredients are supplied, it is often cheaper for a consumer to purchase such a food, either in a complete, ready-to-prepare form, as a frozen heat-and-eat product or as a complete ready-to-eat, take-home food.

6.5   The development of new poultry products

Product development can be divided into three major areas: new product development, market expansion and economic formulation. Of the three areas, new product development is the most difficult. Market expansion is generally an attempt to move an existing product into a new market niche or to create a 'copy-cat' product to compete for market share with another company (increase product diversity). Economic formulation is probably the most widely used type of product development, with the sole purpose of producing items to meet existing specifications at a lower cost.

Since most product development, or research and development, is devoted to manipulation of existing products to provide least-cost formulations, it cannot be separated from further processing. Much of what we accept as product development is often little more than exploitation of new food-processing technologies or marketing opportunities. An excellent example is the chicken nugget. This is obviously a new product that has been widely successful. Through combined efforts in product development, further processing technologies and marketing opportunities, the nugget has become ubiquitous. It is a readily identifiable product, available in fast-food chains, restaurants, institutions (school lunches) and in the grocery store as fresh, partially cooked and frozen products. Nuggets come in a variety of shapes and sizes, including shaped forms aimed at the youth market. Based on the source of meat, white versus a mixture of white and dark meat, ranging from whole-muscle pieces to emulsified and formed products, the varying formulations (differing proportions of protein, fat, water, skin and seasoning) and market channels mean that there are probably many thousands of variations of this simple product. Another example is the Buffalo wing, first developed as a finger food for bars, but which is now available as a standard restaurant item or obtainable as a frozen, ready-to-heat-and-eat product.

6.6   Future trends

There are several emerging issues that may have an impact on further processing and the direction of new product development. The topics include animal welfare, net product weight, use of hormones and antibiotics, organic or natural foods, genetically modified (GM) feedstuffs and food irradiation. Animal welfare organizations are putting more and more pressure on large poultry customers, such as fast-food and grocery-store chains, to require particular standards of animal welfare from their suppliers. Since such a large proportion of poultry production is purchased from these outlets as further-processed products, the welfare issue simply cannot be ignored by the poultry industry. As procedures for animal handling and slaughter are adapted to meet more rigid animal welfare standards, one can expect an impact on raw material quality and the economic competitiveness of the industry.

Net weight is an issue related both to method of chilling carcasses during primary processing and the addition of marinades to some products. Many countries have strict regulations regarding added water and 'adulteration' of the product. Differences in chilling methods between the United States, which primarily uses immersion chilling, and the European Union, which mainly uses air or evaporative chilling, may affect the movement of further-processed products between these two markets. Processors are required to label products with respect to the addition of water, especially in the form of marinades.

Although no major poultry producer uses growth hormones (regardless of often-repeated statements to the contrary), there are potential market restrictions based on the perception that hormones are used. The use of antibiotics at sub-therapeutic levels is also a major issue. Some of these growth-promoting antibiotics are not absorbed by the animal, but are excreted into the environment. The use of therapeutic antibiotics must include a withdrawal time to allow clearance of the antibiotic from the tissues. There are major debates in the scientific and medical communities about the relative benefits of antibiotics in food production and the economics of production versus the impact of antibiotic-resistant pathogens in human health.

Organic, natural and Label Rouge-type products have a slowly growing, but solid niche in the food market. Government regulations are becoming more stringent about the way in which these terms may be used in the market. Many companies are moving in the direction of product diversification to offer specific foods for niche markets. In relation to economic factors, it is hard to predict how well these markets will continue to grow and how responsive the food industry will be to the increasingly strict definitions being applied. Also, a public and scientific debate is occurring in Europe and the USA over GM foods. Although the scientific data is far from conclusive, there remains some controversy concerning the safety of GM food products and products from animals given GM feeds.

Irradiation is a food preservation process that has been tested extensively for over 50 years. It is approved for limited use in many countries. However, the

public image of irradiated foods is still uncertain. The use of irradiation is slowly increasing, primarily for speciality products and for limited markets. Currently, irradiation is not seen as an economically viable process, although, with the potential for increased illness from foodborne pathogens, this situation could change dramatically.

None of these emerging issues appears to have a direct effect on further processing, but there are definite collateral issues that could arise. These may affect market segmentation, proliferation of products, labeling demands, market barriers and new processing and packaging technologies, especially for the marketing of irradiated foods.

6.7   Conclusions

Further processing is, in effect, an interaction between technologies, product forms and marketing presentations. Although some of the factors that impact on further processing are often addressed as separate issues, such as microbiology, packaging and marketing, they are critical to the overall understanding of further processing as a highly interactive concept. Much of this concept is summarized in Table 6.2. One could select almost any combination of processes, product forms and presentations to produce a further-processed product. In such a situation, there are multiple options from a given column to create a multitude of new products. Even within this structure, minor variations in formulation or presentation can make the number of possible products almost infinite.

It is not uncommon for a further-processing plant to produce several hundred product labels. Many of these products may be nothing more than slight variations on particular product types, such as custom-cut fillets, marinated meat, nuggets and entrée portions, to meet specific customer demands. The differences may be minimal, but each product will require a unique label. Thus, the number of generic products, such as 'breast fillets', is much lower than the actual number of items identified by labeling requirements, according to

Table 6.2   Processes, product forms and presentations that can be combined in further-processed poultry products

Processes	Product forms	Presentations
cut-up	whole bird	fresh
deboning	cut-up parts	frozen
marination (tumbling or injection)	boneless, skinless meat	raw
coating	marinated parts or meat	partially cooked
frying (partial or full)	coated parts or meat	fully cooked
smoking	formed products	pre-packaged
grill-marking	emulsified products	take-home, ready-to-eat
formulations	entrées	heat-and-eat
		fast food

formulation, marination, packaging, fresh, frozen, raw, partially-cooked, fully-cooked, or as a meat portion in a complete entrée. It is often said that the one constant over time is change. Further processing is a highly dynamic and rapidly changing industry. As societal standards, habits and expectations change, so will our foods. It is remarkable to see the switch from a basic array of raw agricultural commodities to so many ready-to-eat foods that has occurred in recent years. During the last 30 years, there have been dramatic changes in eating patterns (for example, no or minimal breakfast and a dramatic increase in foods consumed outside the home in restaurants or fast-food outlets), and the domination of convenience foods for in-home preparation. Seldom do we see individuals that are exposed to such labor-saving luxury wish to return to more labor-intensive activity. Based on this observation, it is reasonable to assume that the changes in eating patterns and consumption of convenience foods will only increase. While this increase in further-processed foods continues, there will also be a greater demand for more meal options and choices. Further processing will be expanded by constant product development to provide an ever-changing and constantly evolving array of exciting and exotic foods for consumers wanting variety, quality, value and an easy lifestyle.

6.8 Sources of further information and advice

ANONYMOUS (2003), *International Poultry Exposition Guide*, Cullman, Alabama, USA, Watt Publishing Co Inc.

ANONYMOUS (2003), *Who's Who in the Egg & Poultry Industries in the USA & Canada*, Cullman, Alabama, USA, Watt Publishing Co Inc.

BARBUT S (2002), *Poultry Products Processing*, Boca Raton, Florida, USA, CRC Press.

MEAD G C ed. (1989), *Processing of Poultry*, London, Chapman & Hall.

MOUNTNEY G J (1966), *Poultry Products Technology*, Westport, Connecticut, USA, AVI Publishing Co Inc.

MOUNTNEY G J (1976), *Poultry Products Technology* (2nd edn), Westport, Connecticut, USA, AVI Publishing Co Inc.

MOUNTNEY G J and PARKHURST C R (1995), *Poultry Products Technology* (3rd edn), New York, USA, Food Products Press, Haworth Press Inc.

SAMS A R ed. (2001), *Poultry-meat Processing*, Boca Raton, Florida, USA, CRC Press.

STADELMAN W J, OLSON V M, SHEMWELL G A and PACH S (1988), *Egg and Poultry-Meat Processing*, Chichester, UK, Ellis Horwood Ltd.

7

Poultry packaging

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7.1   Introduction

The need for fresh food to be supplied to distant markets has increased interest in methods of extending product shelf-life. Shelf-life requirements should include not only the time needed to reach the market, but an additional period of refrigerated display and consumer holding time (Jimenez *et al.*, 1991). Microorganisms exist in the environments in which meat is produced, processed, packaged and stored. Merely covering food prevents microorganisms from gaining access and thus acts as a physical barrier to cross-contamination. With packaging systems aimed at extending shelf-life, one goal is to prevent pathogens from growing to dangerous levels before product spoilage becomes obvious to the consumer. This goal can be attained if in-pack conditions inhibit pathogen growth to a degree that is greater than the inhibition of spoilage organisms (Gill and Reichel, 1989). Poultry-meat spoilage depends on a combination of microbial growth and complex biochemical activities (see Chapter 13). Huis in't Veld (1996) concluded that changes in the extrinsic conditions of the product (for example, refrigeration, modified atmosphere packaging (MAP)), are the only way to delay spoilage. Therefore, product shelf-life depends on many factors, of which packaging is one.

A walk past the meat section of a food store will reveal the various types of packaging used for poultry meat. Packaging type is largely determined by the form and desired shelf-life of the product. In the USA, poultry-meat packaging varies from a 'wet shipper', through whole-carcass freezer bags to modified atmosphere, sealed trays. Since there are a limited number of poultry cuts and a relatively small number of processors with sizeable operations, poultry is typically packaged in small, consumer portions (known as 'case ready') at a

central processing location. Retailers absorb a cost for this service, but can eliminate labor, equipment, packaging inventories, contamination problems and the inefficiencies of a small packaging operation. The choice of appropriate packaging, accompanied by chill storage, will extend the shelf-life of poultry meat. The three meat factors limiting shelf-life under these conditions are microbial growth, changes in appearance (mostly due to pigments) and oxidative flavor changes. The extension of shelf-life allows the processor to expand the product line and to extend the distance over which products can be distributed.

7.2   Functions of packaging

The United States Department of Agriculture (USDA, 2000) defines packaging as: the enclosure of products in a wrap, pouch, bag, box, cup, tray, can, tube, bottle or other form of container to perform one or more of the following functions:

1.   Containment for handling, transportation and use.
2.   Preservation and protection of the contents for required shelf- and use-life.
3.   Identification of contents, quantity, quality and manufacture.
4.   Facilitation of dispensing and use.

The functions of a food package can be considered further under four headings: containment, information, convenience and protection. Containment includes holding multiple portions of chicken parts, such as legs, thighs, wings or breasts, allowing them to be sold in various amounts or combinations. Information includes nutritional labeling, proper handling practices, product information and identifiers of source, etc., required by law. The package also contains the product price, claims made for the product, cooking suggestions and pack recycling instructions. Convenience allows single-serving amounts of sliced meat and microwaveable packs for cooking/reheating and serving of the product in the pack. Protection includes that from rodents, dust, microorganisms, chemical contaminants, environmental humidity, light and oxygen. The pack should also protect the product from tampering, physical damage and moisture loss during handling.

The nature of the packaging material provides barrier properties and strength or sealing capability for the overall package. For example, aluminum foil is often added as a layer because of its barrier properties in excluding light and preventing gas exchange. Polyester (polyethylene terephthalate, PET) is often added for strength. Polyethylene (PE) is an excellent sealing agent and is used either as the sole agent or in combination with other materials. The main materials used for specific purposes are:

- *Barriers*: ethylene vinyl alcohol (EVOH), vinylidene chloride copolymer (Saran), and the more rarely used aluminum foil, polyvinyl chloride (PVC) and acrilonitrile (Barex).

- *Strength properties*: polyethylene terephthalate, (PETE), nylons, which are films, and polypropylene (PP) and expanded polystyrene (EPS or Styrofoam) that are used for thermoformed trays.
- *Sealing agents*: polyethylenes (PE, LDPE, LLDPE, HDPE); ionomers are less often used.

Oxygen and moisture permeability are two properties that are very important in meat packaging. Water-vapor transmission rate (WVTR) or, more accurately, water-vapor permeability (WVP) and oxygen transmission rate (OTR) will affect the quality of poultry meat. WVTR is based on the measurement of water vapor passing through a specific surface area of film, while WVP takes account of film thickness and the relative humidity (RH) gradient on either side of the film. Both WVP and OTR are expressed as gas or vapor exchange rates, with both RH and temperature conditions stipulated for a one mil (0.0254 mm or 0.001 inch) thick film at a pressure of one atmosphere. Various ways have been used to report the WVP and OTR of films:

WVP
ml/m^2 in 24 h at 38ºC and 90% RH
ml/m^2 in 24 h at 25ºC and 75% RH
$g/100 in^2$ in 24 h at 100ºF and 90% RH

OTR
ml/m^2 in 24 h at 20ºC and 0% RH
ml/m^2 in 24 h at 25ºC and 50% RH
$ml/100 in^2$ in 24 h at 77ºF and 0% RH

Polymer films used for meat packaging can be categorized according to OTR, measured in ml/m^2 in 24 h, as: 0–10, low; ~60, medium; and $\geq$ 1000, high. The OTR will change for some materials, for example, nylon and EVOH, with changes in temperature and humidity.

Thermal properties of polymers are important to poultry-meat packaging in relation to sealing of the pack and shrinkage of the film around the product. Most bags and trays used in meat packaging are sealed by fusing two layers of polymer together by the application of heat. Also, packaging often requires a skin-tight finish that is accomplished by heat-shrinking.

The properties of packaging materials can be modified in a variety of ways, both during the formation of the individual polymers (use of additives, change in orientation, etc.) and by combining multiple layers of polymers to produce the desired properties. Two methods used to produce multi-layered polymers are lamination and coextrusion. The method chosen depends on the materials to be combined. Lamination involves glueing two polymers together, while coextrusion combines the layers by melting or molding them.

Packaging can also be categorized into primary, secondary and tertiary levels. The primary package is the one with which most consumers are familiar and is the food-contact surface that will carry labeling and any additional consumer

information. A common primary package for poultry meat is a polymer (plastic) film wrap or overwrap; however, the primary package can also be a metal can. In other instances, the package can contain a mixture of materials, such as paper, foil and cellophane, that alters its properties or allows for special graphics. The primary package may be flexible, semi-rigid or rigid. Flexible packaging materials include plastic polymers, paper or a thin laminate; semi-rigid materials include thermo-formed polymers, aluminum foil or paperboard, while rigid materials are thick polymers, metal or glass. The secondary package is an outer box, case or wrapper that contains several primary packages. While this has no contact with the food surface, it serves to protect the primary packages from breakage, damage and soiling during distribution. The secondary package is often a cardboard box containing many tray-packs of chicken parts that are pre-labeled and individually priced. More sophisticated systems may have the secondary package unit flushed with an inert gas, while the fresh meat in the primary package is surrounded by a highly gas-permeable film, which allows the gas to penetrate during storage (see below). The tertiary package holds several secondary packages in shipping loads such as pallet-sized units. Stretch-wrap film is often utilized to stabilize the pallet during loading, shipping and unloading.

7.3   Packaging materials

Although there are relatively few different food-packaging materials, there are many variations within some types of material and many combinations of materials. The types and forms of materials used for poultry-meat products include fiber-based (paper, paperboard), glass and metal. In addition, many poultry packages have plastic materials (Table 7.1) as coatings, linings, overwraps or bags.

7.3.1   Paper, paperboard and fiberboard

These differ in relative thickness, with paper being the thinnest, paperboard thicker, paper sheet more rigid, and fiberboard, made by combining layers of paper, the thickest. The material used in secondary shipping cartons for poultry meat is most often corrugated paperboard, so-named because of the wavy inner layer of paperboard that adds strength. The paperboard boxes are sometimes produced from wood pulp and reprocessed paper, which is bleached and coated or impregnated with waxes, resins, lacquers or plastics. The added layer improves the resistance of the box to high humidity and increases wet strength and grease resistance, while improving appearance and barrier properties. Acid treatment of paper pulp can result in glassine paper with high oil- and water-resistance. The acid modifies the cellulose, giving rise to long wood-pulp fibers that also add strength to the paper.

Table 7.1 Plastic materials used for packaging meat products

Polymer type	Use	Features
EVA-LDPE copolymer	Seal layer, films, wraps	Heat shrinkable
Ionomer	Heat-seal layer	Resists seal contamination
LDPE	Bags, wraps	Low cost, low gas barrier
LLDPE	Heat-seal layer	Good clarity
Nylon (PVdC coated)	Films, thermoformed trays	
Nylon (uncoated)	Films, thermoformed trays	Also used as bone guards
PET (PVdC coated)	Films	
PET (uncoated)	Films, trays	Good clarity
PP (non-oriented)	Semi-rigid containers	
PVC	Fresh-meat wrap	Gas transmission rate depends on plasticization
PVdC	Barrier layer	Barrier less affected by moisture

EVA: ethylene vinyl acetate
LDPE: low-density polyethylene
LLDPE: linear low-density polyethylene
PVdC: polyvinyldiene chloride

For other abbreviations, see text.

7.3.2 Metals

Those used for canned poultry meat include steel and aluminum. Steel has greater strength and resistance to denting, while aluminum is light in weight and resistant to atmospheric corrosion. Steel cans were once coated with tin to prevent corrosion. To reduce cost, however, this layer was later replaced with a steel alloy, such as a chromium alloy. Cans are also coated with an additional organic layer to protect them from corrosion by food constituents, and the food from contamination by the metal, as well as metal-catalyzed degradative reactions. Phenolic compounds are used in this organic layer for meat spreads, while modified epons are used for other meat-containing products. Aluminum foil is used in flexible pouches and is often combined with plastics and paper in layers that offer a complete barrier to light, oxygen and water vapor.

7.3.3 Cellophane

The material is regenerated cellulose film that is manufactured from sheets of wood pulp. The fibrous wood pulp is made into a non-fibrous form and, with the addition of plasticizers, achieves the necessary degree of flexibility. Cellophane is a good gas and grease barrier, but will break down in the presence of moisture, so is often coated with a hydrophobic layer.

7.3.4   Plastic polymers

These are by far the most common packaging materials used for poultry-meat products, due to their versatility, convenience and low cost. They include the materials shown in Table 7.1 and others, such as PS and polycarbonates (PC).

Polyethylene (PE)

The structure of PE is a series of repeating CH_2 units with short side-chains of ethylene that prevent close stacking of the main chain. There are three major types of PE: high-density polyethylene (HDPE), LDPE, and LLDPE, that differ in structure, properties and manufacturing processes. LDPE and LLDPE have different molecular structures, but have similar densities (0.910–0.925 g/cm^3). LDPE and HDPE differ in the length of their side-chains and thus in the overall density of the film. HDPE is denser and less clear, but stronger and stiffer than LDPE. LLDPE is produced under higher pressures, resulting in films with a density similar to LDPE, but with the strength and toughness of HDPE. The latter also forms a good seal at relatively low temperatures and has better grease- and heat-resistance than LDPE. On the other hand, LLDPE is stiffer and has a higher range of heat sealability than LDPE. It can be used as a laminate layer, as well as for bags and stretch-wraps.

Polypropylene (PP)

$$\underset{|}{\overset{CH_3}{}}\quad\underset{|}{\overset{CH_3}{}}\quad\underset{|}{\overset{CH_3}{}}$$

—CH—CH$_2$—CH—CH$_2$—CH—CH$_2$—
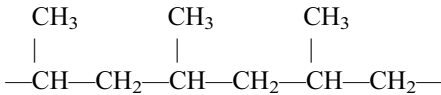
The structure of PP is a carbon chain with alternating methyl side groups instead of hydrogen, as with PE. This material is harder and more resilient than HDPE, with a permeability to water vapor and gases between those of LDPE and HDPE. The structure of PP can be varied in several ways, including changes in orientation, and can be coextruded to create heat-sealable films. The main application of PP in meat packaging is for cook-in-the-bag products, because of its high heat-tolerance and impermeability to moisture during water-bath or steam cooking.

Ionomers (Surlyn)

$$CH_3$$
$$|$$
—(—CH$_2$—CH$_2$)$_x$CH$_2$—C
$$|$$
C—O—(Na or Zn)
$$\|$$
O
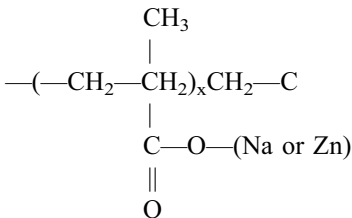
Ionomers are polymers that have been co-polymerized with acid, with part of the acid remaining in the film structure as an ammonium or metal salt. The metal is

usually zinc or sodium. Incorporation of the relevant ions increases the lipophilic nature of ionomers, creating films that are flexible, tough, transparent and excellent heat-sealing agents. Ionomers are used as the food-contact and heat-sealing layer in laminated materials. They have a wide heat-sealing range, possess good grease-resistance and will adhere well to most other packaging materials, including aluminum foil.

Polyvinyl chloride (PVC)

$$—(—CH_2—ClCH—CH_2—)_n—$$

PVC is similar in structure to PE, but has a chloride atom instead of hydrogen at alternating ethylene molecules. PVC is difficult to process by heat, since it begins to break down at about 80ºC, although it is ideal for stretch-and-shrink retail packages, where high O_2- and water-vapor permeability (compared to PVdC) are desired. It is often used as in-store packaging for deli meats, fresh meats and cured meat products.

Polyvinyldiene chloride (PVdC)

$$—(—CH_2—CCl_2—)_n—$$
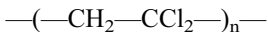
When compared to PVC, PVdC (Saran) has an additional chloride atom in the ethylene molecule and is clear and strong, with low permeability to gas and moisture. PVdC is used as one of the layers in multi-layer pouches, bags and thermo-formed packages, where it functions as an O_2- and water-vapor barrier. PVdC can be heat-sealed, is printable and can withstand cooking or retorting. It is used to package frankfurters, luncheon meats, hams and for any purpose where MAP is preferred.

Ethylene vinyl alcohol (EVOH)

$$(\ldots CH_2—CH_2—CH_2—CH—CH_2—CH_2—CH_2—CH—)_n—$$
$$\qquad\qquad\qquad\quad | \qquad\qquad\qquad\qquad |$$
$$\qquad\qquad\qquad\quad OH \qquad\qquad\qquad\quad OH$$
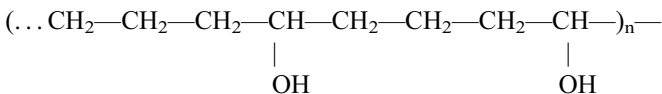
EVOH is an excellent O_2 barrier; however, it is hydrophilic due to hydroxyl (OH) groups being attached to the polymer backbone, and its O_2 permeability will fluctuate with high humidity. EVOH is often placed between layers of PP, PE and/or PET to improve moisture-resistance.

Polystyrene (PS)

$$——(—CH—CH_2—CH—)_n—$$
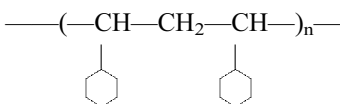
PS has a phenyl (styrene) group substituted for a hydrogen atom in the PE structure. This is a clear, hard, brittle and low-strength material used in

disposable containers and for some packaging films. It can be foamed into expanded polystyrene (EPS) (Styrofoam) to form trays. Both the clear and foamed thermoformed trays have high O_2 permeability. High-impact polystyrene (HIPS) has good tensile strength and stiffness. Styrene is one of the few materials with the thermal melt-strength necessary to form trays.

Polyamides (nylons)

$$H(-N-(CH_2)_{n1}-N-C-(CH_2)_{n2}-C)_n \ OH$$
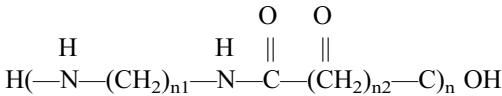
Polyamides are polymers formed by condensation of certain amino acids and, therefore, are the only food 'plastics' containing nitrogen. Nylons are given paired numbers, the first indicating the number of carbon atoms in the amine portion (n1) and the second showing the number of carbon atoms in the carboxylic acid part (n2), nylon 6.6, for example. They have relatively high melting points and low gas permeability, but will absorb moisture, losing strength in the process. Nylons are used for cook-in-the-film applications, sometimes in combination with an ionomer.

Polyesters

$$-(-CH_2-CH_2-O-C-\bigcirc-C-O-)_n-$$
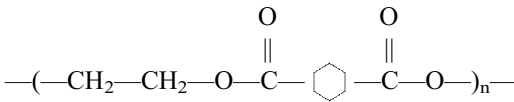
The commonest polyester used in packaging is PET, which is often found in containers for carbonated beverages. PET has excellent strength, clarity and heat stability, and very low permeability to O_2 and moisture. Therefore, it is ideal for vacuum packaging, thermal pouches and cook-in applications for meats.

Polycarbonates (PC)

$$Cl-C-Cl-O-O-C-O-O-C-OH$$
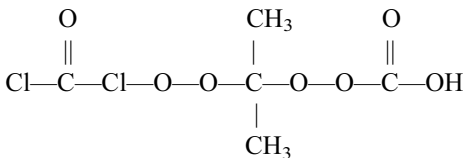
PC contain polyesters of carbonic acid and are stiff, transparent, tough and hard. They have high gas permeability and absorb moisture, which causes loss of mechanical properties. Despite their relatively high cost, an inertness to food has encouraged the use of PC in plates for oven-heated dinners.

7.4   Packaging methods

7.4.1   Whole-bird packaging

The wet shipper was one of the earliest methods used in the USA for distributing fresh poultry. It comprises whole carcasses or cut-up parts mixed with chipped ice and held in a wax-coated, corrugated box. The box is coated with a food-grade wax, such as carnuba wax, and has a fitted lid of the same material. Hand and drain holes are often included for ease of handling. Mechanically deboned meat is also shipped in similar boxes that are less tall and are lined with a polymer film.

The polymer bag was the next generation of packaging for whole carcasses. In this case, the carcass is vacuum-packed in a tough, clear or colored bag that is sealed or clipped. The clipped polymer bag was an improvement in handling over the wet-shipper; however, leaking of purge juices was a problem. The leakage problem has been greatly reduced by the introduction of the heat-sealed, shrink bag. This package has a heat-sealed closure that is then heat-shrunk to fit cleanly around the whole carcass. The process is automated, using a heat-seal, vacuum-chamber machine with domes that drop down over the bagged product then pull a vacuum and seal the bag. The bag is automatically heat-shrunk by passing it rapidly through hot water. The relatively leak-proof, heat-shrunk bag has become the package of choice for whole carcasses in the USA. In contrast, many carcasses in Europe are packaged in trays with an overwrap film. This type of package is nearly identical to that used for cut-up parts and is described in the next section, the only difference being the shape and size of the meat placed in the tray.

7.4.2   Cut-up poultry

Case-ready packaging has become more popular and will continue to grow as supermarkets steadily shift the packaging operation to the processor. This policy has allowed packing companies to provide the expertise to ensure that product presentation is optimized and the pack retains its integrity from processing plant to supermarket. In order to accomplish these goals, all components of the package, as well as the product itself, must be of high standard. Failure of a single component can create an unacceptable package that might even lead to a loss of weight and eventually affect the packaging supplier's reputation.

Several options are available for packaging cut-up poultry, including overwrap trays, ice-packs, bulk-boxes, polymer-lined boxes, and polymer bags. The most common package for chicken parts (90% of all chicken breast, thigh, drumstick and wing portions are packaged as consumer portions) uses a highly oxygen-permeable, expanded-polystyrene foam tray and a polymer-based, stretch-film overwrap. Most of the remaining portions are packaged in bulk ice-packs by the central processor, but are ultimately displayed in a similar tray and stretch-wrap package at the retail level. Bulk boxes and polymer-lined boxes are often used to package frozen parts destined for export. Whole carcasses or

parts can be deep-chilled or crust-frozen in overwrapped trays by passing the package through a chill tunnel (-40ºC or lower). This process freezes the surface of the meat without freezing the interior and greatly extends the shelf-life of the product. The typical fresh-meat package for retail display is a foam tray, overwrapped with a clear film. An absorbent pad is usually placed under the meat to absorb purge. The pad comprises an absorbent material, such as cellulose, surrounded by a porous, non-absorbent 'plastic'. The overwrap film has a relatively high degree of oxygen-permeability to allow the escape of unpleasant odors during storage. The overwrap materials are stretch PVC or stretch-shrink PE, with the trays made from EPS. The tray overwrap process involves a continuous system. The following sections highlight the stresses that are placed on the foam trays during each step of a continuous, case-ready packaging process.

Stage 1. Product transfer
Most poultry plants have a layout which includes a series of conveyors in a race-track formation that carry products to a line of overwrap machines. The predominant machine in the USA is produced by the Ossid Corporation, model 'Ossid 500E'.

Trays must withstand the transfer between the conveyor system and the packaging machine. Product weights can exceed 8 lb in some of the larger tray sizes. Typically, the trayed product is moved manually from the conveyors to the entrance to the machine. During that transfer, machine loaders are inclined to grab one end of the trayed product, resulting in a significant amount of stress to the side-wall and base area of the tray.

Stage 2. Loading the machine
In entering the machine, the back end of the tray must withstand a stainless-steel pusher plate that advances the trayed product. This method of moving the product into the machine exerts a significant amount of stress along the contact points at the rear of the tray.

Stage 3. Application of stretch-film
The film is stretched tightly over the tray through a series of rollers and adjustable gripper chains. The rollers and chains combine to exert simultaneous downward and outward forces along all four side walls of the tray. The side walls must have enough elasticity to withstand these forces without cracking, while possessing the ability to recover their shape once the stress is relieved.

Stage 4. Movement of the product
Once the trayed product enters the main body of the machine, textured side belts snuggly grip the lips of the trays. These side belts, in contact with a minimal part of the lip, are the only means for advancing the product through the machine. There are no rollers or moving belts underneath the tray, so the side belts must compensate for the weight of the product and all friction between the bottom of

the tray and the metal vacuum lance. As these side belts move the product, a longitudinal seal is produced along the base of the tray. The product is also positioned for a transverse seal at the end of the tray.

Stage 5. Removal of air
Prior to completing the final transverse seal, air must be removed to provide a tight, wrinkle-free pack at the retail store. The Ossid 500E is equipped with a vacuum system that utilizes an impulse vacuum and a constant-bleed vacuum. The impulse vacuum removes most of the air when the machine is in continuous operation. This is timed to match the timing of the seal bar. The constant-bleed vacuum is necessary to prevent air re-entering the pack when the machine is operated to start and stop sequentially. All processing plants struggle to keep a continuous flow of product to their machines, so the constant-bleed vacuum is always an important factor in the operation. The vacuum cycle pulls air from the rear of the package, so that the product has a force trying to pull the tray back towards the entrance to the machine. The only method of preventing the tray from slipping backwards is the side-belts in contact with the lip. If the tray slides backwards, the machine will jam and must be reset, while the accumulated products will need to be reworked due to inadequate clearance for the end-seal and knife.

Stage 6. End-seals and exit belts
Immediately following the vacuum cycle, a trailing transverse seal is applied at the same time that a leading transverse seal is applied to the next package. During the application of the transverse seals, there is an open area where the side belts release the tray to another set of adjustable side belts known as the exit belts. These exit belts advance the packaged product to the shrink tunnel. The same principles in advancing the tray with the side belts apply to the exit belts. Again, the side walls need to have the ability to recover once the belt pressure is removed.

Stage 7. Hot-air shrink tunnel
Special poultry films are designed as stretch, shrink, end-seal films. A hot-air tunnel applies the initial shrink. After leaving the exit belts, the tray side walls must recover to their original shape, if any deflection resulted prior to entering the shrink tunnel. The tray side walls are then subjected to transverse stresses as the film shrinks around the trayed product. Poultry films are designed to have high shrink tensions to keep the product secure throughout distribution. The tray side walls must withstand this tension, without allowing distortion of the tray.

Stage 8. Hot-water shrink tunnel
The final stage in completing the package occurs in a hot-water tunnel. This provides a better medium for heat-transfer than the hot-air tunnel to finalize the appearance of the package. Water temperatures up to 200° F will provide the final shrink, resulting in additional tension along all four side walls of the tray.

Stage 9. Post-shrink handling and crust-freezing
Upon leaving the hot-water tunnel, any package failure that occurs at this point in the process means that the product is either re-worked or shipped out damaged. Processing staff can be extremely abusive during this phase of handling. Typically, packages leave the hot-water tunnel and fall into a crate at a 45º angle onto the leading tray end. This results in a significant force on the leading edge of the tray, as personnel work to keep up with the speed of the machine. The trays will sometimes crash into each other in the hot-water tunnel, as machine speeds allow insufficient time to keep the product flow from being obstructed. The finished packages travel to a blast-freezer, where each package is crust-frozen, with internal temperatures remaining above freezing due to industry regulations concerning fresh poultry. After the blast-freezer, the products are usually weighed and priced prior to placing them in corrugated boxes. These boxes are normally a standard size and may not exactly fit the product being shipped. The inappropriately sized boxes, along with uneven product surfaces, result in a significant stress along each side wall, as well as on the base of each tray. The trays need to cope with the stresses of handling and distribution without cracking during distribution to the warehouse or supermarket.

In conclusion, the saying that the 'chain is only as strong as the weakest link' definitely applies to case-ready packaging by overwrap equipment.

7.4.3   Ground and further-processed poultry in MAP
Vacuum packaging was one of the first types of MAP used for foods and is still the primary method for cured meats and primal cuts of red meat, prior to retail packaging. Vacuum packaging utilizes a high-barrier film that restricts O_2 transmission. After packaging, residual meat respiration and microbial growth will utilize any remaining O_2 present in the package and increase the concentration of CO_2. Vacuum-skin packaging is a modification which utilizes a thermoformable film that can be heat-shrunk around the product, thereby reducing purge and showing clearly the product surface. Both types of vacuum pack are restricted to products that are not adversely affected by the lack of oxymyoglobin pigment. While oxymyoglobin development is important for red meats, research has shown that it is not extensive in poultry meat, even when the meat is stored under high O_2 concentrations.

   Raw poultry meat is highly perishable, even when held under chill conditions. The growth of certain psychrotrophic bacteria is most often the cause of spoilage, as described in Chapter 11. While other factors will also limit shelf-life, especially initial bacterial levels, vacuum or gas packaging can usefully extend it, particularly when a vacuum or an initial CO_2 atmosphere is combined with chill storage. Also, increasing the CO_2 level to 80% or more can reduce the growth rate of aerobic spoilage bacteria on chicken compared to that in 20% CO_2 or in vacuum packs.

Generally three methods are used to vacuum-package meat:

1. The meat is held in a heat-shrinkable plastic bag with low O_2 permeability, and sealed with a metal clamp.
2. The chamber method, in which the meat is placed in a bag, the bag is evacuated and then heat-sealed.
3. The thermoforming method, in which the meat is placed in a tray and a plastic lid is sealed to the tray under a vacuum.

Ogilvy and Ayres (1951) published the first study on the use of CO_2-enriched atmospheres for packaging cut-up chicken. They reported a linear relationship between CO_2 concentration and shelf-life, but observed discoloration of the meat at CO_2 levels above 20%. This study was preceded by the application of MAP to fruit to reduce rotting from fungi (Brown, 1922; Kidd and West, 1927); to extend the shelf-life of pork and lamb meat (Killefer, 1930); to improve the stability of pork and bacon (Callow, 1932); to reduce mold growth on meat (Tomkins, 1932; Moran *et al.*, 1932) and to maintain fish quality (Coyne, 1933). Haines (1933) was the first to show an inhibitory effect of CO_2 on aerobic spoilage bacteria of meat.

Ground poultry meat requires different packaging conditions to maintain its color. Traditionally, ground meats have been packaged in high O_2 atmospheres (with CO_2), usually in PS foam trays with an overwrap film or lid that is a barrier to O_2. The package headspace is in accordance with a gas-to-meat volume ratio of 3:1 or greater. Ground turkey breast meat is a popular product of this kind and is sometimes mixed with the corresponding thigh meat. Due to a lack of color stability, less ground chicken is available.

MAP can be accomplished passively by allowing the atmosphere within the pack to equilibrate in the presence of O_2 absorbers or actively by flushing the package headspace with the desired atmosphere before sealing. Active gas flushing is commonly used for fresh poultry and is usually performed on a form-fill-seal machine, where the gas mixture is injected into the package to replace the ambient air. Some systems first pull a vacuum in the package to remove air, then flush the package before sealing with the desired gas mixture. In these types of MAP, the package usually takes the form of a gas-impermeable tray and film, with the film sealed to the tray or overwrapped. Film permeability has been found to affect the growth of spoilage bacteria on chill-stored poultry, because it influences the concentrations of CO_2 and O_2 that develop within the pack.

Shrimpton and Barnes (1960) evaluated films with high and low permeability to oxygen, including PE, PVC/PVdC copolymer and a modified PE. The highly impermeable copolymer, in combination with vacuum packaging, delayed the detection of spoilage odors and resulted in a higher concentration of CO_2 in the package headspace compared to the other films evaluated. Packaging must also be able to keep the moisture content constant within the package, in order to maintain product quality (Stollman *et al.*, 1996). Films of varying O_2 permeability will affect not only the growth of bacteria, but also the color and
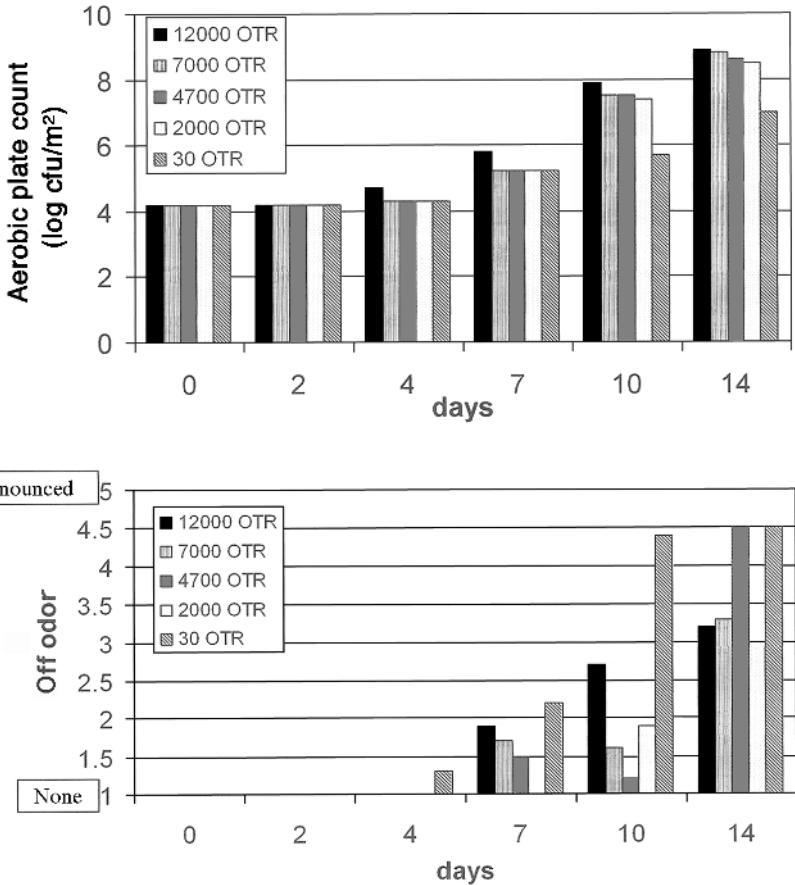
Fig. 7.1   The effect of film oxygen transmission rate (OTR) on the shelf-life of ground chicken leg meat (Dawson *et al.,* 1995a).

the odor of refrigerated poultry meat (Dawson *et al*., 1995a). Generally, low OTR films will retard bacterial growth, while high OTR films will reduce the impact of any unpleasant odors on opening the pack (Fig. 7.1).

In the use of CO_2-enriched atmospheres for chilled poultry, the CO_2 affects both the lag phase of bacterial growth and the generation times of the organisms present. A minimum concentration of 20% in the package headspace is required to see a significant improvement in shelf-life (Greengrass, 1993; Shaw, 1995), while growth of psychrotrophic foodborne pathogens may be inhibited by increasing the CO_2 concentration and storing packs at 1ºC. However, certain lactic acid bacteria are not inhibited and are usually involved in ultimate spoilage (Sander and Soo, 1978). Skinless poultry meat is usually packaged in a high O_2 atmosphere (70–80% with the balance being CO_2) to maintain color, but limit the growth of spoilage bacteria. A refrigerated shelf-life of 14 days is attainable using this system (Lawlis and Fuller, 1990), and slightly longer if

accompanied by deep chilling. Where necessary, N_2 may be used as a filler gas to minimize purge, without the inclusion of O_2.

7.4.4 Master bulk-packaging

Master packs are particularly suitable for food-service purposes and involve a slightly different approach in that retail tray packages with gas-permeable films are placed in large, master packages sealed with a gas-impermeable film (Fig. 7.2). The master packages are flushed with 100% CO_2 or N_2 to minimize bacterial growth. When the retail packs are removed, the headspace in each one equilibrates with the air which, for highly pigmented meats, allows the red pigment, oxymyoglobin, to develop. Several MAP packaging systems exist for fresh poultry meat, including: flexible trays with vacuum or gas-flush, rigid trays with lid stock and gas-flush, heat-sealable bags with vacuum or gas-flush, and master/bulk-packaging overwrap for vacuum storage or multiple gas-flush packages (Lawlis and Fuller, 1990).

In a bulk-pack system described by Timmons (1976), the retail packages are placed in corrugated containers, which are then transferred to a master bag. A modified atmosphere is then introduced. This system provides approximately five additional days of shelf-life compared to a non-MAP method. A low-oxygen barrier material, such as HDPE/LDPE co-extrudate, is used to allow release of unpleasant odors produced during storage. Due to concern about a build-up of odors in the package, high-barrier film materials have limited use in the poultry industry. Only about 1–2% of poultry meat requires high-barrier packaging, including pre-cooked products. Other requirements of fresh/frozen poultry packages are non-fogging, non-wrinkling, high clarity, puncture resistance and sealability.
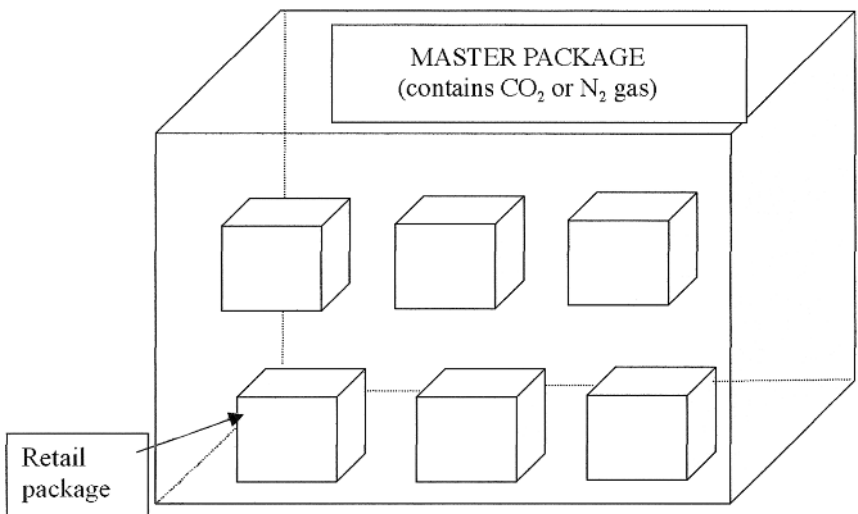
Fig. 7.2 A master bulk-packaging system.

7.4.5   MAP for cooked and cured products

Processed meat products include nitrite-cured meat and non-cured, cooked products, which are typically packaged in heat-shrinkable films, such as EVA/PVdC/EVA or nylon/EVOH/ionomer coextruded materials. Nylon or PET-based film, with a heat-sealable layer (ionomer or EVA), is also used for processed poultry meat. Dried-meat products stored at room temperature require a good O_2 and moisture barrier, such as PVdC, EVOH, or aluminum foil (PE laminated) films. Two common tray packages used for poultry are:

1. A non-barrier EPS (PS foam) tray, overwrapped with a barrier film.
2. An EPS (PS foam) tray with a built-in barrier and barrier lidding sealed to the tray.

The package layer structure is:

• Tray: HIPS (PS)/PS foam/HIPS/adhesive/barrier film.
• Barrier film: 2–3 mil (0.0508–0.0762 mm) thick LLDPE/adhesive/PVdC coated nylon/heat-seal coating
• Lidding: PVdC coated PET/LLDPE/2.5 mil (0.0635 mm) thick EVA.

The barrier material used is either PVdC or EVOH. A nylon material is used in packages for hot wings and roasted chicken lines because of its oxygen barrier, toughness, heat-resistance and forming properties. PET is used for printability, clarity and relatively low cost compared to nylon. LLDPE adds toughness and is low in cost, while EVA provides a heat-sealing layer and seal strength on cooling. Research has demonstrated positive shelf-life effects on processed meat.

Baker *et al*. (1972b) found that frankfurters packaged without vacuum developed mold during refrigerated storage, while others from the same batch that were vacuum-packaged did not develop mold, even after 24 days under the same conditions. Natural-casing weiners held in MAP with a mixture of 70% N_2, and 30% CO_2 were shelf-stable for 30 days (Lawlis and Fuller, 1990). Cured meats packaged in low OTR films, with removal of O_2 from the package, will maintain their cured-meat color and flavor, while the growth of spoilage organisms is inhibited.

7.4.6   Cook-in packaging

Cook-in-the-bag products include restructured deli-type meats, such as turkey hams, breasts and rolls, that are cooked in the package. Cook-in technology has advantages that include increased shelf-life, higher quality product and increased product yield. To withstand the required cooking temperatures, cook-in packaging consists of layers that perform different functions. EVOH is the moisture and gas barrier, while the adhesion layer is made from nylon and/or Surlyn. Film-to-meat adhesion minimizes package purge after cooking and during storage. Non-adhering bags are used for products that are cooked in the package, then removed for further processing, such as smoking, browning or

a)   b)
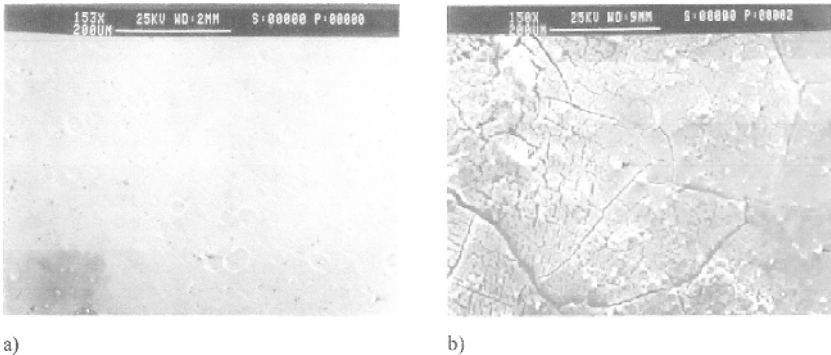
Fig. 7.3   Osmium tetroxide-stained films, peeled away from cooked, ground chicken
meat: (a) non-binding film, (b) binding film.

addition of flavoring. The cook-in packaging process requires a combination of
stuffers, clippers, pumps and shrink tunnels.

Meat-surface and film-sealant layer interactions are similar to the interactions
between myofibrillar proteins dissolved at the surface of meat-tissue particles,
during preparation of comminuted meat products (Seigel, 1982; Terlizzi *et al.*,
1984). The degree of meat-to-film binding is dependent on the extracted
myofibrillar protein in the meat product (Rosinski *et al.*, 1990). Meat-to-film
adhesion has been examined with the 'peel' test (Rosinski *et al.*, 1989, 1990).

The effect on meat-to-film binding of special binding films can be seen from
scanning electron micrographs of film surfaces, when ground chicken meat
emulsions were exposed to binding and non-binding films during heating. Little
or no meat residue appeared on the non-binding film (Fig. 7.3a). However, when
the same emulsion was exposed to a binding film (Fig. 7.3b), meat residue
adhered to the film surface (Clardy and Dawson, 1995).

The effect of film type (PE, nylon or Surlyn-based) on meat binding at the
film surface was also determined by exposing films to a weak protein solution
extracted from chicken breast. The total bound protein and the classes of bound
amino acids were determined in samples held in a constant-temperature water
bath and in a water bath that provided a temperature gradient. Protein adhesion
occurred in all three film types; however, adhesion followed the trend Surlyn >
nylon > polyethylene after 60 min of heating at 25.8ºC (Clardy *et al.*, 1998). The
amount of bound protein increased, in the case of Surlyn, with heating from
55ºC to 80ºC, while PE and nylon showed little or no increase (Fig. 7.4). Based
on the classes of amino acids bound to the film, both hydrophobic interactions
and hydrogen bonding participate in meat-to-film adhesion.

7.4.7   Active packaging

Active packaging interacts with the environment and/or the food itself.
Available systems include oxygen scavengers, moisture absorbers and films
with selective permeability to gases.
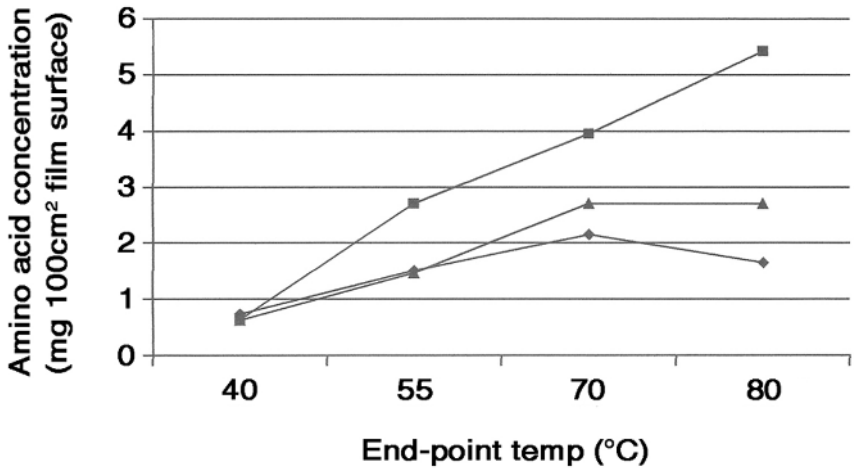
Fig. 7.4 Bound amino acid concentrations at three film surfaces exposed to a weak chicken protein solution (12 mg protein/ml) at different end-point temperatures. Samples were heated at 1°C/min.

Oxygen scavengers
Oxygen scavengers were first used to extend shelf-life and maintain the quality of beer. Oxygen will accelerate the deterioration of fresh and cured meat-color and allow growth of aerobic bacteria and molds. Incorporation of O_2 scavengers in a package, along with a physical barrier, such as PVdC or EVOH, can maintain the O_2 level inside the package at almost 0%. Chemical oxidizing systems, such as metaxylene adiamide plus a cobalt-salt catalyst or enzyme-reacting system, using glucose oxidase with catalase, remove O_2 from the package (Yoshi, 1992). A mixture of iron powder and calcium hydroxide scavenges both O_2 and CO_2 (Labuza and Breene, 1989). In relation to meats, oxygen-reducing packaging systems are restricted to products where pathogenic anaerobes such as *Clostridium botulinum* are not a concern. Exclusion or removal of O_2 can be used for fully cured poultry-meat products, since multiple hurdles then exist to prevent outgrowth of *C. botulinum* spores.

Moisture absorbers
Purge can facilitate bacterial growth, so moisture absorbers are placed in fresh meat packages or incorporated as part of the film. Absorbent pads are commonly placed beneath fresh poultry to reduce the accumulation of purge, or films with entrapped propylene glycol are used to absorb moisture from the meat surface (Labuza and Breene, 1989).

Temperature-compensating films
Films are available that can change in permeability with changing temperature. This is achieved by the use of long-chain fatty acids with alcohol-based side chains that are oriented in a linear pattern and can change to a random alignment.

While originally designed for use with respiring plant materials, there may be applications to poultry for maintaining quality, while restricting microbial growth in products that are frozen in transit, then thawed for retail display.

Antimicrobial packaging

Edible films and coatings can act as carriers of antimicrobial compounds, as well as being barriers to microorganisms. Much of the reported work with antimicrobial films and coatings has utilized acids carried in a variety of materials (Torres and Karel, 1985; Vojdani and Torres, 1990; Rico-Pena and Torres, 1990; Siragusa and Dickson, 1992; Davidson and Juneja, 1990; Robach and Sofos, 1982; Maas *et al*., 1989). Sorbic acid has been incorporated in corn zein (Torres and Karel, 1985), methyl cellulose and hydroxy propyl methyl-cellulose (Vojdani and Torres, 1990) to form a coating to inhibit bacterial growth on food surfaces. Calcium alginate was used as a carrier for acetic and lactic acids to reduce populations of *Listeria monocytogenes* on beef surfaces (Siragusa and Dickson, 1992).

Nearly all commercial overwrap and vacuum-skin films are produced by a heat-extrusion method. The exceptions are some meat casings produced from collagen. Films using soy and corn proteins have been prepared by heat-extrusion to incorporate antimicrobials within their structure (Padgett *et al*., 1998). Making films from proteins by the heat-extrusion method is a new technology, and will enable the film to act as a carrier to deliver the antimicrobial to the food product (Dawson, 1998). For example, nisin and lysozyme, in combination with EDTA, when incorporated into the structure of soy- and corn-protein films, inhibited the growth of certain strains of Gram-positive and Gram-negative bacteria (Dawson *et al*., 1995b).

The application of nisin as a coating and its use to impregnate polymer films and coatings for meat packaging have been reviewed by Dawson and Sheldon (2000). Examples include the incorporation of nisin into protein and PE films (Hoffman *et al*., 2001). Further testing of these films has evaluated their effectiveness against *L. monocytogenes* and *Escherichia coli*. Reductions in *L. monocytogenes* of 3–4 log units (Dawson *et al*., 1999) and 2–3 log reductions in *E. coli* (Padgett *et al*., 1998) were obtained when the bacteria were exposed directly to the films. Nisin formulations have also been delivered to the surface of fresh poultry meat using agar and calcium alginate (Natrajan and Sheldon, 1995). The mean log reduction in *Salmonella* Typhimurium populations exceeded three and four log units after 72 and 96 hours of exposure respectively at 4ºC. These nisin formulations have also been added to absorbent meat pads, reducing *S.* Typhimurium populations by up to five log units (Fig. 7.5), and, in some cases, resulting in no recoverable organisms (Sheldon, 1996). The combination of EDTA with nisin or with lauric acid, or an EDTA/lauric acid/nisin combination inhibited the growth of *E. coli*, while EDTA with lauric acid or the two combined with nisin effectively inhibited *S.* Enteritidis (Hoffman *et al*., 2001).

Chitosan has been examined as an antimicrobial coating for chicken. This substance is a carbohydrate obtained by alkali treatment of skeletal material
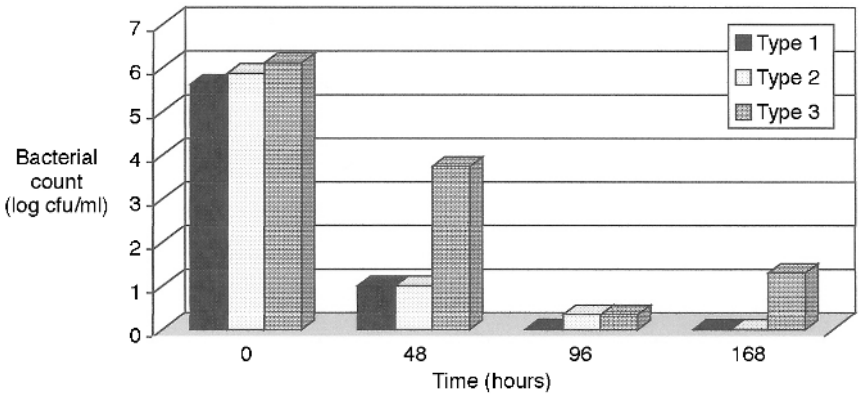
Fig. 7.5   Inhibitory effect of nisin-containing pads on *Salmonella* Typhimurium (with permission of Dr. Brian W. Sheldon, North Carolina State University, Raleigh, NC, USA).

from shellfish and is a modified form of chitin. As a by-product of commercial shellfish production, it can be processed to form a coating that has anti-fungal and anti-bacterial properties. Chitosan coating reduced the total bacterial population on chicken drumsticks by one log unit (90%) (Dawson, 1998).

7.4.8   Heat-stable pouches and cans

Poultry-meat products contained in thermal pouches and cans are small meat chunks or particulates found in sauces, soups and stews. These meat particulates are from both intact and restructured sources.

Sous vide is a packaging and processing method in which the food is first vacuum packaged, then cooked, cooled and stored under refrigeration. The product is usually reheated prior to consumption. Advantages of the sous-vide process include cooking the meat in its own juices, sealing-in volatile flavor compounds and minimal loss of moisture or nutrients, resulting in a more flavorful, tender and nutritionally complete product. Sous-vide products are said to retain their 'just-cooked' flavor for several weeks in refrigerated storage (Baird, 1990). Concern has arisen about the safety of meats and other foods prepared by the sous-vide method, because the process is designed to maintain the desired organoleptic properties of the food, without proper attention to guidelines on obtaining commercial sterility (Rhodehamel, 1992). The relatively mild heat treatment associated with the cooking process may not kill all vegetative cells and certainly will not inactivate spores. Sous-vide products are formulated with few or even no preservatives, are not shelf-stable and are packaged under vacuum, which inhibits aerobic spoilage organisms, but provides an ideal environment for the growth of some pathogens (Rhodehamel, 1992). The mild heat treatment, accompanied by vacuum packaging, tends to select for *C. botulinum*. There is a risk that any *C. botulinum* spores will outgrow and toxin production will occur, since commercial sterility is uncertain (Conner

et al., 1989). While refrigeration will prevent the outgrowth of *C. botulinum*, this alone does not guarantee the safety of the food (Palumbo, 1986; Moberg, 1989). The Meat and Poultry Group of the US National Advisory Committee on Microbiological Criteria for Foods recommended that refrigerated foods containing cooked, uncured meat should receive a heat treatment sufficient to achieve a four log reduction in *L. monocytogenes* (USNACMCF, 1991). Smith *et al.* (1990) recommended a more severe heat treatment for these products, sufficient to achieve a 12–13 log reduction in *Enterococcus faecalis*. Sous-vide foods subjected to mild temperature abuse during storage, distribution or preparation would run the risk of causing food poisoning from various pathogens including *C. botulinum, Staphylococcus aureus, Vibrio parahaemolyticus, Bacillus cereus* and *Salmonella.* Adequate temperature controls do not exist throughout the food distribution system and Wyatt and Guy (1980) found that conditions were unsatisfactory in seven out of ten US retail stores tested. Harris (1989) found that 7, 17, 26 and 23%, respectively, of the refrigerated retail cases in major, independent, family-owned and convenience stores maintained temperatures at or above 10.5ºC. Fresh-meat display cases were found to have the best temperature control (only 4% above 10ºC), but delicatessen sections were the poorest in this respect with 26.1% of the products above 10ºC (Daniels, 1991).

Closely related to the sous-vide process are cooked poultry-meat entrées, which are packaged under modified atmospheres with very low partial pressures of O_2. These products often have the meat combined with cooked vegetables or pasta, or on a bed of rice. Products handled in this manner are subject to the same risks from pathogens as the sous-vide products. Of special concern again are *C. botulinum* spores, especially those capable of outgrowth at and above 5ºC. While these products have a good record to date, the risk of serious foodborne illness is always present.

7.5   Biopolymer packaging for poultry meat

Each year, large amounts of packaging waste are discarded into municipal waste systems. In the USA alone, over 23 million tons of plastic packaging waste were generated in 1998. To reduce the amount of such waste, a considerable research effort has been devoted to the production of polymer films from natural sources. The use of plant material for this purpose is an active area of research (Jane and Wang, 1996). As new uses for such materials are still emerging, characterization of renewable biopolymers is very important, if these are to be used for packaging applications.

A key question concerning the use of biopolymers is why they should be used instead of petroleum-based materials that are highly functional and relatively inexpensive. The advantages in using biopolymers for food packaging include: reduced dependence on petroleum-based packaging, use of a renewable, agricultural resource that can be mass-produced, the

biopolymers can act as carriers to deliver shelf-life extenders, such as antimicrobials or antioxidants, and they are biodegradable. Biopolymers can originate from a variety of sources that include both plant and animal materials. Since the forming of a film requires cross-linking of molecular units to impart strength and flexibility, proteins and carbohydrates are often the best candidates for biopolymer films.

Proteins investigated include wheat gluten, corn zein, whey, pea protein, meat proteins, egg proteins and soy. Carbohydrates described in the literature include alginate, polysaccharides, cellulose, carrageenans, microbial poly-saccharides and chitosan. There has been significant research activity to develop bio-based packaging in Europe, while some US companies are already utilizing modified starch materials. Commercial raw materials include polylactate produced by Cargill Dow (trade name: NatureWorks PLA) and by Mitsui, under the trade name LACEA. Other raw, starch-based packaging materials include Novamont (Mater Bi), Biotec (Bioplast), and Earth (Earth Shell). These materials require chemical modification of native starch materials and have been tested as molded containers (Salvage, 2000).

Much of the research on biopolymer films has involved the method of solvent casting to produce the film. In contrast, thermal processing methods such as compression-molding and extrusion have received only limited attention. Jane and Wang (1996) and Huang *et al.* (1995) reported on an extrusion/molding technique, whereas Paetau *et al.* (1994), Jane *et al.* (1994) and Paulk *et al.* (1995) used compression-molding to produce films from soy-protein isolates. Other studies discuss the compression molding of starch and corn zein films. Some of these films were reported to be rigid and brittle, due to the absence of a plasticizer in the pre-processed mixture. The reducing agents in the Jane and Wang (1996) method break the disulfide bonds in protein fractions to allow processing of the soy-protein isolates. The disadvantage of a chemically modified protein is that the individual molecules are not structurally bonded, and water-resistance is markedly reduced.

Cross-linking has been found to stabilize polymer chains and decrease vapor and gas permeability in protein-derived films (Kumins, 1965). Guilbert (1986) improved the barrier characteristics of films from various proteins (dried gelatin, casein, albumin and ovalbumin) by the addition of organic acids. Various cross-linking agents and treatments that have been used in preparing cast films include formaldehyde, glutaraldehyde, cysteine, transglutaminase, ultraviolet radiation and glyoxal. A different method was developed to produce biopolymer films via heat extrusion, without the use of such agents (Ogale *et al.,* 2000; Cunningham *et al.*, 2000). These resulted in films with physical properties that were comparable to those produced using cross-linking agents. These agents add cost and sometimes involve compounds that are not approved for contact with food. In addition, qualitative comparisons have been made between cast- and heat-pressed protein films, using scanning electron microscopy. Results showed a higher porosity in cast-pressed compared to heat-pressed films (Dawson, 1998).

Table 7.2 Biopolymer films and coatings tested for meat and poultry products

Material	Meat product	Application	Reference
Albumen/gelatin	Chicken parts	Breading adhesion	Suderman *et al.* (1981)
Albumen/soy/ wheat protein	Meat parts	Batter/breading adhesion	Baker *et al.* (1972a)
Alginates	Beef, pork, chicken	Texture modifier, moisture barrier	Allen *et al.* (1963)
Carrageenan	Poultry	Moisture/oxygen barrier	Pearce and Lavers (1949)
Chitosan	Chicken	Inhibit microbial growth	Acton *et al.* (2000)
Corn zein	Cooked turkey	Oxygen barrier, anti-oxidant carrier	Herald *et al.* (1996)
Corn zein	Sausage	Moisture/oxygen barrier	Turbak (1972)
Gelatin	Meats	Mold reduction, barrier	Kiel (1961); Kiel *et al.* (1960)
Gelatin	Frozen chicken	Oxygen barrier, antioxidant carrier	Klose *et al.* (1952)
Gelatin	Smoked chicken	Moisture barrier	Moorjani *et al.* (1978)
Gelatin	Breaded meat	Oil barrier	Olson and Zoss (1985)
Methyl cellulose	Pork and poultry	Breading adhesion	Bauer *et al.* (1969)
Soy protein	Sausage	Moisture/oxygen barrier	Turbak (1972)
Soy protein	Chicken	Antimicrobial carrier	Dawson (1998)
Wheat gluten	Sausage	Moisture/oxygen barrier	Turbak (1972); Mullen (1971)
Wheat gluten	Turkey	Antimicrobial carrier	Schilling and Burchill (1972)
Wheat gluten	Bologna	Antimicrobial carrier	Dawson *et al.* (2002)
Whey protein	Frozen chicken	Physical protection	Alcantrac and Krotcha (1996)

Research on the formation of biopolymeric films has been on-going since the 1940s, but with increased intensity in recent years. Pearce and Lavers (1949) reported using carrageenan to protect frozen poultry, and Klose *et al.* (1952) incorporated an antioxidant into a gelatin coating to slow the development of oxidative rancidity in poultry portions, prior to freezing. The functions of edible films when used for poultry meat, include roles as a moisture barrier, oxygen barrier, texture modifier, aid to adhesion of breading, mold suppressor, bacterial inhibitor, physical protectant, oil barrier, antimicrobial carrier and antioxidant carrier (Table 7.2). Nearly all commercial overwrap and vacuum-skin films are produced by a heat-extrusion method. The exceptions are some meat casings produced from collagen. Films using soy and corn materials have been formed by heat-extrusion to carry antimicrobials within their structure (Padgett *et al.*, 1998). Creating films from natural plant materials by the heat-extrusion method is a new technology and will enable the film to act as a carrier for delivering the antimicrobial to the food product (Dawson, 1998).

7.6   Future trends

Aseptic packaging and aseptic processing may have future applications for poultry and are inseparable by virtue of the interaction between the two in producing the final product. The major advantage of aseptic packaging is the reduction in the initial microbial load of the food and maintenance of package integrity after sterilization. The total process can be described as pre-sterilization of the food before filling it into a pre-sterilized package, within a sterile environment, followed by closing of the package in a sterile manner. While most packaging materials are sterile immediately after their production, they are easily contaminated by dust and through handling during storage prior to use. Therefore, sterilization for the aseptic process/package system must occur just before filling. Sterilization of the food in the aseptic system is most often accomplished by high-temperature, short-time processing. Other methods, such as ohmic or microwave heating, are also being used for thermal processing of foods containing poultry-meat particulates. These food-sterilization processes follow traditional, thermal, death-time methodology for ensuring commercial sterility.

The methods of sterilizing packages range from steam and high heat for metal containers, as with the 'Dole' process, to non-heating methods for flexible containers, such as use of hydrogen peroxide, ultraviolet radiation or ionizing radiation. To ensure complete sterilization of the entire package surface, hydrogen peroxide treatment can be coupled with hot-air drying, ultrasonic energy, ultraviolet radiation (UV) or copper ions. There are major drawbacks with UV radiation, including limited penetration into liquids, no sterilization of surfaces shaded by package geometry or dust, and the presence of rare microbial species that can survive UVradiation damage and eventually repair damaged DNA. Ionizing gamma-ray radiation is widely used to sterilize aseptic packages

in the medical and pharmaceutical industries; however, this is not the case with foods because of the need for extreme safety measures to protect the workers. Nevertheless, electron beams have gained approval for food use and could be adapted for package sterilization. A more likely application is in-package sterilization with ionizing radiation, since maintenance of a sterile zone and a pre-sterilized product and package would not be required in that case.

7.7   Sources of further information and advice

BLACKISTONE B A (ed.) (1999), *Principles and Applications of Modified Atmosphere Packaging of Foods,* 2nd edn, Gaithersburg, MD, Aspen.

BRODY A L (ed.) (1989), *Controlled/Modified Atmosphere Packaging of Foods*, Trumbull, CT, Food and Nutrition Press.

CUNNINGHAM F E and COX N A (eds) (1987), *The Microbiology of Poultry Meat Products,* San Diego, CA, Academic Press.

JENKINS W and HARRINGTON J P (eds) (1991), *Packaging Foods with Plastics*, Lancaster, PA, Technomic Publishing Co.

PETERS J W (1995), Materials Section in *Packaging Encyclopedia*, Boston, MA, Cahners Publishing Co, 53–115.

ROBERTSON G L (ed.) (1998), *Food Packaging,* New York, Marcel Dekker.

ROLLER S (ed.) (2000), *Natural Antimicrobials for the Minimal Processing of Foods*, Cambridge, CRC Press, Woodhead.

SAMS A R (ed.) (2001), *Poultry Meat Processing*, London, UK and Boca Raton, Florida, CRC Press.

7.8   References

ACTON J C, OGALE A A and DAWSON P L (2000) 'New developments in edible films and coatings', *Proceedings of the International Congress on Meat Science and Technology*, *Buenos Aires, Argentina*, 748–751.

ALCANTRAC C R and KROTCHA J M (1996) 'Mechanical properties of whey-isolate coated freeze-dried chicken white-meat dice', *Proceedings of the Annual Meeting of the Institute of Food Technologists, Chicago, Illinois*, 179.

ALLEN L, NELSON A I, STEINBERG M P and McGILL J N (1963), 'Edible corn-carbohydrate food coatings. II. Evaluation on fresh meat products', *Food Technology*, 17, 104–108.

BAIRD B (1990), 'Sous Vide: What's all the excitement about?', *Food Technology,* 44(11), 92–93.

BAKER R C, DARFLER J M and VADEHRA D V (1972a) 'Prebrowned fried chicken. 2. Evaluation of predust materials', *Poultry Science,* 51, 1220–1222.

BAKER R C, DARFLER J and VADEHRA D V (1972b), 'Effect of storage on the quality of chicken frankfurters', *Poultry Science*, 51, 1620–1625.

BAUER C D, NEUSER G L and PNIKALLA H A (1969), 'Edible meat coating composition', US Patent 3,483,004.

BROWN W (1922), 'On the germination and growth of fungi at various temperatures and

in various concentrations of oxygen and carbon dioxide', *Annals of Botany,* 36, 375–383.

CALLOW E H (1932), 'Gas storage of pork and bacon. I: preliminary experiments', *Journal of the Society of Chemical Industry,* 51, 116T–119T.

CLARDY C B and DAWSON P L (1995), 'Film type effects on meat-to-film adhesion examined by scanning electron microscopy', *Poultry Science,* 74, 1053–1057.

CLARDY C B, HAN I Y, ACTON J C, WARDLAW F B, BRIDGES W B and DAWSON P L (1998), 'Protein-to-film adhesion as examined by amino acid analysis of protein binding to three different packaging films', *Poultry Science,* 77, 745–751.

CONNER D E, SCOTT V N, BERNARD D T and KAUTTER D A (1989), 'Potential *Clostridium botulinum* hazards associated with extended shelf-life refrigerated foods: A review', *Journal of Food Safety,* 10, 131–152.

COYNE F P (1933), 'The effect of carbon dioxide on bacterial growth', *Proceedings of the Royal Society, Series B,* 113, 196–217.

CUNNINGHAM P, OGALE A A, DAWSON P L and ACTON J C (2000), 'Thermal processing and tensile properties of soy protein isolate films', *Journal of Food Science,* 65, 668–671.

DANIELS R W (1991), 'Applying HACCP to new-generation refrigerated foods at retail and beyond', *Food Technology,* 45(6), 122, 124.

DAVIDSON P M and JUNEJA V K (1990), Antimicrobial agents, in *Food Additives,* (eds Branen A L, Davidson P M and Salminen S), New York, Marcel Dekker, 83–137.

DAWSON P L (1998), 'Developments in Antimicrobial Packaging', *Proceedings of the Thirty-Third National Meeting on Poultry Health and Processing, Ocean City, Maryland,* 94–102.

DAWSON P L and SHELDON B W (2000), Nisin in the decontamination of animal products, in *Natural Antimicrobials for the Minimal Processing of Foods,* (ed. Roller S) Cambridge, Woodhead, 34–63.

DAWSON P L, HAN I Y, VOLLER L M, CLARDY C B, MARTINEZ R M and ACTON J C (1995a), 'Film oxygen transmission rate effects in ground chicken meat quality', *Poultry Science,* 74, 1381–1387.

DAWSON P L, ACTON J C, HAN I Y, PADGETT T, ORR R and LARSEN T (1995b), 'Incorporation of antibacterial compounds into edible and biodegradable packaging films', *Research and Development Activities Report for Military Food and Packaging Systems,* 47 (2), 203–210.

DAWSON P L, BIRK T L, NIELSEN H J, HAN I Y and ACTON J C (1999), 'Nisin-impregnated corn zein films inhibit bacterial growth' *Proceedings of the International. Congress on Improved Traditional Food for the Next Century, Valencia, Spain,* 277–288.

DAWSON P L, CARL G D, ACTON J C and HAN I Y (2002), 'Effect of lauric acid and nisin-impregnated soy-based films on the growth of *Listeria monocytogenes* on turkey bologna', *Poultry Science,* 81, 721–726.

GILL C O and REICHEL M P (1989), 'Growth of cold-tolerant pathogens *Yersinia enterocolitica, Aeromonas hydrophila* and *Listeria monocytogenes* on high-pH beef packaged under vacuum or carbon dioxide', *Food Microbiology,* 6, 223–230.

GREENGRASS J (1993), Films for MAP foods, in *Principles and Applications of Modified Atmosphere Packaging of Foods,* (ed. Parry R T), Glasgow, Blackie Academic and Professional, 63–100.

GUILBERT S (1986), Technology and application of edible protective films, in *Food Packaging and Preservation. Theory and Practice,* (ed. Mathlouhi M), London, Elsevier Applied Science, 271–290.

HAINES R B (1933), 'The influence of carbon dioxide on the rate of multiplication of certain bacteria as judged by viable counts', *Journal of the Society of Chemical Industry*, 52, 13–17.

HARRIS R D (1989), 'Kraft builds safety into next generation refrigerated foods', *Food Processing,* 50(13), 111–112, 114.

HERALD T J, HACHMEISTER K A, HUANG S and BOWERS J R (1996), 'Corn zein packaging materials for cooked turkey', *Journal of Food Science*, 61, 415–417, 421.

HOFFMAN K L, HAN I Y and DAWSON P L (2001), 'Antimicrobial effects of corn zein films impregnated with nisin, lauric acid, and EDTA', *Journal of Food Protection,* 64, 885–889.

HUANG H C, HAMMOND E G, REITMEIR C A and MYERS D J (1995), 'Properties of fibers produced from soy protein isolate by extrusion and wet-spinning', *Journal of American Oil Chemists' Society*, 72, 143–146.

HUIS IN'T VELD J H J (1996), 'Microbial and biochemical spoilage of food; An overview', *International Journal of Food Microbiology*, 33, 1–18.

JANE J and WANG S (1996), 'Soy protein-based thermoplastic composition for preparing molded articles', US Patent 5,523,293.

JANE J, LIM S, PAETAU I, SPENCE K and WANG S (1994), Biodegradable plastic made from agricultural biopolymers, in *Polymers from Agricultural Coproducts* (eds Fishman M L, Friedman R B, and Huang S J), Washington DC, American Chemical Society, 92–100.

JIMENEZ S M, SALSI M S, TIBURZI M C, RAFAGHELLI R C and PIROVANI M E (1991), 'Combined use of acetic acid and modified atmosphere packaging for extending the shelf life of chilled chicken breast portions', *Journal of Applied Microbiology*, 87, 339–344.

KIDD F and WEST C (1927), 'Gas storage of fruit', Food Investigation Board Special Report No. 30, Department of Scientific and Industrial Research, UK.

KIEL HL (1961) 'Coating foods and composition thereof', US Patent 2,971,849.

KIEL H L, HAGEN R F and FLAWS R W (1960), 'Coating composition, method of applying same to food, and coated food product', U.S. Patent 2,953,462.

KILLEFER D H (1930), 'Carbon dioxide preservation of meat and fish', *Industrial and Engineering Chemistry,* 22, 140–143.

KLOSE A A, MEECHI E P and HANSON H L (1952), 'Use of antioxidants in frozen storage of turkeys', *Food Technology*, 6, 308–311.

KUMINS C A (1965), 'Transport through polymer films', *Journal of Polymer Science*, Part C, 10, 1–8.

LABUZA T P and BREENE W M (1989), 'Applications of ''active packaging'' for improvement of shelf-life and nutritional quality of fresh and extended shelf-life food', *Journal of Food Processing and Preservation,* 13, 31–38.

LAWLIS T L and FULLER S L (1990), 'Modified-atmosphere packaging incorporating an oxygen-barrier shrink film', *Food Technology,* 44(6), 124–125.

MAAS M R, GLASS K A and DOYLE M P (1989), 'Sodium lactate delays toxin production by *Clostridium botulinum* in cook-in-bag turkey products', *Applied and Environmental Microbiology,* 55, 2226–2229.

MOBERG L (1989), 'Good manufacturing practices for refrigerated foods', *Journal of Food Protection,* 52, 363–367.

MOORJANI M W, RAJA K C M, PUTTARAJAPPA P, KHABUDE V S, MAHENDRAKAR N S and MAHADEVASWAMY M (1978), 'Studies on curing and smoking poultry meat', *Indian Journal of Poultry Science*, 13, 52–57.

MORAN T, SMITH E C and TOMKINS R G (1932), 'The inhibition of mould growth on meat by

CO_2', *Journal of the Society of Chemical Industry,* 51, 114T–116T.

MULLEN J D (1971), 'Film formation from non-heat coaguable simple proteins with filler and resulting product' US Patent 3,615,715.

NATRAJAN N and SHELDON B W (1995), 'Evaluation of bacteriocin-based packaging and edible film delivery systems to reduce Salmonella in fresh poultry', *Poultry Science,* 74(SUPP), 31.

OGALE A A, CUNNINGHAM P, DAWSON P and ACTON J C (2000), Viscoelastic, thermal, and microstructural characterization of soy protein isolate films', *Journal of Food Science*, 65, 672–679.

OGILVY W S and AYRES J C (1951), 'Post-mortem changes in stored meats. II. The effect of atmospheres containing carbon dioxide in prolonging the storage life of cut-up chicken', *Food Technology,* 5, 97–102.

OLSON S and ZOSS R (1985), 'Fried foods of reduced oil absorption and methods of preparation employing spray film forming agents', US Patent 4,511,583.

PADGETT T, HAN I Y and DAWSON P L (1998), 'Incorporation of food-grade antimicrobial compounds into biodegradable packaging films', *Journal of Food Protection,* 61, 1330–1335.

PAETAU I, CHEN C and JANE J (1994), 'Biodegradable plastic made from soybean products. 1. Effect of preparation and processing on mechanical properties and water absorption', *Industrial Engineering and Chemical Research*, 33, 1821–1827.

PALUMBO S A (1986), 'Is refrigeration enough to restrain foodborne pathogens?', *Journal of Food Protection,* 49, 1003–1009.

PAULK J, OGALE A A, DAWSON P L and ACTON J C (1995), 'Formation of thermally-set polymer films from soy protein', *Proceedings of the Annual Technical Conference, Society of Plastics Engineers*, Boston, MA, 3149–3150.

PEARCE J A and LAVERS C G (1949), 'Frozen storage of poultry. V. Effects of some processing factors on quality,' *Canadian Journal of Research*, 27(6), 253–265.

RHODEHAMEL E J (1992), 'FDA's concerns with sous vide processing', *Food Technology,* 46(12), 73–76.

RICO-PENA D C and TORRES J A (1990), 'Oxygen transmission rate of edible methylcellulose-palmitic acid film', *Journal of Food Process Engineering,* 13, 125–133.

ROBACH M C and SOFOS J N (1982), 'Use of sorbates in meat products, fresh poultry and poultry products: A review', *Journal of Food Protection,* 55, 1468–1469.

ROSINSKI M J, BARMORE C R, DICK R L and ACTON J C (1989), 'Film sealant and vacuum effects on two measures of adhesion at the sealant-meat interface in a cook-in package system for processed meat', *Journal of Food Science,* 54, 863–866.

ROSINSKI M J, BARMORE C R, DICK R L and ACTON J C (1990), 'Research note: Film-to-meat-adhesion strength for a cook-in-the-film packaging system for a poultry-meat product', *Poultry Science,* 69, 360–362.

SALVAGE B (2000), 'Bio-packaging for sandwiches penetrating Fast-Food Arena', www.meatingplace.com, 11/9/00.

SANDER E H and SOO H M (1978), 'Increasing shelf-life by carbon dioxide treatment and low temperature storage of bulk pack fresh chickens packaged in nylon Surlyn film', *Journal of Food Science*, 43, 1519–1534.

SCHILLING E D and BURCHILL P I (1972), 'Forming filled edible casing', US Patent 3,674,506.

SEIGEL D G (1982), 'Technical aspects of producing cook-in-hams', *Meat Processing*, 11, 57–73.

SHAW R (1995), MAP of meats and poultry, in *Conference Proceedings, Modified Atmosphere Packaging (MAP) and Related Technologies,* Campden, Campden and Chorleywood Food Research Association, 85–115.

SHELDON B W (1996), 'Efficacy of nisin impregnated pad for the inhibition of bacterial growth in raw packaged poultry', *Poultry Science,* 75(SUPP 1), 97.

SHRIMPTON D H and BARNES E M (1960), 'A comparison of oxygen permeable and impermeable wrapping materials for the storage of chilled eviscerated poultry', *Chemistry and Industry,* 1492–1493.

SIRAGUSA G R and DICKSON J S (1992), 'Inhibition of *L. monocytogenes* on beef tissue by application of organic acids immobilized in a calcium alginate gel', *Journal of Food Science,* 57, 293–296.

SMITH J P, TOUPI C, GAGNON B, VOYER R, FISET P P and SIMPSON M V (1990), 'Hazard analysis and critical control point (HACCP) to ensure the microbiological safety of sous vide processed meat/pasta product', *Food Microbiology,* 7, 177–198.

STOLLMAN U, JOHANSSON F and LEUFVEN A (1996), Packaging and Food Quality, in *Shelf-life Evaluation of Foods* (eds Man C M D and Jones A A), Gaithersburg, MD, Aspen, 42–56.

SUDERMAN D R, WIKER J and CUNNINGHAM F E (1981), 'Factors affecting adhesion of coating to poultry skin. Effects of various proteins and gum sources in the coating composition', *Journal of Food Science*, 46, 1010–1015.

TERLIZZI F M, PERDUE R R and YOUNG L L (1984), 'Processing and distributing cooked meats in flexible films', *Food Technology,* 38(3), 67–73.

TIMMONS D (1976), ' "Dryer fryer" is CVP the ultimate bulk pack?', *Broiler Business*, December, 10–17.

TOMKINS R G (1932), 'The inhibition of the growth of meat attacking fungi by carbon dioxide', *Society for Chemical Industry,* 261T–264T.

TORRES J A and KAREL M (1985), 'Microbial stabilization of intermediate moisture food surfaces. III. Effects of surface preservative concentration and surface pH control on microbial stability of an intermediate moisture cheese analog', *Journal of Food Processing and Preservation,* 9, 107–111.

TURBAK A F (1972), 'Edible vegetable protein casing', US Patent 3,615,715.

USDA (2000), United States Department of Agriculture, Food Safety and Inspection Service, http://www.fsis.usda.gov/OA/pubs/meatpack.htm.

USNACMCF (1991), 'Recommendations of the US National Advisory Committee on Microbiological Criteria for Foods: I HACCP principles, II meat and poultry, III seafood', *Food Control*, 2, 202–210.

VOJDANI F and TORRES J A (1990), 'Potassium sorbate permeability of methylcellulose and hydroxypropyl methylcellulose coatings: effects of fatty acids', *Journal of Food Science,* 55, 941–946.

WYATT L D and GUY V (1980), 'Relationship of microbial quality of retail meat samples and sanitary conditions', *Journal of Food Protection,* 43, 385–389.

YOSHI J (1992), 'Recent trends in food packaging development in consideration of environment', *Packaging Japan,* 13(6, 7), 74–77.

8

Poultry refrigeration

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8.1 Introduction: the importance of refrigeration

Refrigeration can have an important effect on poultry even before the bird is hatched. Glatz (2001) found that layers given chilled drinking water consumed more feed and produced eggs with thicker and heavier shells than those given water at a temperature of 30ºC. After slaughter of birds, the main purpose of refrigeration is to reduce and then maintain the temperature of the meat below a value that will ensure a high-quality, safe product. There are clear differences between the environmental conditions required for cooling processes, that is, primary and secondary chilling and freezing, which are heat removal/ temperature reduction processes, and those required for subsequent stages of the cold chain, that is, chilled storage, frozen storage, transport, retail display and home storage, where the aim is to maintain a set product temperature. Many storage problems are due to a failure to remove all the required heat in the cooling process. This failure can be due to a number of causes:

- insufficient time allowed
- insufficient refrigeration capacity to cater for high initial product load
- overloading
- variation in size of product
- incorrect environmental conditions.

Attaining and maintaining the correct temperature can substantially influence product quality and it is important to maintain the correct conditions throughout the cold chain.

8.2   The effects of refrigeration on product quality

8.2.1   Flavour

Refrigeration processes can influence the cooked flavour of poultry and poultry products; however, the main effects are from storage rather than chilling or freezing.

In relation to chilling, conflicting results have been obtained. Hale and Stadelman (1969) and Hale *et al.* (1973) showed that commercially-processed, dry-chilled broilers had a subtle, but detectable flavour advantage over conventional, immersion-chilled broilers. On the other hand, Zenoble *et al.* (1977) and Pedersen (1972) found no effect of chilling on meat flavour and Ristic (1982) found that water chilling of broilers produced a more favourable flavour than air chilling for both leg and breast meat. Cryogenic chilling systems may have an effect on flavour. In a review of chilling systems, Lillard (1982) stated that improved flavour is one of the particular claims for chilling systems using liquid nitrogen or carbon dioxide. With turkeys, Brodine and Carlin (1968) investigated three chilling methods that utilised a spin chiller: one hour spin, one hour spin plus three hours in slush ice, one hour spin plus 23 h in slush ice prior to freezing. They also utilised three thawing methods: four days in a refrigerator, 10 h in cold running water and cooking from frozen. None of the chilling or thawing methods had any effect on either flavour or juiciness of cooked breast or thigh meat.

Freezing itself appears to have no effect on the aroma or flavour of poultry meat (Carlin *et al.*, 1949). However, birds that were aged and frozen tended to be less juicy than those that were aged and kept unfrozen. Freezing can cause some changes in nutritional composition. In comparison with fresh chicken skin, van Heerden *et al.* (2002) found that frozen skin had a higher mineral and vitamin A content, but a lower level of vitamin E. Medium-chain fatty acids were higher and long-chain unsaturated fatty acids were lower in frozen than in fresh chicken tissues. Cholesterol was higher in fresh than frozen fat. Carbon dioxide freezing of mechanically deboned poultry meat will reduce its frozen storage life in comparison with air-blast freezing because of increased lipid oxidation (Barbut *et al.*, 1990). When combined with aerobic storage, this method achieved a life of two months at -18ºC and vacuum packing extended it to four months. A storage life of up to five months was achieved with air-blast freezing.

Turkey roasts that had been cooked before freezing and reheated after thawing had a less intense turkey flavour and were drier than roasts that were not cooked before freezing (Cash and Carlin, 1968). Brunton *et al.* (2002) stated that cooked turkey breast is particularly susceptible to lipid oxidation-mediated 'off'-flavour development during refrigerated storage. Compared to liquid nitrogen-cooled turkey breast, the levels of a number of unsaturated carbonyl compounds were much higher in freshly cooked air-cooled samples and showed large increases in the chilled meat during storage.

8.2.2   Colour and appearance

The appearance of poultry has a substantial effect on its sales appeal, and different refrigeration processes can influence this aspect of product quality. For example, the method and speed of chilling can be critical. With 16 kg turkey carcasses, Evans *et al.* (1988) found that evaporative chilling at an air speed of 3.0 m/s and a temperature of 0ºC with spraying for 60 s at 20-minute intervals during the first half of the chilling period produced the best appearance. Chilling in air at 3.0 or 0.2 m/s and 0ºC without sprays produced birds of slightly inferior appearance. Lyon and Lyon (2002) state that discolouration of raw or cooked tissue can occur from cell disruption and blood migration caused by slow or variable chilling rates.

Pale, soft, exudative meat is a growing problem in the poultry industry and is characterised by a rapid *post mortem* pH decline (Woelfel and Sams, 2001). The low pH condition while the body temperature remains high leads to protein denaturation, causing a pale colour and reduced water-holding properties. Rapid chilling will alleviate this problem.

When frozen by liquid immersion or air-blast, Barrie *et al.* (1964) found small differences in the colour of the skin and meat of turkey hens and toms. However, flavour, juiciness and tenderness scores and shear values were similar for the two methods. Rapid freezing of poultry results in the production of very small reflective ice crystals at the surface. These give the product a light appearance that is highly desirable in some markets. Poor temperature control during storage will cause the small crystals to grow, merge and lose their lightness.

The occurrence of a dark, apparently uncooked layer, around bones in cooked poultry is a problem in the catering industry. Brant and Stewart (1950) carried out a comprehensive study of the occurrence, causes and prevention of bone darkening in frozen poultry. It was shown that freezing and thawing released haemoglobin in the bone marrow and made it possible for the pigment to penetrate the bone. Leg, thigh and coracoid bones were the most seriously affected. The occurrence and amount of blackening could not be related to the extent of bleeding, chilling method, freezing rate, temperature and length of storage or temperature fluctuations during storage. Age of bird had a significant effect, with 16 to 17-week-old birds showing less discolouration than younger birds. No discolouration was found in one-year-old birds. A combination of storage at −30ºC, rapid thawing and immediate cooking, or cooking the carcasses before freezing, reduced the discolouration.

8.2.3   Texture

Poultry meat does not require the same amount of ageing as red meat to develop its optimum texture. However, the desire for more rapid processing is producing textural problems. Also, Northcutt *et al.* (2001) showed that cooking loss was greater from chicken breast fillets excised immediately after chilling and decreased after post-chill ageing of two hours or more. Similarly, tenderness

increased when carcasses were aged in the same way. Chicken breast fillets marinated hot (less than or equal to one hour *post mortem*) were found to be tougher and drier than similarly treated breast fillets that had either been chilled in slush ice for two hours or aged at 4ºC for 24 h (Singh *et al.*, 2002). During chilling and ageing, poultry tenderises rapidly with high tenderness scores being recorded for carcasses aged for 24 h (Carlin *et al.*, 1949). Freezing was also found to markedly increase tenderness in carcasses aged for less than six hours. Where carcasses had been aged for 24 h, there was little difference in tenderness between frozen and unfrozen birds.

There are textural problems with hot boning. Contreras and Beraquet (2001) found that the average shear value was significantly lower for conventionally aged and boned birds (5.2 kg/g) than for hot-boned birds (7.9 kg/g). Sensory analysis confirmed the shear-value results. Conventionally aged and boned breasts had an average tenderness score of 7.4, compared with an average of 5.3 for hot-boned breasts. As with red meat, electrical stimulation (ES) can help to alleviate textural problems in poultry. To quote from Sams (2002)

> Post-mortem electrical stimulation (ES) is not a new technology but has only recently become a commercial possibility for use in broiler processing. In broilers, ES seeks to reduce the toughness of meat that is deboned prior to the normal ageing (or maturation) period. This is different from its previous use in red meat in which it is largely used to improve many aspects of the quality of meat that is aged on the carcass. Although many different ES techniques have been studied, the systems can be grouped into low amperage (0–200 mA per bird) and high amperage systems (350–500 mA per bird). Both types of system have been used by processors and high amperage stimulators are available from a commercial manufacturer. The low amperage systems vary in their conditions and are commonly combined with other, enhancing procedures. The low amperage systems accelerate rigor development and prevent sarcomere shortening in the breast fillet after deboning, while the high amperage systems also induce the additional effect of myofibrillar damage to further improve tenderness.

ES has also been used to reduce the ageing time of mature chickens. Dickens *et al.* (2002) electrically stimulated carcasses for 60 s with 200 V AC, one second on, then one second off, during bleeding. Fillets removed from stimulated carcasses after two hours of chilling and then cooked required over 50% less force to shear and their cooking loss was 1.8% less than that of the non-stimulated controls.

8.2.4   Weight loss

From the moment an animal is slaughtered, the meat produced begins to lose weight by evaporation. In addition to the direct loss in saleable meat, there are also secondary losses. Excessive evaporation during initial chilling and chilled

storage produces a dark, unattractive surface on the carcass or portion. Either this has to be removed by trimming, or the meat is downgraded and sold at a reduced price. Freezing does not stop weight loss. After meat is frozen, sublimation of ice from the surface occurs. Tight, shrink-wrapping will alleviate the problem while loose wrapping and temperature fluctuations will accelerate sublimation. If the degree of sublimation is excessive, the surface of the meat becomes dry and spongy, a phenomenon called 'freezer burn'.

Carcasses will lose weight during air chilling but gain in either a continuous water spray or immersion process. In air chilling, losses of 1–1.5% are common and can be 3% in badly designed equipment, while weight gains of 4–8% occur in immersion chillers (Veerkamp, 1990). In evaporative air-chilling, losses are reduced to approximately 1%. Weight loss during evaporative (intermittent sprays combined with air chilling) and air chilling at 3.0 m/s, 0ºC of 16 kg turkey carcasses was 1.1% (Evans *et al.*, 1988). Chilling in air at 0.2 m/s and 0ºC produced weight losses of approximately 2%. Veerkamp (1986) states that using sprays at five and 15 minutes during air chilling would reduce weight loss to 0.8% in broilers and the application of four to five sprays in the chilling process would eliminate any loss. Simeonovov *et al.* (1999) found average weight gains of 0.7–1.7% in the spray chilling of dressed broilers and up to 3.3% in immersion chilling. The type of immersion system used was not defined, but the authors state that the weight gains were below the European Union (EU) limit of 4.5%.

Ice formation in poultry muscles during freezing will always cause some cell disruption. Therefore, when the meat is thawed, fluid will exude from the product and collect as drip. There is a popular notion that fast freezing causes less cell disruption than slower freezing and consequently less drip on thawing. However, most of the scientific literature points to a far more complicated situation. For example, Crigler and Dawson (1968) carried out a study of the effect of freezing rate on drip and cell disruption. Poultry carcasses were chilled in slush ice for eight hours before the breast muscles were removed. Each breast was placed in a plastic bag with a thermocouple positioned at the centre of the largest muscle. Packs were frozen under different conditions to produce freezing times to a centre temperature of -5ºC ranging from 0.5–1869 minutes (approximately 31 h). Breasts were then stored at -18ºC for one to three weeks, before being thawed at 16ºC for 18 h and the amount of drip measured. Minimum drip losses of approximately 3% were observed at freezing times of 0.5 and approximately 220 minutes. Peak drip losses of approximately 8, 6.1 and 7.5% occurred at freezing times of 87, 252 and 1042 minutes, respectively. These data indicate that there are critical freezing times to aim for and others that should be avoided. However, in the experimental situation there would have been a range of freezing times throughout the breast muscles. Therefore, the rate of freezing at the centre of the muscle may not be the critical factor. The drip loss measured could be related to the average freezing rate throughout the muscle, a time-temperature integration of the freezing process or some other factor. In industrial practice, the range of freezing rates between and within

individual poultry carcasses will be far larger. It is therefore impossible to recommend a practical freezing process that will minimise drip production on thawing.

8.3   The main stages in poultry refrigeration: chilling, freezing and cooling

8.3.1   Primary chilling

Chilling is required to prevent the growth of most foodborne pathogens and delay the growth of spoilage organisms. Good overviews of the primary chilling process have been written by Thomson *et al*. (1974), Thomas (1977), Lillard (1982) and Jul (1986). Overall the choice of a chilling system is based on a combination of economic, hygienic and legislative factors and market demands.

Air, immersion and spray systems are the three most common methods of chilling dressed poultry. The term 'spray' covers a number of different options and is sometimes referred to as 'evaporative air chilling' to further confuse matters. It is thought that only one true spray-chilling system, relying on large quantities of refrigerated water (12 litres per bird), sprayed continuously on the carcasses was ever installed commercially (Leistner *et al.*, 1972). Experimental 'spray-chilling installations, using very large volumes of refrigerated water produced microbiological results comparable with those obtained in well operated controlled immersion chilling systems' (Thomas, 1977). Other spray-chilling systems rely on intermittent sprays, for example at five and 15 minutes after the start of air chilling, on four or five occasions during the whole chilling process (Veerkamp, 1986). The principle of the process is to increase the rate of evaporative heat loss and by replacing the water lost, reduce the overall weight loss. Although often called evaporative air-chilling, it should not be confused with true evaporative chilling of poultry as described by Klose (1975). In this study, poultry carcasses were placed in a vacuum chamber and the cooling rates produced were similar to those achieved in immersion systems. However, the 5% weight loss that occurred was considered too high for industrial use.

Water-immersion chilling systems were initially operated to maximise weight gain. Carcasses were immersed in water at temperatures above 12ºC, where they absorbed between 12 and 15% of their weight. They were then transferred to water at 1–2ºC to complete the chilling process. Nowadays, counter-current immersion-chilling systems are used with a maximum water inlet temperature of 4ºC. Dwell-time and degree of water agitation are controlled to limit water absorption by the carcasses. Chilling rates in an immersion system are usually far faster than those achieved in air, with spray chilling producing times in between air and immersion methods. The earliest publications on the rate of cooling emanated from Canada and the USA and were concerned with still- or blast-air cooling systems (Hannan and Shepherd, 1956). In the 1930s and 1940s wet (water immersion) cooling found favour in the USA. However, in the mid 1950s air and contact (plate) cooling of uneviscerated carcasses were the

most common industrial practices in the UK. At that time, Hannan and Shepherd (1956) carried out a comparison between typical dry, contact and wet cooling methods. Plate-contact cooling was found to be no faster than slow-moving air at 0°C. Cooling times from 40 to 10°C in the plate systems were approximately five hours for a 2.5–3.5 kg uneviscerated carcass. In slow moving air, air blast (2.5 m/s) and an ice/water mix, cooling times were 4.4, 3.1 and 2.1 h, respectively.

Chilling rates in immersion systems are a function of the cooling medium used, its temperature, the size of the carcass being chilled and whether it is wrapped or unwrapped. Typical chilling times for a range of immersion systems are given in Table 8.1. These data from Esselen *et al.* (1954) show that immersion in slush ice is far more effective than water immersion at the same temperature. In all cases, unwrapped carcasses cooled far faster than those that were wrapped, the effect of wrapping being a doubling in the cooling time in some cases. These data also clearly demonstrate the effect of carcass size on cooling time, with unwrapped broilers cooling in 55–71% of the time required for unwrapped fowls under the same conditions.

Mielnik *et al.* (1999) studied the effect of evaporative air-chilling on the quality of fresh chicken carcasses, when compared with air chilling as a reference method. Cooling efficiency and total heat loss were significantly higher for evaporative air-chilling. The chilling method affected the skin colour and the amount of moisture on the surface of the skin. After evaporative air-chilling, the carcasses had a lighter colour and more water on the back and under the wings. The moisture content in skin and meat, cooking loss, and pH were not affected by chilling method. Odour attributes of raw chicken and odour and

Table 8.1   Chilling times to 4.5°C for chicken and turkeys in different chilling environments (Esselen *et al.*, 1954)

Type of carcass and average weight	Cooling medium used	Time to chill to 4.5°C (minutes)	
		Wrapped	Unwrapped
Broiler 0.9 kg	0°C slush ice	95	50
Broiler 1.1 kg	0°C water	105	60
Broiler 1.0 kg	−5°C brine	70	27
Broiler 0.9 kg	−18°C brine	42	24
Broiler 1.3 kg	−29°C brine	35	16
Fowl 2.0 kg	0°C slush ice	190	90
Fowl 1.9 kg	0°C water	195	100
Fowl 1.6 kg	−5°C brine	105	38
Turkey Stag 2.7 kg	0°C slush ice	220	95
Turkey Stag 2.7 kg	0°C water	235	135
Turkey Stag 2.5 kg	−5°C brine	165	55
Turkey Hen 5.3 kg	−18°C brine	215	110
Turkey Hen 5.3 kg	−29°C brine	160	60
Turkey Tom 10.8 kg	−29°C brine	205	–
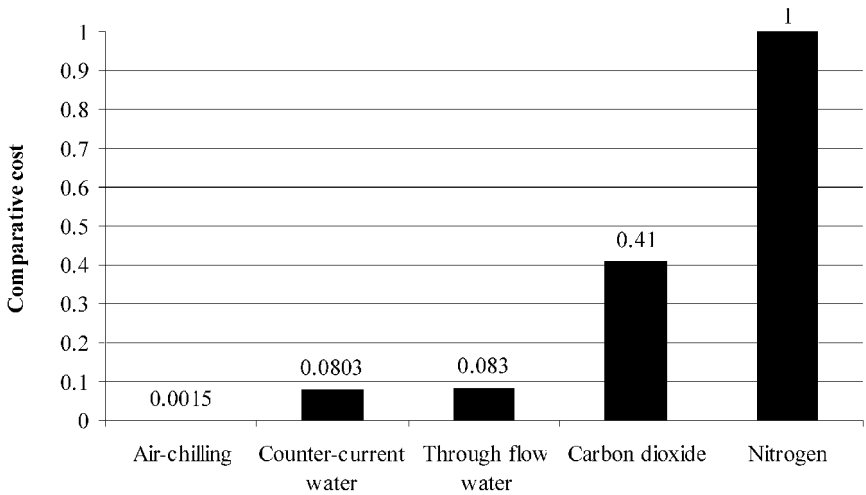
Fig. 8.1   Comparative operating costs of different chilling systems (Pedersen, 1979).

flavour attributes of cooked chicken did not show any significant differences between the two chilling methods. The shelf-life of chicken stored at 4ºC or −1ºC was not affected significantly by chilling method. Storage time and temperature appeared to be the decisive factors for sensory and microbiological quality of fresh chicken carcasses.

Calculating the operating costs of the various chilling systems is not an easy task. Pedersen (1979) calculated the relative costs of five different chilling systems. When only energy costs were considered, the cost of a counter-current water-chilling system was one fifth of an air-chilling method. However, when the costs of the water and wastewater disposal were added, the water-chilling cost was over 50 times that of the air system (Fig. 8.1). If the cost of weight loss is also included in the calculations, then the relationship changes again. A 1% weight loss was worth 0.8 units on the comparative cost scale.

Allen *et al.* (2000) carried out an evaluation of six commercial poultry chilling systems in relation to factors affecting microbial contamination of carcasses. These systems included water-immersion chilling, air chilling and air chilling with evaporative cooling, using water sprays. Samples of neck skin and body cavity were taken from carcasses, together with samples from the chilling environment. These were examined for total aerobic mesophiles, counts of presumptive coliform bacteria and *Pseudomonas* spp. The samples were taken at specific points in the chilling process. The results obtained for water-immersion chilling confirmed previous experience that the washing effect reduces microbial contamination of carcasses, although, initially, the numbers of pseudomonads tended to increase. The air chillers varied in design and mode of operation, but had little overall effect on microbial contamination of the skin. When a completely dry process was used, microbial numbers were reduced approximately ten-fold in the body cavity. However, the use of water sprays

tended to increase contamination of the cavity, while relatively heavy spraying using non-chlorinated water, resulted in a substantial increase in the numbers of pseudomonads. From similar studies, Mead *et al.* (2000) concluded that, despite the ease of microbial transmission from inoculated carcases, cross-con-tamination during air chilling is likely to be less than that occurring at earlier stages of poultry processing, when carcasses are more heavily contaminated.

8.3.2   Freezing

Poultry meat for further processing is usually frozen in the form of carcasses or bone-in and bone-out portions in cartons weighing up to 25 kg. Most bulk meat, consumer portions and other poultry products are frozen in air-blast freezers. Some small, individual items, such as chicken burgers, may be frozen in cryogenic tunnels and a small amount of offal, mechanically recovered meat and other meat is frozen in plate freezers. It is not unusual for poultry meat to be frozen twice before it reaches the consumer. During industrial processing, frozen raw material is often thawed or tempered before being turned into pies, convenience meals, burgers, etc. or consumer portions, such as breast fillets. These consumer-sized portions are often refrozen before storage, distribution and sale.

The early work of DuBois *et al.* (1942) on air freezing of poultry carcasses showed that different freezing conditions could result in freezing times from less than five to over 35 hours (Fig. 8.2). The different freezing rates resulted in substantial differences in the ice-crystal structure in the muscle tissue. However, when the meat was roasted, taste panels detected 'no easily discernable difference in flavour, aroma or texture between the two extremes'. The taste
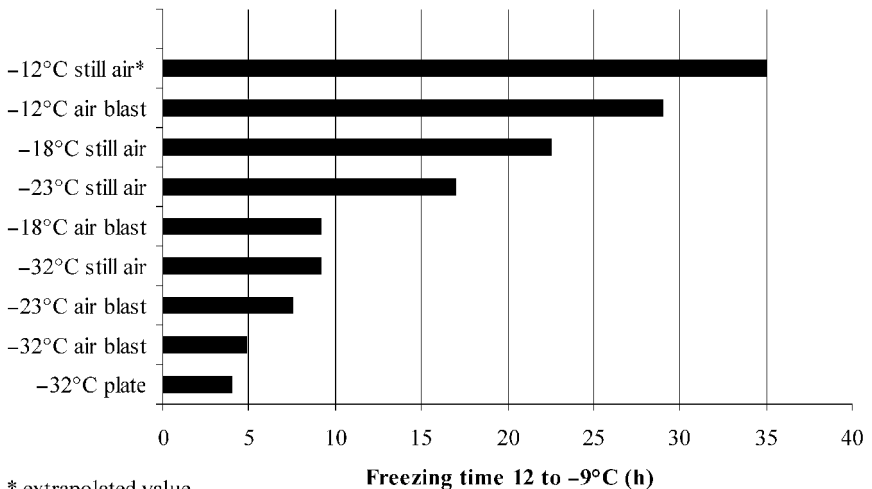
* extrapolated value

Fig. 8.2   Freezing time of 2.3 kg chicken carcasses under different freezing regimes (DuBois *et al.*, 1942).

Table 8.2   Freezing times to −9.5ºC for chicken and turkeys in different freezing environments (Esselen *et al.*, 1954)

Type of carcass and average weight	Cooling medium used	Time to freeze to −9.5ºC (minutes)	
		Wrapped	Unwrapped
Broiler 0.9 kg	−18ºC brine	135	55
Broiler 1.3 kg	−29ºC brine	85	35
Turkey Hen 5.3 kg	−18ºC brine	500	280
Turkey Hen 5.3 kg	−29ºC brine	290	140
Turkey Tom 10.8 kg	−29ºC brine	425	−

panel results showed no real differences between any of the freezing treatments and the unfrozen controls. In at least one example, the scores for aroma, texture, flavour, tenderness, juiciness or overall quality were better from a frozen than an unfrozen product.

Immersion freezing (Table 8.2) is far faster than can be achieved in air-freezing systems (Fig. 8.3). In air-blast freezing of chicken carcasses, both air temperature and air velocity have a substantial effect on freezing time, as shown in Figs 8.3 and 8.4 (van den Berg and Lentz, 1958). However, the small reduction in freezing time achieved by increasing the air velocity above 4 m/s would not normally compensate for the increased energy cost. Similarly, use of air temperatures below −40ºC is not commercially viable. Bishop (1972) stated that, under optimum freezing conditions (air at −40ºC, velocity 2.5–3.5 m/s), a 1.5 kg poultry carcass can be frozen in less than three hours. The study showed
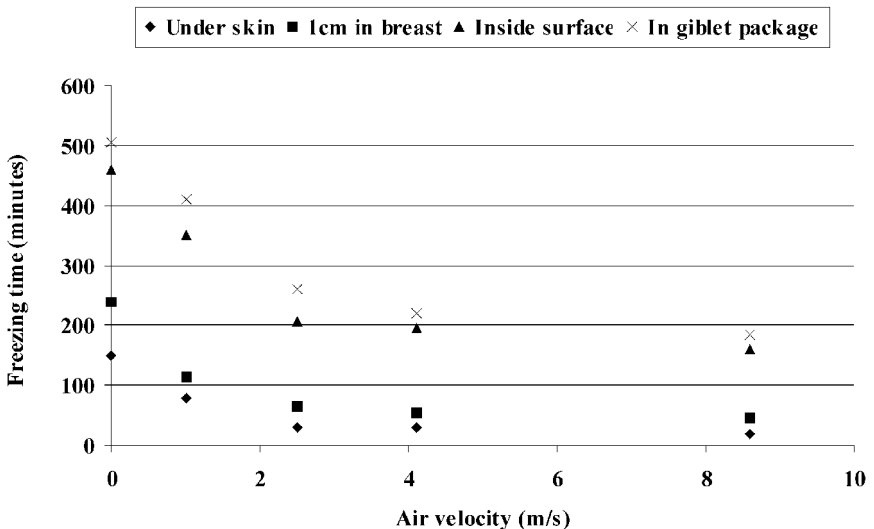
Fig. 8.3   Freezing of 3 kg poultry carcasses from 0 to −4ºC in air at −20ºC (van den Berg and Lentz, 1958).
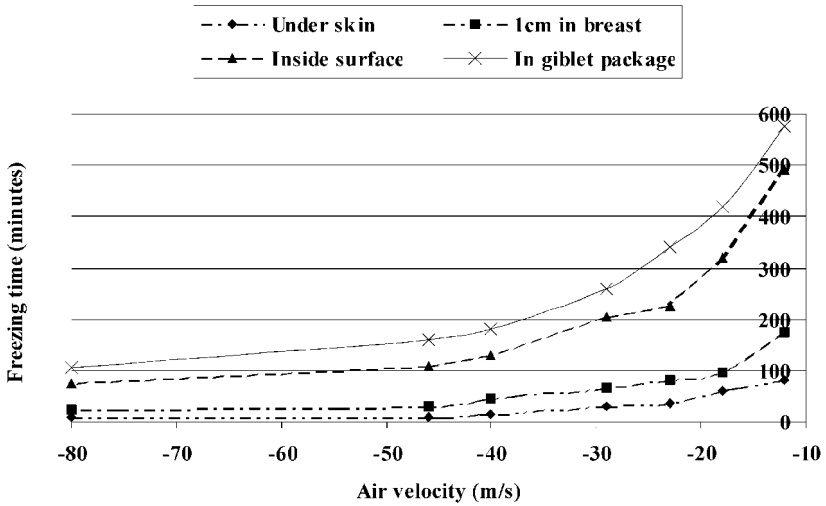
Fig. 8.4   Freezing of 3 kg poultry carcasses from 0 to -4ºC in air at $2\,\mathrm{ms}^{-1}$ (van den Berg and Lentz, 1958).

an interesting design for a large-scale air-blast freezer. Cardboard cartons, each containing 10 carcasses were loaded onto racks holding 56 cartons. The racks were suspended on a slightly inclined rail and passed slowly by gravity through a chamber operating at -40ºC. After passing through the chamber, the racks were unloaded and then slightly elevated. The empty racks were then returned to the starting point by gravity.

8.3.3   Secondary cooling

Poultry carcasses must be chilled immediately after dressing. It is critical that the average temperature of the carcass is reduced below 4ºC and preferably to a temperature approaching 0ºC during primary processing. Any subsequent handling process such as cutting, mixing or tumbling will add heat to the meat and increase its temperature. A secondary cooling operation is therefore required with all raw poultry products to reduce their temperature to approaching 0ºC and maintain their storage life.

Rapid cooling is also required after cooking of poultry to prevent growth of any surviving microbes. There is little published data on the cooling of cooked whole carcasses or poultry portions. Darlington (1987) carried out some studies on the air chilling of cooked whole chickens (approximate uncooked weight 1 kg) and produced charts for cooling times. The charts cover all temperatures that avoided surface freezing and air velocities of 'calm air', 0.6, 1.3, 2.5 and 4.5 m/s, respectively. The use of an initial ambient-temperature cooling stage was also investigated experimentally and it was claimed that the total cooling time from 85ºC to 4ºC was two to two and a half hours. Cooling times for larger (6.4 kg), whole, boneless turkeys were much longer (Burfoot *et al.*, 1990).

Cooling from 85ºC to 10ºC took almost nine hours in air at 0ºC, velocity 1.2 m/s; almost seven hours in iced water and 36 minutes in a vacuum cooler. Although the vacuum cooler was substantially faster, weight losses approached 8%, almost four times greater than in air. In a cured, cooked poultry product, bologna (70% chicken), populations of *Clostridium perfringens* remained relatively unchanged during chilling from 54.4ºC to 7.2ºC and declined slightly during refrigerated storage under vacuum at 4.4ºC (Taormina *et al.,* 2003).

8.4   The storage and transportation of chilled poultry meat

Extensive data are available on the attainable chilled-storage lives (time) for many products (Table 8.1). In most cases, the limiting factors that control the storage life of chilled poultry meat are those affecting microbial growth. 'Off' odours and slime caused by microorganisms are detected when populations reach approximately 10^7 to 10^8 organisms/cm^2. Temperature is the principal factor affecting the rate of microbial growth and hence the storage life of chilled meat, as discussed in Chapter 13. Bailey *et al.* (2000) carried out storage trials on half poultry carcasses at temperatures between 4ºC and −18ºC. Counts of mesophilic bacteria per ml of rinse liquid were about log 4.6 on day zero, increased by 2 logs after seven days on carcasses held at 4ºC, and were unchanged at all other storage temperatures. Psychotroph counts/ml were about log 3.6 on day zero and increased during the first seven days by about 3.9, 1.9 and 1.4 logs, respectively, on carcasses held at 4ºC, 0ºC and −4ºC. There was less than a one log increase at −12ºC and −18ºC. Coliform counts were about log 2.2/ml on day zero and had declined to about log 1.5/ml or less by day 7 for all storage temperatures. *Escherichia coli* counts/ml were about log 2 on day zero and were reduced about one log or more at all temperatures on other storage days.

In the USA (Jul, 1986), extensive use is made of 'deep' or 'super' chilling techniques in which carcasses are stored and distributed at −1ºC to −2ºC. (Veerkamp (1990) gives a temperature range of −2ºC to −4ºC). At these temperatures, a shelf-life of five weeks is achieved. To reach such temperatures, after a water chilling process, the carcasses are placed in a blast freezer operating at approximately −15ºC for 30 minutes. They are then packed and passed through the freezer again to reach the desired, final average temperature.

The factors that influence the storage life of frozen poultry meat may act at any one of three stages: prior to freezing, during the actual freezing process and post-freezing in the storage period itself. As long as the temperature is maintained below −12ºC, it will be quality considerations rather than microbial factors that will limit storage life. The importance of fat oxidation in frozen meat is illustrated by a short quotation from a paper published by Lea (1931): 'it is often the deterioration of the fat which limits the storage life – from the point of view at least of palatability – of the meat'. This view has been reiterated many times and, as freezing technology has improved, it is true to say that fat oxidation remains the obstacle to very long-term storage of frozen meat.

Treating chicken breasts with 10% trisodium phosphate and sodium tripolyphosphate solution significantly reduced drip and cooking losses, as well as minimising ice-crystal formation and freeze-induced shrinkage of myofibrils after ten months of storage at −20ºC (Yoon, 2002). No significant toughening was observed. The water-binding ability of the meat was the most important factor in maintaining meat quality during extended frozen storage.

Long-distance transportation of chilled or frozen poultry, or poultry products, is now well organised. Most International Standards Organisation containers for food transport are either 6 or 12 m long, hold up to 26 tonnes of product and can be 'insulated' or 'refrigerated' (Heap, 1986). The refrigerated containers incorporate insulation and have refrigeration units built into their structure. The units operate electrically, either from an external power supply on board ship, at the dock or from a generator on a road vehicle. Insulated containers utilise either plug-type refrigeration units or may be connected directly to an air-handling system in a ship's hold or at the docks. Close temperature control is most easily achieved in containers that are placed in insulated holds and connected to the ship's refrigeration system. However, suitable refrigeration facilities must be available for any overland sections of the journey. When the containers are fully loaded and the cooled air is forced uniformly through the spaces between cartons, the maximum difference in temperature between delivery and return air can be less than 0.8ºC. The entire amount of product in a container can be maintained to within ±1.0ºC of the set point.

Refrigerated containers are easier to transport overland than the insulated types, but often have to be carried on deck when shipped because of problems in operating the refrigeration units within closed holds. On board ship, they are therefore subjected to much higher ambient temperatures and consequently larger heat gains, which make it far more difficult to control product temperature. For bulk transportation of frozen meat, refrigerated cargo-ships are commonly used (Heap, 1997). Frozen meat is generally stored and transported at −18ºC or below. Unlike the situation with chilled poultry, small temperature changes during loading and unloading can be tolerated with frozen meat.

Overland transportation systems range from 12 m long refrigerated containers for long-distance road or rail movement of bulk chilled or frozen products to small non-insulated vans supplying food to local retail outlets or even directly to the consumer. Some of the first refrigerated road and rail vehicles for chilled products were cooled by air that was circulated by free or forced systems over large containers of ice (Ciobanu, 1976). Similar systems, using solid carbon dioxide as the refrigerant, have also been used for cooling of transport vehicles. However, most overland vehicles for long-distance transport are now refrigerated by different means. The majority of current road-transport vehicles for chilled foods are refrigerated using either mechanical, eutectic-plate or liquid-nitrogen cooling systems. Irrespective of the type of refrigeration equipment used, the product will not be maintained at its desired temperature during transportation unless it is surrounded by air or surfaces that are at or below the temperature in question. This is usually

achieved by a system that circulates moving air, either forced or by gravity, around the load. Inadequate air distribution is probably the principal cause of product deterioration and loss of shelf-life during transport. Conventional forced-air units usually discharge air over the stacked or suspended products, either directly from the evaporator or through ducts towards the rear cargo doors. Because air takes the path of least resistance, it circulates through the channels that have the largest cross-sectional area. These tend to be around rather than through the product. If products have been cooled to the correct temperature before loading and do not generate heat, then they only have to be isolated from external heat ingress. Surrounding them with a blanket of cooled air achieves this purpose. Care has to be taken during loading to avoid any contact between the product and the inner surfaces of the vehicle, because this would allow heat ingress during transport. Many trucks are now constructed with an inner skin that forms a return air duct along the sidewalls and floor, with the refrigerated air being supplied via a ceiling duct.

In a 1970–71 survey of vehicles used to transfer chilled meat from small abattoirs to shops, almost 70% were found to be unrefrigerated and 20% had no insulation (Cutting and Malton, 1972). The non-insulated vehicles were mostly 10 cwt (0.5 ton) delivery vans, with no partition between driver and load. Since that time, the intensifying demand from legislation and retailers for lower delivery temperatures has put increasing pressure on fleet operators to improve temperature control. However, there are substantial difficulties in maintaining the temperature of chilled foods transported in small-refrigerated vehicles that conduct multi-drop deliveries to retail stores and caterers. The vehicles have to carry a wide range of products and operate under diverse ambient conditions. During any one delivery run, the chilled product can be subjected to as many as 50 door openings, causing heat ingress directly from the outside and from personnel entering the vehicle to select and remove product. The design of the refrigeration system has to allow for extensive differences in load distribution, dependent on different delivery rounds, days of the week and removal of product during a delivery run. The ability of a refrigeration system to respond to sudden demands for increased refrigeration is often restricted by the power available from the vehicle. All these problems combine to produce a complex interactive system.

Projects recently completed by the author's research centre have produced predictive models that will assist cold-store operators and transport-fleet operators in specifying the design of refrigeration equipment for chilled- and frozen-product stores and small delivery vehicles (Gigiel and James, 1998; Evans, 2003).

8.4.1   Retail display and consumer handling

In general, display cabinets have to accommodate three types of meat and meat products: (1) chilled, wrapped, (2) chilled, unwrapped and (3) frozen, wrapped products. The required display life and consequent environmental conditions for wrapped, chilled products differ from those for unwrapped products. The desired

chilled display life for wrapped meat and meat products ranges from a few days to many weeks and is primarily limited by microbiological considerations. Retailers of unwrapped meat and delicatessen products, such as sliced meats and pâté, normally require a display life of one working day. Frozen products can remain on display for many weeks. Surveys carried out in a number of EU countries revealed retail display cabinets to be the weakest link in the chill chain (Malton, 1972; Moerman, 1972; Bøgh-Sørensen, 1980; Lyons and Drew, 1985).

To achieve the display life required for wrapped, chilled poultry the product should be maintained at a temperature as close to its initial freezing point, −1.5ºC as possible. Maintaining product temperature in the range −1ºC to 0ºC is the stated aim of at least one manufacturer of multi-deck display cases for wrapped meats (Brolls, 1986).

Air movement and relative humidity (RH) have little effect on the display life of a wrapped product, but the degree of temperature control can be important, especially with transparent, controlled-atmosphere packs. During any control cycle, the cabinet temperature rises, heat enters the pack and the atmosphere inside the pack warms with consequent reduction in RH and an increase in the surface temperature of the product. As the surface temperature rises, so does its saturation vapour pressure (a factor controlling evaporation) and more water evaporates into the sealed atmosphere of the pack. If the cabinet temperature were stabilised, then evaporation would continue until the atmosphere became saturated. In practice, however, the cabinet air temperature cycles and, as it is reduced, the wrapping film is cooled. If it reaches a temperature below the dew point of the atmosphere inside the pack, then water vapour will condense on the inner surface of the pack. This film of water can obscure the product and consequently reduce consumer appeal. As the temperature-cycling process continues, the appearance of the product deteriorates.

As with wrapped poultry, it has been recognised for many years that temperatures close to the initial freezing point are required to provide a long display life for unwrapped meat. Changes in appearance are normally the criteria that limit display of unwrapped products, rather than microbiological considerations. Deterioration in the appearance of unwrapped meats has been related to the degree of dehydration, which makes the product unattractive to consumers (James and Swain, 1986). The rate of dehydration is a function of the temperature, velocity and RH of the air passing over the surface of the food. James and Swain (1986) found that changes in RH had a substantial effect, with a reduction from 95% to 40% increasing weight loss over a six-hour display period by a factor of between 14 and 18. The effect of air velocity on weight loss was confounded by that of RH. Raising the air velocity from 0.1 m/s to 0.5 m/s had little effect on the weight loss at 95% RH; however, the magnitude of the effect increased as RH decreased, producing maximum changes at 40% RH. On changing the temperature from 2ºC to 6ºC, the effect on weight loss was far smaller than the changes in RH or air velocity.

Studies carried out at the author's research centre also showed that RH was the main factor controlling weight loss during the display life of delicatessen

products. At a RH of 40%, the effect of surface drying became apparent after approximately 100 minutes. At 85% RH, the products could be displayed for between four to six hours before surface drying could be observed. The overall weight loss at 40% RH was approximately three times that at a RH of 85%. In the same work, it was also found that changing the lighting combination of 50 W sons and 100 W halogen lights to 100 W sons and a colour 83 fluorescent lighting significantly increased weight loss. The increase was similar in magnitude to that produced by a 20% reduction in RH. On average, the rate of weight loss under the combination of 50 W sons and 100 W halogen (spot) lights was approximately 1.4 times less than with the 100 W sons and colour 83 fluorescent lighting.

The past decade has seen a considerable increase in legislation defining maximum temperatures during the production, distribution and retailing of chilled food. However, as soon as the consumer purchases the food, it is outside any of these legislative requirements. Increasingly, food poisoning incidents have been found to be due to mishandling of food in the home, with insufficient refrigeration or cooling being the most frequent factor causing disease (WHO, 1992). Out of the 1562 cases of food poisoning reported in England and Wales during 1986 to 1988, 970 (62%) were caused in the home (Public Health Laboratory Service Communicable Disease Surveillance Centre).

It is well known that unprotected, chilled food will warm up during transportation to the home. Survey results (James and James, 2002) showed that consumers took, on average, 43 minutes to bring meat, fish or dairy items home from the shops and place them in a refrigerator. Although insulated bags and boxes are widely sold, only a small percentage (12.7%) of shoppers used them to transport some of their food home. The vast majority (87.3%) did not use any means of protecting food from temperature gains during transportation. Some of the meat-product temperatures in samples placed in a car boot rose to around 30ºC during a one-hour car journey, whilst most of the samples placed in an insulated box cooled during the car journey, except for a few at the top of the box, which remained at their initial temperature. The temperature of frozen products (starting at −25ºC), both placed in the cold box and held at ambient temperature in the car boot, rose during the one-hour journey. Chicken carcasses and meat pies placed in the car boot reached temperatures approaching 10ºC. Frozen meat products in the cold box kept below −10ºC for the period of the journey.

In the past decade, there have been at least eight surveys of temperatures in domestic refrigerators (James, 2003). The results are very similar (Table 8.3), with overall mean temperatures ranging from 4.5ºC to 6.6ºC and maximum temperatures from 11ºC to 14ºC. These results are worrying since they imply that the average temperature of at least 50% of domestic refrigerators is above 4.5ºC. When we look at the percentage of temperatures measured that were above set points, the results are even more worrying. In the last French study, 80% of the temperatures were above 5ºC and in the Greek work, 50% were above 9ºC. The ongoing investigation of Jackson (2003) has shown that only

Table 8.3 Temperatures measured in eight surveys of domestic refrigerators in homes (James, 2003)

Reference	Country	Number of samples	Measurement	T_{min}	T_{mean}	T_{max}	% $> x$ºC
Flynn et al. (1992)	Northern Ireland	150	Thermometer (3 levels: T, M, B)	0.8	6.5	12.6	71% > 5ºC
James and Evans (1992)	U.K	252	Data logger (3 levels: T, M, B)	0.9	6.0	11.4	23% > 7ºC
Victoria (1993)	France	102	Thermometer (3 levels: T, M, B)			14	70% > 6ºC
De Lezenne Coulander (1994)	The Netherlands	125	Thermometer				70% > 5ºC
O'Brien (1997)	New Zealand	50	Thermometer (2 levels: T, B)	0	4.9	11	60% > 4ºC
Sergelidis et al. (1997)	Greece	136	Thermometer				50% > 9ºC
Laguerre et al. (2002)	France	119	Data logger (3 levels: T, M, B)	0.9	6.6	11.4	80% > 5ºC
Jackson (2003)	Northern Ireland	30	Data logger (1 level M)	-5	4.5	13.0	53% > 5ºC
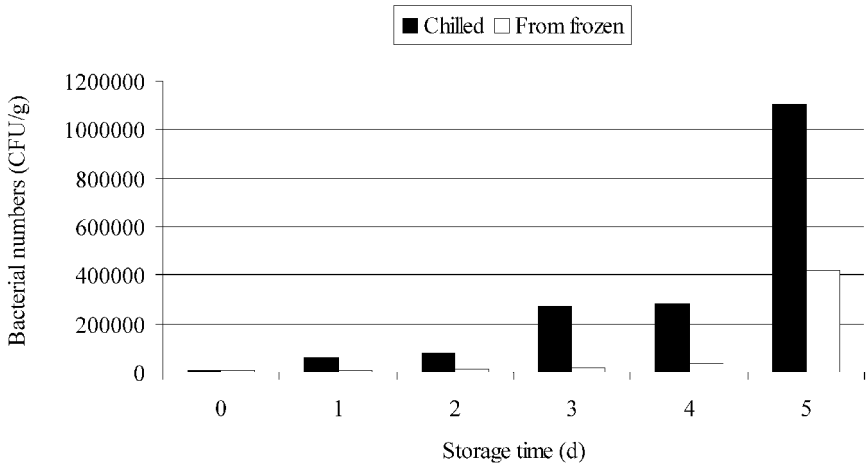
Fig. 8.5   Increase in bacterial numbers on chilled and frozen turkey steaks stored in a domestic refrigerator (Conner *et al.*, 1953).

17% of refrigerators were below 5ºC and 20% operated above this temperature for the entire week of monitoring.

After five days of storage in a domestic refrigerator, microbial numbers on fresh turkey steaks had risen from 5×10^3 to over 1×10^6 cfu/g (Fig. 8.5). Numbers on frozen steaks that had been thawed and stored in the same refrigerator had reached 4.2×10^5 cfu/g after five days.

8.5   Sources of further information and advice

International Institute of Refrigeration, 177 Boulevard Malesherbes, F-75017 Paris, France. Tel.: +33 1 4227 3235. http://www.iifiir.org.

Food Refrigeration and Process Engineering Research Centre (FRPERC), University of Bristol, Churchill Building, Langford, North Somerset BS40 5DU. www.frperc.bris.ac.uk.

8.6   References

ALLEN V M, CORRY J E L, BURTON C H, WHYTE R T and MEAD G C (2000), 'Hygiene aspects of modern poultry chilling', *International Journal of Food Microbiology,* 58, 39–48.

BAILEY J S, LYON B G, LYON C E and WINDHAM W R (2000), 'The microbiological profile of chilled and frozen chicken', *Journal of Food Protection,* 63, 1228–1230.

BARBUT S, KAKUDA Y and CHAN D (1990), 'Research note: Effects of carbon dioxide freezing and vacuum packaging on the oxidative stability of mechanically deboned poultry meat', *Poultry Science*, 69, 1813–1815.

BARRIE P J, GOERTZ G E and FRY J L (1964), 'Acceptability of blast frozen and liquid frozen

turkey hens and toms', *Food Technology* 18, 163–165.

BISHOP E (1972), 'Poultry freezing', *Refrigeration and Air Conditioning,* 75, 37–40, 85.

BØGH-SØRENSEN L (1980), 'Product temperature in chilled cabinets', *Proceedings of the 26th European Meeting of Meat Research Workers, Colorado, USA,* Chicago, American Meat Science Association, Paper no. 22.

BRANT A W and STEWART G F (1950), 'Bone darkening in frozen poultry', *Food Technology*, 4, 168–174.

BRODINE M V and CARLIN A F (1968), 'Chilling and thawing methods and their effect on quality of cooked whole turkeys', *Food Technology*, 22, 73–76.

BROLLS E K (1986), 'Factors affecting retail display cases', *Recent Advances and Developments in the Refrigeration of Meat Chilling*, Paris, International Institute of Refrigeration, Section 9, 405–413.

BRUNTON N P, CRONIN D A and MONAHAN F J (2002), 'Volatile components associated with freshly cooked and oxidized off-flavours in turkey breast meat', *Flavour Fragrance Journal*, 17, 327–334.

BURFOOT D, SELF K P, WILKINS T J and JAMES S J (1990), 'Effect of cooking and cooling method on the processing times, mass losses and bacterial condition of large meat joints', *International Journal of Food Science and Technology,* 25, 657–667.

CARLIN A F, LOWE B and STEWART G F (1949), 'The effect of ageing versus ageing, freezing and thawing on the palatability of eviscerated poultry', *Food Technology,* 3, 156–159.

CASH D B and CARLIN A F (1968), 'Quality of frozen boneless turkey roasts precooked to different internal temperatures', *Food Technology*, 22, 143–146.

CIOBANU A (1976) 'The cold chain', in *Cooling Technology in the Food Industry*, ed. Ciobanu A, Lascu G, Bercescu V and Niculescu L, Tunbridge Wells, Kent, Abacus Press, 477–498.

CONNER J W, SNYDER E S, MacDOUGALL D and ORR H L (1953), 'Experiments with the preparation and storage of turkey steaks', *Poultry Science*, 32, 208–216.

CONTRERAS C C and BERAQUET N J (2001), 'Electrical stunning, hot boning, and quality of chicken breast meat', *Poultry Science,* 80, 501–507.

CRIGLER J C and DAWSON L E (1968), 'Cell disruption in broiler breast muscle related to freezing time', *Journal of Food Science*, 33, 248–250.

CUTTING C L and MALTON R (1972), 'Recent observations on UK meat transport', *Proceedings of the Meat Research Institute Symposium, 'Meat Chilling – Why & How'*, Langford, UK, Meat Research Institute, 24.1–24.11

DARLINGTON R (1987), 'Application of research results to the improvement of food engineering processes. Case study No. 3. Cooling of cooked meat products', British Food Manufacturers and Related Industries Research Association Research Report No. 682. Leatherhead, UK, Leatherhead Food Research Association.

DE LEZENNE COULANDER P A (1994), 'Koelkast temperature thuis', Report of the Regional Inspectorate for Health Protection, Leeuwarden, The Netherlands.

DICKENS J A, LYON C E and BUHR R J (2002), 'The effects of electrical stimulation during bleeding on shear values and cook loss of breast fillets from mature chickens deboned at two or twenty-four hours post-evisceration', *Journal of Applied Poultry Research*, 11, 111–116.

DUBOIS C W, TRESSLER D K and FENTON F (1942), 'The effect of the rate of freezing and temperature of storage on the quality of frozen poultry', *Refrigeration Engineering*, 44, 93–99, 111.

ESSELEN W B, LEVINE A S, PFLUG I J and DAVIS L L (1954), 'Brine immersion cooling and

freezing of ready to cook poultry', *Refrigeration Engineering*, 62, 61–63.

EVANS J A (2003), 'Computer model with crystal ball', *Air Conditioning and Refrigeration Today*, June, 17.

EVANS J A, MacDOUGALL D B, GREY T C and GIGIEL A J (1988), 'Preliminary design data on turkey chilling', Institute of Food Research – Bristol Laboratory Chemical Engineering Group Industrial Report. Bristol, Food Refrigeration and Process Engineering Research Centre.

FLYNN O M, BLAIR I and MCDOWELL D (1992), 'The efficiency and consumer operation of domestic refrigerators', *International Journal of Refrigeration* (5), 307–312.

GIGIEL A J and JAMES S J (1998), 'Modelling chilled food distribution', *Advances in the Refrigeration Systems, Food Technologies and Cold Chain*, Paris, International Institute of Refrigeration, 591–598.

GLATZ P C (2001), 'Effect of cool drinking water on production and shell quality of laying hens in summer', *Asian and Australian Journal of Animal Science,* 14, 850–854.

HALE K K and STADELMAN W J (1969), 'Flavour differences between wet-chilled and dry-chilled broilers', *Poultry Science,* 48, 1814–1815.

HALE K K, STADELMAN W J and BRAMBLETT V D (1973), 'Effect of dry-chilling on the flavour of fried chicken', *Poultry Science,* 52, 244–252.

HANNAN R S and SHEPHERD H J (1956), 'Cooling of the uneviscerated poultry carcass by various methods in common use', Department of Science and Industrial Research Food Investigation Technical Paper no. 4. London, Her Majesty's Stationery Office.

HEAP R D (1986), 'Container transport of chilled meat', *Recent Advances and Developments in the Refrigeration of Meat Chilling*, Paris, International Institute of Refrigeration, 505–510.

HEAP R D (1997), 'Chilling during transport, including control', *World Congress on Food Hygiene, Proceedings*, Wageningen, Netherlands, 51–55.

JACKSON V (2003), 'Food safety knowledge and practices in Irish homes', PhD Thesis in preparation. University of Ulster at Jordanstone.

JAMES S J (2003), 'Developments in domestic refrigeration and consumer attitudes', *Bulletin International Institute of Refrigeration*, 5, 4–17.

JAMES S J and EVANS J A (1992), 'Consumer handling of chilled foods: temperature performances', *International Journal of Refrigeration*, 5, 299–306.

JAMES S J and JAMES C (2002), *Meat Refrigeration*, Cambridge, Woodhead Publishing.

JAMES S J and SWAIN M V L (1986), 'Retail display conditions for unwrapped chilled foods', *The Proceedings of the Institute of Refrigeration* London, Institute of Refrigeration, 83, Session 1986–87, 3.1.

JUL M (1986), 'Chilling broiler chicken: an overview', *Recent Advances and Developments in the Refrigeration of Meat by Chilling,* Paris, International Institute of Refrigeration, 133–144.

KLOSE A A (1975), 'Perspective on evaporative chilling of poultry', *Poultry Science,* 54, 1889–1893.

LAGUERRE O, DERENS E and PALAGOS B (2002), 'Study of domestic refrigerator temperature and analysis of factors affecting temperature: a French survey', *International Journal of Refrigeration,* 25, 653–659.

LEA C H (1931), 'Chemical changes in the fat of frozen and chilled meat', *Journal of the Society of Chemical Industry*, 50, 207T.

LEISTNER L, ROSSMANITH E and WOLTERSDORF W (1972), 'Rationalising the spray method of chilling poultry', *Fleischwirtschaft*, 52, 362–364.

LILLARD H S (1982), 'Improving chilling systems for poultry', *Food Technology,* February, 58–67.

LYON B G and LYON C E (2002), 'Colour of uncooked and cooked broiler leg quarters associated with chilling temperature and holding time', *Poultry Science*, 81, 1916–1920.

LYONS H and DREW K (1985), 'A question of degree', *Food,* December, 15–17.

MALTON R (1972), 'Observations on refrigerated display cabinets in the UK', *Meat Chilling: Why and How? Meat Research Institute Symposium No. 2* (Ed. C L Cutting), Langford, UK, Meat Research Institute, 29.1–29.11.

MEAD G C, ALLEN V M, BURTON C H and CORRY J E L (2000), 'Microbial cross-contamination during air chilling of poultry', *British Poultry Science,* 41, 158–162.

MIELNIK M B, DAINTY R H, LUNDBY F and MIELNIK J (1999), 'The effect of evaporative air chilling and storage temperature on quality and shelf-life of fresh chicken carcasses', *Poultry Science*, 78, 1065–1073.

MOERMAN P C (1972), 'Experience with refrigerated display cabinets and prefabricated butchers chillrooms', *Meat Chilling: Why and How? Meat Research Institute Symposium No. 2* (Ed. C L Cutting), Langford, UK, Meat Research Institute, 28.1–28.7.

NORTHCUTT J K, BUHR R J, YOUNG L L, LYON C E and WARE G O (2001), 'Influence of age and postchill carcass ageing duration on chicken breast fillet quality', *Poultry Science,* 80, 808–812.

O'BRIEN G D (1997), 'Domestic refrigerator air temperatures and the public's awareness of refrigerator use', *International Journal of Environmental Health Research,* 7, 141–148.

PEDERSEN R (1972), 'Immersion chilling fresh chickens. Organoleptic characteristics, shelf-life and determination of water uptake', Landbrugsministeriets Slagteri- og Konserveslaboratorium, Report No. 230, Copenhagen.

PEDERSEN R (1979), 'Advantages and disadvantages of various methods for the chilling of poultry', Landbrugsministeriets Slagteri- og Konserveslaboratorium, Report No. 189, Copenhagen.

RISTIC M (1982), 'Influence of the water cooling of fresh broilers on the shelf life of poultry parts at −15ºC and −21ºC', *Lebensmittel-Wissenschaft und -Technologie*, 15, 113–116.

SAMS A (2002), 'Post-mortem electrical stimulation of broilers', *World's Poultry Science Journal,* 58, 147–157.

SERGELIDIS D, ABRAHIM A, SARIMVEI A, PANOULIS C, KARAIOANNOGLOU P and GENIGEORGIS C (1997), 'Temperature distribution and prevalence of Listeria spp. in domestic, retail and industrial refrigerators in Greece', *International Journal of Food Microbiology,* 34, 171–177.

SIMEONOVOV J, INGR I, JELINKOVA D, BOZEK, R and MIKA O (1999), 'Water absorption at two processes of broiler chilling', *Czechoslovakian Journal Animal Science,* 44, 2, 93–96.

SINGH R P, YADAV A S and VERMA S S (2002), 'Effect of filleting and marination processes on the quality of roasted chicken breast fillets', *Journal of Food Science and Technology – Mysore*, 39, 2, 155–157.

TAORMINA P J, BARTHOLOMEW G W and DORSA W J (2003), 'Incidence of Clostridium perfringens in commercially produced cured raw meat product mixtures and behaviour in cooked products during chilling and refrigerated storage', *Journal of Food Protection*, 66, 72–81.

THOMAS N L (1977), 'The continuous chilling of poultry in relation to EEC requirements', *Journal of Food Technology*, 12, 99–114.

THOMSON J E, WHITEHEAD W K and MERCURI A J (1974), 'Chilling poultry – meat a literature review', *Poultry Science*, 53, 1263–1281.

VAN DEN BERG L and LENTZ C P (1958), 'Factors affecting freezing rate and appearance of eviscerated poultry frozen in air', *Food Technology*, 12, 183–185.

VAN HEERDEN S M, SCHONFELDT H C, SMITH M F and VAN RENSBURG D M J (2002), 'Nutrient content of South African chickens', *Journal of Food Compositional Analysis*, 15, 47–64.

VEERKAMP C H (1986), 'Control of weightloss by evaporative air chilling', *Recent Advances and Developments in the Refrigeration of Meat by Chilling,* Paris, International Institute of Refrigeration, 101–105.

VEERKAMP C H (1990), 'Chilling of poultry and poultry products', *COST 91bis 'Chilled Foods – The State of the Art',* London, Elsevier Science Publishers, 147–158.

VICTORIA R (1993), 'Ne joues pas avec le froid', *50 Millions de Consommateur*, 267, 36–37.

WHO (1992), WHO Surveillance Programme for Control of Foodborne Infections and Intoxication in Europe, Fifth Report, 1985–1989.

WOELFEL R L and SAMS A R (2001), 'Marination performance of pale broiler breast meat', *Poultry Science,* 80, 1519–1522.

YOON K S (2002), 'Texture and microstructure properties of frozen chicken breasts pretreated with salt and phosphate solutions', *Poultry Science*, 81, 1910–1915.

ZENOBLE O C, ROBERTS J A and CUNNINGHAM F E (1977), 'Eating quality of spent hens processed with and without immersion chilling', *Poultry Science*, 56, 843–845.

9

Other poultry preservation techniques

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9.1   Introduction

Fresh meat is perishable, since it contains all the nutrients required by spoilage bacteria, the pH is not inhibitory and it has abundant free water. Storing meat after slaughter represents a challenge to meat processors, retailers and consumers. If proper storage conditions (for example, refrigeration) or other preservation methods (for example, heating, irradiation) are not used, the meat will spoil within a matter of hours or days. In areas where refrigeration is not available, poultry is marketed live and slaughtered immediately prior to consumption. In areas where refrigeration is available, modern procedures, such as use of the Hazard Analysis Critical Control Point (HACCP) system, ensure low microbial counts and consumer safety.

   The history of food preservation methods employed by humans is very long. Thousands of years ago, people were already using different methods, without necessarily understanding the scientific principles behind them. Some historians recognise two major periods in relation to food consumption. The first is the food-gathering phase, which covers the time between ten thousand and over one million years ago, when humans first appeared on the planet. The second is the food-producing phase that still continues today (Jay, 2000). It appears that food spoilage problems were encountered early in the second phase, when people started to produce and store their own food for extended periods. Spoilage problems and foodborne disease caused by improper handling and storage have required some innovative solutions. Drying was one of the earliest methods employed to treat foods like grain and fruits, but was also used to preserve meat. Some cultures discovered that drying and smoking meat over a fire could substantially extend the shelf-life of the product. Later, fermentation of grain

resulted in the production of beer, which can be traced back to ancient Babylonia at around 7000 BC. The Samaritans were known to use salted meat, fish and dried skins. Salted meat was also used by the Israelites, the Chinese and the Greeks, the last-named passing the technology on to the Romans. Evidence for production of fermented sausages by the ancient Babylonians and Chinese people goes as far back as 1500 BC. It is doubtful whether people at that time understood the nature of food preservation by fermentative microorganisms; however, they used the method fairly successfully. It was probably common to 'seed' a new batch of food with material from a good fermented batch and by that means propagate the 'right-culture' to reduce the chances of spoilage (today this practice is called 'back-slopping' in the meat industry). It is also doubtful whether people fully understood the role of food in transmitting diseases or the danger of eating meat from infected animals.

Advances in the understanding of food poisoning and food spoilage were made within the first millennium AD (Jay, 2000). Concern over meat butchers is mentioned for the first time in documents on Swiss butchers handling marketable and non-marketable meat in 1156. In 1276, a compulsory slaughter and inspection order was issued for abattoirs in Augsburg. Although people were aware of the quality attributes of meat by the thirteenth century, it is doubtful whether there was any knowledge at that time of the causal relationship between meat quality and microorganisms. One of the first people to suggest a role for bacteria in the spoilage of food was a monk by the name of A. Kircher, who examined decaying carcasses and milk, and referred to 'worms' that were invisible to the naked eye. His observations did not receive wide acceptance, although in 1765 L. Spallanzani showed that beef bouillon that had been boiled for an hour and sealed, remained sterile and did not spoil. This experiment was designed to disprove the 'spontaneous generation of life' theory, but did not convince the critics, since they thought that oxygen was vital to spontaneous life-generation. Only a hundred years later, Schwann carried out a similar experiment, but supplied sterile air to the system by passing the air through a heated coil and thus demonstrated that the theory was wrong.

One of the most important events in food preservation occurred about 200 years ago, when François Appert succeeded in preserving meat in glass jars, after keeping them in boiling water for extended periods. His development of the canning process in 1795 won a French government prize of 12,000 francs for establishing a practical method of food preservation. In 1810, Appert obtained a patent for his process. This development preceded Louis Pasteur by about 50 years. Pasteur, who is considered the father of modern microbiology, demonstrated the role of bacteria in spoilage of French wines, and suggested ways of preventing contamination and spoilage. The process developed by Pasteur is now known as 'pasteurisation'.

The following chapter will describe various means of preservation and some equipment used to preserve poultry meat. In addition, the reader is referred to Chapters 11 and 13, which are devoted to microbiological aspects of poultry

meat production and storage. Also, useful information on the application of HACCP in processing can be found in Chapter 15.

9.2   Preservation techniques: heating

Heat is used by the food industry and some professions (the medical profession, for example) to inactivate microorganisms. The degree of microbial inactivation depends on the temperature and exposure time. Generally speaking, two levels of heat processing are used by the food industry. The first is pasteurisation at a range of about 60–90ºC (for cooked poultry products, usually 70–75ºC), designed to inactivate some of the spoilage organisms and most of the pathogenic bacteria. The shelf-life of the product is extended, but it must be refrigerated. The second level is referred to as sterilisation, where a temperature > 100ºC is used to prepare so-called 'commercially sterile' food products that can be stored at room temperature for an extended period (canned food, for example). This process results in the killing of all spoilage microorganisms, as well as destroying food poisoning bacteria and virtually all spores. All heat treatments will result in changes to the product in terms of texture, flavour, odour and microbial load. The extent of the changes increases with higher temperature and exposure time. The degree of microbial destruction by heat can be described by the Decimal Reduction Time (D value) for a particular heating temperature, which is the time necessary to reduce the viable count ten-fold. Overall, there is quite a large variation in the heat sensitivity of different vegetative bacteria, spores and viruses. Table 9.1 shows the D-values for several pathogens of concern to the poultry industry.

Cooking methods can vary from cooking the meat in its own juices to grilling and frying in oil. Heat can be transferred to the product in three different ways:

1. *Conduction* – heat is conducted from an outside source and is transferred directly from one particle to the next, with little or no mixing and no movement of the product (Fig. 9.1a), which is usually true for solid, semi-solid and very viscous foods.

Table 9.1   D-values of different foodborne pathogens subjected to heat treatment

Organism	Heat resistance
Bacillus cereus	D_{100} = 2–8 minutes
Campylobacter jejuni	D_{55} = 60 seconds
Clostridium botulinum spores (type A, proteolytic strain)	D_{121} = 0.21 seconds
Escherichia coli	$D_{71.1}$ = 1 second
Listeria monocytogenes	$D_{71.1}$ = 3 seconds
Staphylococcus aureus	$D_{71.1}$ = 4.1 seconds

Adapted from Garbutt (1997).

(a)   (b)
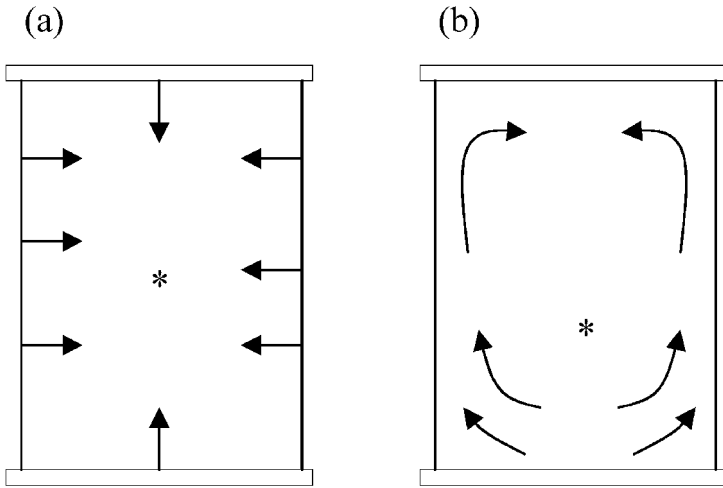
* Indicates the slowest heating.

Fig. 9.1   Heat transfer into a solid food product, such as a chicken roll by conduction (a) and by convection into a liquid or particulates in a liquid, such as meat chunks in chicken soup (b).

2. *Convection* – involves heat transfer by mixing and moving of particles in a fluid. Heated particles are less dense and move up to the top, whereas colder particles are denser and move to the bottom. This is a more efficient heating process than conduction, since it results in mixing of hot and cold particles via heat currents (Fig. 9.1b). Additional mixing during heating can be achieved by agitating, pumping or stirring. The coldest point in the vessel is above the middle of the first third (Fig. 9.1b), and that is where the temperature should be monitored.

3. *Radiation* – is the transfer of heat energy through space, in which a hot object gives up heat. For food applications, infrared lamps are normally used to emit energy, which is absorbed at the surface of the product.

The factors that affect heat transfer include: the temperature differential between the heat source and the product, the length of time heating is applied and the medium involved. The composition of the meat, in terms of moisture and fat content, also affects the heating rate. 'Thermal conductivity' is the term used to express the rate of heat movement through a material. The other term is 'specific heat', which quantifies the amount of energy (heat) required to change the temperature of one gram of material by 1ºC. Lean meat has more moisture and thus shows a higher specific heat compared to fat meat, meaning that it needs more energy to heat up identical quantities.

Heating whole poultry, cut-up parts or further-processed products (sausages, for example) can be done in regular, convection or microwave ovens, by immersion in water (provided the product is properly packaged) and by frying in

oil. The various methods provide different rates of microbial inactivation and confer different textural and flavour characteristics on the product. Choosing one method over another is commonly based on product identity, equipment available, operating costs and government regulations. The two main objectives of the cooking operation are to destroy food-poisoning bacteria, while reducing the number of spoilage microorganisms, and to denature the proteins, thus providing a firm texture (Barbut, 2002). Part of the cooking operation can include a smoke application. This can be done in a specially designed oven that includes a smoking unit (for example, generator of natural smoke or a spray system for liquid smoke); the effect of smoking on preservation is discussed later in the chapter.

9.2.1   Canning

The canning operation, which achieves 'commercial sterility', is commonly accomplished by using a retort that is a large metal chamber capable of operating under pressure (Fig. 9.2). The pressure is required to achieve temperatures above 100ºC. Usually, a temperature of 120ºC or slightly higher is used in retorts, which helps reduce the processing time required to destroy heat-resistant, spore-forming microorganisms. Poultry products that are processed in such a way include canned chicken soup, chunks of chicken meat in gravy, turkey cubes with vegetables, etc. The product is usually packed in metal cans, glass jars or flexible retort pouches, and can be stored later at room temperature. The rate of heat penetration into the product is very important. Figure 9.1 shows heat-penetration patterns for solid and liquid foods. As indicated earlier, in solid foods, such as chicken rolls, heat transfer is by conduction, and for liquid or particulate foods, such as meat pieces in a chicken soup, convection currents provide a faster rate of heat transfer. Other factors that are important in determining the rate of heat transfer are the packaging material (stainless steel containers have a thermal conductivity of about 20 Wm/K compared to glass, with a value of 0.52, and polyethylene with 0.55 Wm/K (Fellows, 1988)). Other factors include the size and shape of the container, temperature of the process (a higher temperature difference between the food and the heating medium results in faster heat penetration) and agitation of the container.

The rate of heating has to be measured so that the time required can be calculated. Thermocouples are placed in experimental cans and especially around the slowest heating point (Fig. 9.1). The high-temperature treatment in the retort usually involves the use of saturated steam under high pressure, which provides a temperature above 100ºC. The time-temperature calculations to achieve commercial sterility (also known as the 12-D concept) are complex and beyond the scope of this book. For additional information, the reader is referred to textbooks such as that of Fellows (1988).

The different types of commercial retort basically involve batch or con-tinuous operation. In a batch-type operation, cans are placed in a large basket and lowered into a high-pressure chamber which is then closed, whereupon the

(a)

(b)
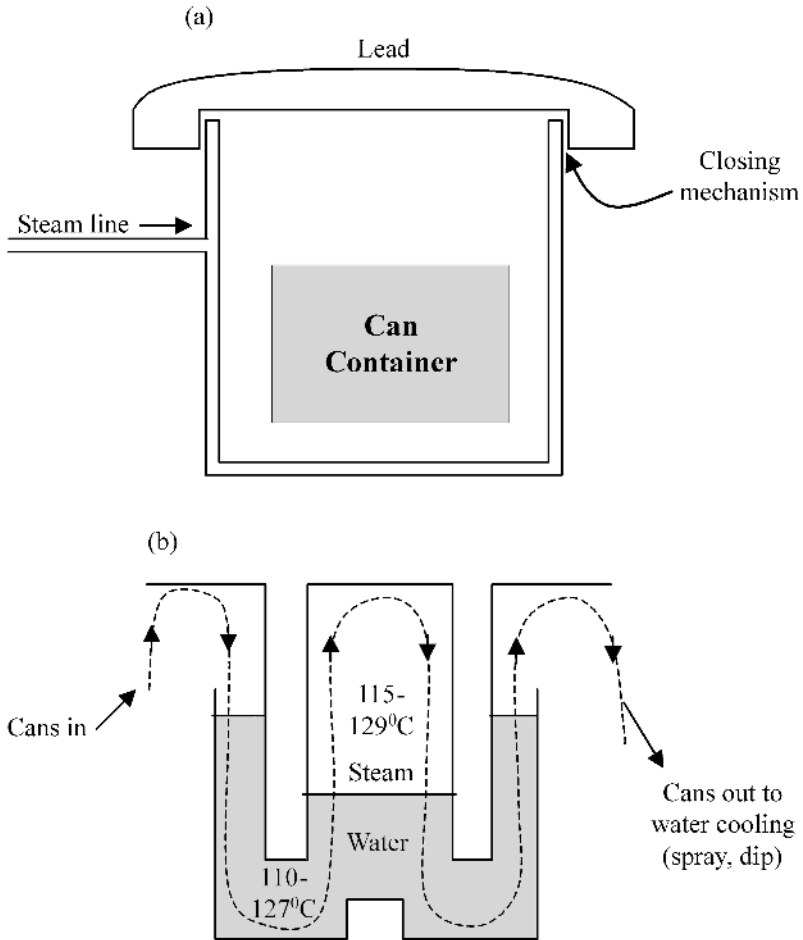
Fig. 9.2   Retorts used for a canning operation. A batch-type steriliser employing a high pressure (a) and a continuous-type retort (b). Adapted from Fellows (1988).

temperature is increased by injecting live steam (Fig. 9.2a). In a continuous retort, the cans move continuously through the equipment, in which a hydrostatic head-pressure is produced in between two columns of water (Fig. 9.2b). This allows for a more efficient process and closer control over the conditions. The initial 'leg' of the process is used to bring up the temperature of the product gradually, before it is transferred into the steam chamber. Later, the last 'leg' is used for the initial cooling of the product, followed by water sprays and possibly dipping in a cold-water bath. An essential step is to seal the can properly prior to heating, since the high temperature causes pressure to build up inside the can. Incorrect sealing or defects in the seam will cause leakage and ingress of external water or air, which will recontaminate the food inside. A thermal, plastic sealing compound is usually placed in between the can and the

lid and it melts during the heating process so as to fill the space and provide an additional barrier. Glass jars are covered with a metal lid, which also has a thermal, plastic sealing compound. Retort pouches are composed of multiple layers (for example, aluminum foil, polyethylene) and one of them is a thermal, plastic material or coating, which becomes fluid on heating, and serves as a sealant. From a consumer standpoint, it is important to remember that when in doubt (for instance in the cases of swollen can or sensing 'off' odour), canned food should not be consumed.

9.2.2   Microwave heating

This is based on inducing friction between water molecules found in a food material (lean meat has about 70% water). Since the angle between the two hydrogen atoms of water is 107°, the water molecule is negatively charged at the oxygen atom, and positively charged at the hydrogen atoms, thus forming an electric dipole. Microwave heating is attained by applying a rapidly oscillating electric field, which causes reorientation of the water molecules. The frequencies used in commercial microwave ovens are 2450 MHz, and sometimes 915 MHz in the US or 896 MHz in Europe. These frequencies are kept for microwave heating so that there is no disturbance to radio waves used for communication. The realignment of water molecules causes friction, which heats the product. There is a delay of a fraction of a millisecond before the dipoles respond to the oscillating electrical field, and this is called the 'relaxation time'. The relaxation time is affected by the viscosity of the material being heated and depends on temperature. When water changes to ice, the dielectric constant, that is, the ratio of capacitance of the food to the capacitance of air or, in some cases, vacuum, falls and continues to decrease as the ice is cooled further. This means that ice is more 'transparent' to microwave energy than water, and thus may cause problems when food is thawed in a microwave.

Since microwave heating is not dependent on the thickness of the product, it is sometimes referred to as 'heating from the inside', which takes less time than relying on heat to be conducted from the outside in a convection oven. The rapid rate of heating in a microwave oven usually does not allow enough time for the development of browning on meat cuts. Therefore, some new ovens include both microwave and convection processes to speed up cooking and provide browning. The destruction of *Listeria monocytogenes* strain Scott A by microwave cooking was investigated by Lund *et al.* (1989), with more than 10^7 cells/g being used to inoculate chicken stuffing and 10^6–10^7 cells/g for chicken skin. Using a home-type microwave unit, heating to an internal temperature of 70°C for one minute was shown to give a 6 log reduction in numbers. The thermal destruction of *L. monocytogenes* is similar to that of most other bacteria relative to the pH of the suspending medium, but resistance is higher at pH values close to 7.0 than values in the acid range.

Packaging material should be transparent to microwave energy, but materials such as metals reflect the energy and result in arcing, as well as excessive

RADIO WAVES

TV

INFRARED RADIATION

AM-FM RADIO

VISIBLE RADIATION →

X-RADIATION

COMMUNICATIONS BANDS

ULTRAVIOLET RADIATION

MICROWAVES

GAMMA RADIATION

RADAR

1 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22}
Frequency in Hertz (cycles per second)

3×10^8 3×10^7 3×10^6 3×10^5 3×10^4 3×10^3 3×10^2 3×10^1 3×10^{-1} 3×10^{-2} 3×10^{-3} 3×10^{-4} 3×10^{-5} 3×10^{-6} 3×10^{-7} 3×10^{-8} 3×10^{-9} 3×10^{-10} 3×10^{-11} 3×10^{-12} 3×10^{-13} 3×10^{-14}
Wavelength in Meters

4×10^{-15} 4×10^{-14} 4×10^{-13} 4×10^{-12} 4×10^{-11} 4×10^{-10} 4×10^{-9} 4×10^{-8} 4×10^{-7} 4×10^{-6} 4×10^{-5} 4×10^{-4} 4×10^{-3} 4×10^{-2} 4×10^{-1} 4 4×10^1 4×10^2 4×10^3 4×10^4 4×10^5 4×10^6 4×10^7
Photon Energy in Electron Volts

Fig. 9.3   The frequencies, wavelengths and photon energies of the major part of the electromagnetic spectrum. The boundaries of the named segments are more or less arbitrary, and there is now some tendency to reduce the overlapping by defining the range between TV and infrared radiation as microwaves and the range between visible radiation and x-radiation as ultraviolet. From CAST (1986). With permission.

heating of the material. Therefore, various plastics, glass and paper with low dielectric-loss are commonly used (Fellows, 1988).

9.2.3   Infrared heating

This process employs electromagnetic radiation that is emitted by hot objects and absorbed by the food. Infrared heating is less controllable and has a wider range of frequencies than microwave heating (Fig. 9.3). In addition, the depth of penetration is lower and heat transfer relies upon conduction from the surface to the interior of the food. The rate of heat transfer depends on factors such as the surface properties of the food and the temperature-difference between the food and the heating lamp. Equipment used includes quartz or halogen tubes fitted with electric filaments, ceramic heaters and metal heaters. The temperature of the heating element can range from 900ºC for a quartz tube operating at medium wavelength to 2200ºC for a heat lamp operating in the short-wavelength range. Infrared radiation is used mainly to keep food hot in a display case, but is also used for drying non-meat products, such as cocoa, pasta and flours, which are usually passed through a drying tunnel. The drying of cocoa, etc., is mentioned here because solar energy (indicated earlier as an old way of drying meat) consists of approximately 48% infrared energy.

9.2.4   Dielectric heating

This operates on a principle similar to that of microwave heating, but at lower frequencies. The food is passed between capacitor plates, where high-frequency
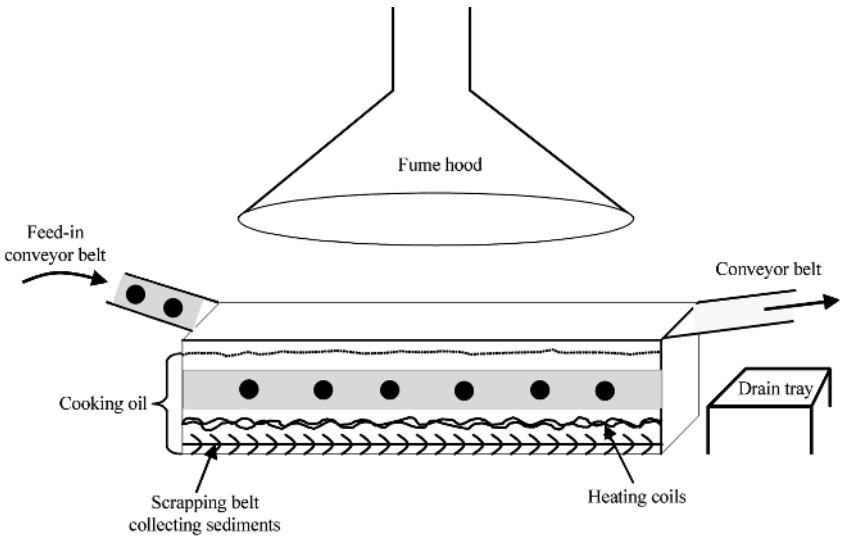
Fig. 9.4   A schematic diagram of a continuous fryer. Courtesy of Stein Inc.

energy is applied to the food by using an alternating electrostatic field. Changes in the orientation of dipoles are similar to that involved in microwave heating. However, in this case, the thickness of the food is restricted by the distances between the capacitor plates. The main usage of dielectric heating in the meat industry is for thawing blocks of frozen meat and sometimes for cooking.

9.2.5   Frying

This operation is used to heat the product, to change the physical characteristics of the food, develop a brown/gold colour on the surface, for example, and to inactivate microorganisms. A schematic diagram of a continuous fryer is shown in Fig. 9.4. The high temperature employed during the frying operation (180–200ºC) is very effective in sterilising the surface of the product, but it should be remembered that the internal temperature usually does not exceed 75ºC. Overall, there is a trade-off between oil temperature and product quality. At a lower temperature, more oil will be absorbed by the product, whereas at a higher temperature, the oil will deteriorate faster. This occurs by hydrolysis and later by polymerisation of fatty acids, and results in foaming, darkening and oxidation of the oil and the product surface.

   If the product is only par-fried at the processing plant, for example a one-minute treatment at about 195ºC for chicken nuggets, it must be fully cooked by the consumer/food-service operator. Fully cooked products (at the plant) are either eaten cold or only warmed by the consumer prior to consumption.

9.3   Preservation techniques: drying

Drying of relatively thin slices of meat over fire or under the sun has been practised since prehistoric times. The principle of this preservation method is based on reducing the water activity to a level that is too low to support microbial growth. Dried foods usually contain no more than 25% moisture and have a water activity (A_w) of 0.00 to 0.60. Another category is the intermediate-moisture food, which contains between 15 and 50% moisture, with A_w values between 0.60 and 0.85 (Barbut, 2002). In general, most spoilage bacteria do not grow at A_w values below 0.92, spoilage yeasts at below 0.90 and spoilage moulds at below 0.80 (Jay, 2000).

Today, commercially-dried poultry meat is used in dry soup mixes, dried foods for camping and foods carried by astronauts to outer space. The most economical way of drying is by using hot air. For this purpose, small or thin slices of meat are placed on trays and exposed to circulating, dry air. Large meat chunks are not normally dried, since surface hardening, that is, fast migration of water from the surface, can result in unacceptable products. Attention should be given to the shape of the product, since the product may shrivel and come out twisted or deformed. This is especially important for products such as turkey jerky, which is dried and later sold in flat packages. Another area of concern is fat oxidation, which is accelerated during hot-air drying, because of the large surface area exposed to oxygen. In order to overcome this problem, antioxidants should be added. The antioxidants can include synthetic substances, such as butylated hydroxy anisole (BHA) and butylated hydroxy toluene (BHT) or, if these are not permitted or desired, natural anti-oxidants, such as rosemary oleoresin.

9.3.1   Freeze drying

This process is another way of removing moisture from the product, while maintaining its original shape. The frozen product is placed in a freeze-drying chamber, where vacuum is applied (usually 1–1.5 mm of mercury). Ice sublimates from the product without passing through the liquid phase. In commercial freeze dryers, rapid sublimation is achieved, both by applying a vacuum and raising the chamber temperature, while the product is held on a colder surface (cooled by a refrigeration coil). The product maintains its original shape, because the water is sublimated while the product is frozen, and structural changes, such as shrinking, do not occur. Preserving the structure is desirable for products like soup mixes, for which re-hydration is easier and faster following freeze drying, compared to air-dried products, and thus textural characteristics are better. The moisture content of freeze-dried meats is usually 2% or less and the A_w well below 0.60. It is very important to package the product properly and exclude all moisture and oxygen from the surrounding atmosphere. Cooking the meat prior to freeze-drying usually results in a more stable product compared to freeze-drying fresh meat. The overall shelf-life of a cooked, freeze-dried product is about two to two-and-a-half years (provided it is properly packaged), which is usually two to four times greater than the shelf-life of freeze-dried fresh meat.

9.4   Preservation techniques: chemical treatments

9.4.1   Salting

Sodium chloride (NaCl) is one of the oldest ingredients used to preserve meat. Preservation is achieved by lowering the A_w and hence reducing the water available for microbial growth. In addition, a high salt concentration outside a bacterial cell can interfere with its metabolism, since the salt draws water from the cell. The salt concentration within the cell is around 0.90%. When the external salt concentration is about the same, the cells experience so-called isotonic conditions. When more salt is added, the higher external concentration results in water moving out of the cell in order to maintain an equilibrium (a condition known as 'plasmolysis', which can inhibit growth and possibly destroy the cell). In order to make a meat product shelf-stable at ambient temperature, a concentration of 10–15% salt should be used. This is much higher than the 1.0–2.5% level commonly used in commercial, further-processed poultry products that are manufactured today (Barbut and Findlay, 1989). At such concentrations, other means of preservation, such as refrigeration, are needed to maintain product shelf-life. For example, poultry frankfurters containing 2% salt and left at room temperature will spoil within 1–2 days. It should be mentioned that some microorganisms are inhibited by a salt level of only 2.0%, but the high A_w (around 0.98–0.99) that results is not sufficient to inhibit most bacteria, moulds or yeasts (see also Chapter 13). Another important point to remember is that salt is water-soluble and, in calculating the salt concentration needed for preservation, this should be in relation to the lean-meat part. For example, if 3% salt is added to a turkey sausage containing 30% fat, the salt concentration actually experienced by bacteria in the lean phase is 4.2%.

9.4.2   Phosphates

These are salts of phosphoric acid. Different types are used by the industry and the most common is sodium tripolyphosphate (TPP). Phosphates can alter the pH of the food and emulsify fat, thereby affecting microbial cell membranes and causing a salt imbalance inside the cells. The use of phosphate rinses and dips for cleaning poultry carcasses was suggested over 50 years ago. The detergent activity of phosphates, which is also utilised in laundry and dishwashing detergents, results from their hydrophilic/hydrophobic structure. In 1992, a commercial mixture of about 10% TPP and a few other ingredients was approved in the USA, for decontamination of poultry skin. The mixture is effective against some pathogens, but not all. Figure 9.5 shows the results of using a TPP solution to remove bacteria from turkey carcasses (Bautista *et al.*, 1997).

9.4.3   Acids

Different organic acids are used to inhibit microbial growth in and on meat products. The acids can be applied as sprays or rinses for carcasses, as
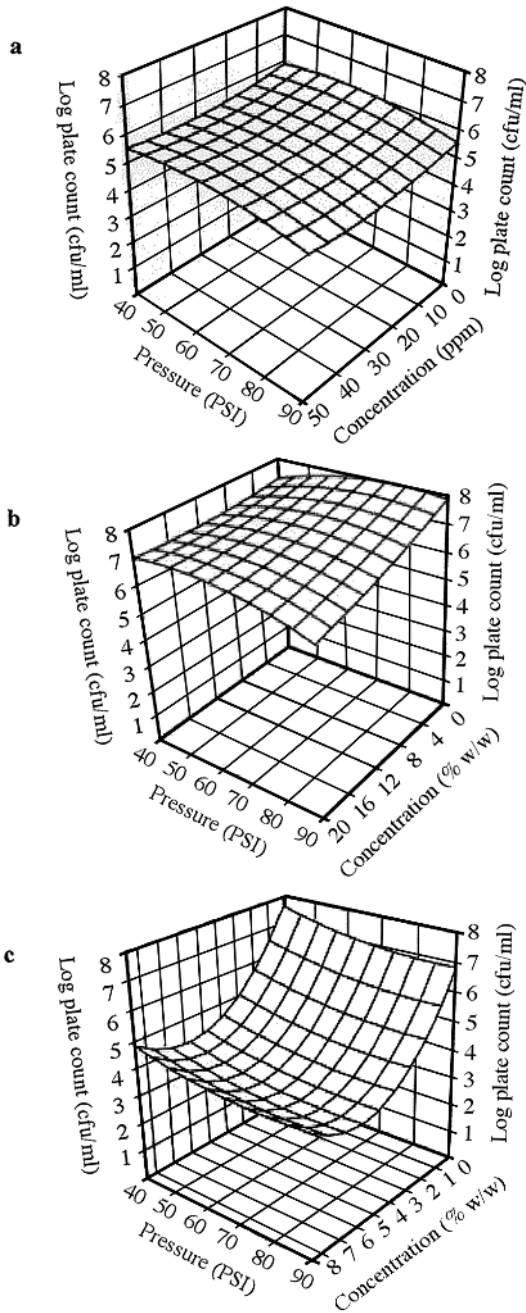
Fig. 9.5   Response surface diagram showing the effect of a spray wash and concentration of (a) chlorine, (b) tripolyphosphate and (c) lactic acid on the total counts from turkey carcasses inoculated with intestinal contents. From Bautista *et al*. (1997). With permission.

marinades, and can even be produced within the product during fermentation, for example lactic acid during summer-sausage fermentation. Application of a lactic acid rinse to poultry carcasses has been reported as a useful means of reducing microbial loads (Fig. 9.5); however, not all organic acids are as effective (Bautista *et al.*, 1997; Barbut, 2002).

Marinating cut-up chicken with ingredients such as lemon juice and vinegar is inhibitory to many microorganisms and helps in extending the shelf-life of the product. Marinated poultry parts, such as chicken wings, are becoming very popular, and are sold as convenience items, requiring only grilling. The different acids used also add distinctive flavours and aromas. The antimicrobial activity of organic acids is due to both the reduction in pH, below the growth range of microorganisms, and metabolic inhibition by the undissociated acid molecules. Often, the inhibitory effect of a specific organic acid is best measured by determining titratable acidity. This simply indicates the amount of acid that is capable of reacting with a known amount of base and is a better indicator of acid content than pH (Jay, 2000).

Sorbic acid is used as a food preservative at a level of $\leq 0.2\%$, mainly as a fungal inhibitor. The acid works best below pH 6.0 and is generally not effective above pH 6.5. Sorbate can also be used as a spray on fermented and other sausages, in order to inhibit growth of moulds and yeasts; however, sorbate is also effective against a wide range of bacteria. In general, catalase-positive cocci are more sensitive than catalase-negative bacteria, and aerobes are more sensitive than anaerobes. The resistance of lactic acid bacteria to sorbate allows this substance to be used as a fungistat in fermented meat products, without affecting the fermentation (Jay, 2000). In addition, a combination of sorbate and nitrite can be used to control *Clostridium botulinum*, but some flavour problems, described as 'chemical' notes, can arise.

9.4.4   Nitrite

Sodium nitrite ($NaNO_2$) and sodium nitrate ($NaNO_3$) are used in the curing processes for different meat products. The effects of nitrite can be divided into three categories:

1. inhibiting the growth of food poisoning bacteria, such as *C. botulinum*, and certain spoilage organisms
2. stabilising the pink colour of meat by forming the nitrosohemochrome complex
3. contributing to flavour development with inhibition of oxidation and formation of the so-called 'warmed-over' flavour.

The main reason for adding nitrite is to inhibit the outgrowth of *C. botulinum* spores, since most meat products are not cooked to temperatures above 100ºC, so that textural problems can be avoided. This allows spores to survive. The active compound derived from nitrite is nitric oxide (NO), which inhibits *C. botulinum* by interfering with iron/sulphur-containing enzymes, such as

ferredoxin, and thus prevents the synthesis of adenosine triphosphate from pyruvate. The chemical degradation of sodium nitrite within an aqueous meat system is shown as:

$$NaNO_2 \longrightarrow HNO_2 + Na + H_2O$$
$$3HNO_2 \longrightarrow 2NO + HNO_3 + H_2O$$
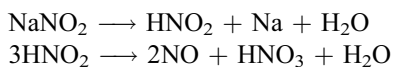
If nitrate is used, it will be reduced first to nitrite by microorganisms present in the meat. Nitrate is also used in longer processes, for example preparation of fermented meat products, where slow release of nitrite is required.

Nitrite levels used in processed meat products are very low and usually range from 100–150 parts per million (ppm). Permitted usage levels are controlled by government agencies because of the potential production of nitrosamines, which are formed by the reaction between nitrite and secondary or tertiary amines under acidic conditions at high temperatures. Since some of the nitrosamines are known to be carcinogenic, the levels of added nitrite are closely monitored by the inspection agencies. In meat products that will be processed shortly after addition of nitrite, (frankfurters, for example), reducing agents such as ascorbate and erythorbate are used at a level of about 500 ppm to quickly convert the nitrite into nitric oxide and reduce the chance of nitrosamine formation. In certain products that will be exposed to high-temperature cooking, such as turkey bacon, which is usually fried, lower levels of nitrite are prescribed.

To put things in perspective, one should be aware that meat products are not the major source of nitrite in our diet. Certain vegetables, such as celery, have nitrite levels up to 300 ppm. In addition, microorganisms present in the human gut produce significant amounts of nitrite within the body. During the cooking of sausages and other meat products, the level of nitrite is substantially reduced due to the conversion of nitrite to nitric oxide. During storage, there is a further reduction in the amount of measurable nitrite and, by the time the product is consumed, nitrite levels can be as low as 10–30 ppm. Over the past few decades, several suggestions have been made for eliminating or reducing nitrite levels in meat products; however, none have gained wide acceptance. One example of a means of reducing the level of nitrite was the proposed addition of 0.25% potassium sorbate, with about 40 to 80 ppm of nitrite. This combination was found to be inhibitory to *C. botulinum*, but some flavour problems were reported. Another patented alternative was the use of 35 ppm of encapsulated dinitrosyl ferrohemochrome as a colouring agent and 3000 ppm sodium hypophosphite as an antimicrobial agent in a nitrite-free curing formulation for wieners (Yun *et al.*, 1987). However, the process is not used on a wide commercial scale.

9.4.5   Antibiotics and bacteriocins

Antibiotics are compounds produced by microorganisms that inhibit or kill other competing microorganisms. Some of the most useful antibiotics in human

medicine are produced by moulds (for example, *Penicillium* spp). Other antibiotic-like substances are produced by bacteria, such as *Bacillus* spp., and nisin is produced by a strain of *Lactococcus lactis*. Nisin belongs to one of the four major classes of bacteriocins. Like antibiotics, bacteriocins inhibit or kill other microorganisms, but only those of closely-related species or strains of the same species (Jay, 2000).

In the 1950s, two antibiotics, tetracycline and subtilin, were approved for use in foods in the USA; however, they were later removed from the approved list and currently cannot be added to meat or meat products. Although these antibiotics are very effective, there is a risk of developing microbial resistance to tetracycline, which might be transferred to bacteria that affect human beings. Since tetracycline is used as a therapeutic drug, it is also banned in some countries from animal feed. In general, addition of any antibiotics to meat products is prohibited in most countries.

Nisin has been used by the cheese industry to prevent spoilage of Swiss cheese by *C. butyricum*. Today, nisin is clearly the most widely used bacteriocin in food preservation, and is permitted for use in around 50 countries. Some of its advantages are: heat stability, excellent storage stability, the fact that it is produced naturally, is destroyed by digestive enzymes in the body, does not contribute to 'off' flavours or odours, is not toxic to humans, and is not employed in human medicine.

9.4.6   Smoke

Smoking has been used for centuries to preserve meat. The phenols, ketones, aldehydes and organic acids found in various kinds of wood smoke have bacteriostatic and bactericidal effects and thus can inhibit or kill microorganisms. Over 400 compounds have been isolated from wood smoke and they can be grouped into the four major groups indicated above. Phenols and organic acids contribute most to the preservative effects of smoke. Today, smoked poultry products (frankfurters and salami, for example), receive only a light application to enhance the exterior colour and provide some special flavour notes (hickory, oak-smoke flavouring). This means that the smoke is deposited on the surface of the product and may penetrate to a depth of 1–3 mm. The treatment provides some bacteriostatic and bactericidal capability to the surface, but none to the bulk of the product. In some applications, cold smoking is used effectively to inhibit the growth of moulds on uncooked, dry, fermented sausages in countries such as Canada, where sorbic acid (mould inhibitor) is prohibited for this purpose.

9.4.7   Spices

These substances are rarely used as antimicrobial agents *per se*, but some possess antimicrobial and antifungal properties. The antimicrobial activity is usually due to specific chemicals or essential oils found in a particular spice,

which are designed to combat microbial attack in the living plant. Examples of some antibacterial compounds are:

- Cinnamon – sinnamic aldehyde and eugenol
- Cloves – eugenol
- Mustard – isothiocyanate
- Oregano – carvacrol and thymol
- Sage – thymol and eugenol (Shelef, 1983).

9.4.8   Antioxidants

The compounds are used mainly to prevent lipid oxidation, but they also possess some antibacterial activity. The phenolic structure of antioxidants, such as BHA and BHT, are inhibitory to Gram-positive and Gram-negative bacteria, as well as to yeasts and moulds, at concentrations ranging from 10 to 1000 ppm, depending on the substrate. Foodborne pathogens, such as *Salmonella*, *Staphylococcus aureus* and *Bacillus cereus*, are inhibited by concentrations of > 500 ppm, while *Pseudomonas* spp. are among the most resistant bacteria to BHA/BHT (Jay, 2000).

9.5   Preservation techniques: irradiation

The use of ionising radiation is currently acceptable in some countries and has been gaining popularity. Ionising radiation is defined as radiation with a wavelength of 2000 angstroms or less (Fig. 9.3). The types of radiation of primary interest to the food industry are: gamma rays, beta rays, x-rays and alpha particles. Their quanta contain enough energy to ionise molecules in their path. Ionising radiation used for food preservation destroys microorganisms without increasing the temperature of the product and, therefore, is sometimes called 'cold sterilisation'. The radiation sources used by the food industry include machine-type and isotopic radiation. Machine-type radiation is produced by an electron accelerator, which generates a high-energy electron beam or high-energy x-rays for treating food. Isotopic irradiation is obtained by using isotopes such as cobalt-60 (^{60}Co) or caesium-137 (^{137}Cs) as a source of gamma rays. The isotope ^{60}Co is produced in nuclear reactors by neutron-induced transmutation of naturally-occurring ^{59}Co. The caesium is a fusion product and is extracted from by-products of nuclear reactor fuel elements. The 'strength' of an isotopic source is commonly expressed in terms of the rate of disintegration of radionuclides. The standard unit of activity is the curie, which is equivalent to 37 billion disintegrations per second. In addition to its activity, the frequency of gamma ray emission should also be mentioned. In the case of ^{137}Cs, gamma ray emission occurs in only 85% of its disintegrations, while ^{60}Co emits two gamma rays per disintegration. Another important characteristic is the isotopic half-life, which describes the length of time for the activity of the source to be halved as a

Rads
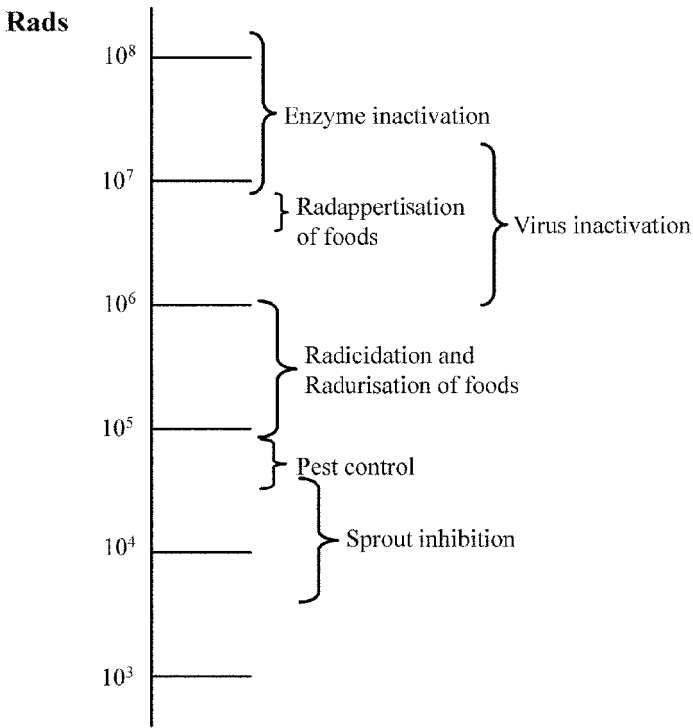
Fig. 9.6   Radiation dose ranges for various specifications. Adapted from Grunewald
(1961).

result of decay. The half-life of caesium is 30 years and that of cobalt 5.2 years
(Faw and Chang-Mei, 1987).

Measuring the amount of radiation absorbed by the material, in this case
food, is described as the 'dose'. This can be compared roughly to the amount of
heat (calories) a food product absorbs, while being held in a hot environment.
Measuring the amount of radiation absorbed is called 'dosimetry' and is
expressed by a unit called the rad. A rad is equivalent to the absorption of
100 ergs/g of matter. A newer unit for an absorbed dose is the gray (1 Gy = 100
rads = 11 joule/kg).

The radiation dose used for different applications is shown in Fig. 9.6.
Similar to heat processing, small radiation doses can result in pasteurisation, that
is killing of some spoilage and pathogenic microorganisms, whereas a high dose
will result in so-called 'commercial sterilisation', or 'radappertisation', similar
to the situation in heat-treated, canned food (usually at levels of 30-40 kGy).
'Radicidation' is a process similar to pasteurisation of milk and is designed to
reduce numbers of non-spore-forming pathogens, other than viruses. Typical
levels are 2.5–10 kGy. 'Radurisation' is a lower level pasteurisation, which is
used to reduce numbers of specific spoilage microorganisms, using a dose of

Table 9.2   Average radiation D-values for bacteria and viruses in a variety of foods

Organisms/Substrate	D (kGy)
Bacteria	
Clostridium botulinum, type E Beluga	0.8
C. botulinum, 62A spores	1.0
C. botulinum, type B spores	2.38
C. botulinum A toxin in meat slurry	36.08
Escherichia coli	0.20
Listeria monocytogenes	0.42–0.43
on meat at 5ºC	0.44
on meat at 0ºC	0.45
on meat at −20ºC	1.21
Pseudomonas putida	0.08
Salmonella typhimurium	0.50
S. enteritidis in poultry meat at 22ºC	0.37
Staphylococcus aureus	0.16
Yersinia enterocolitica in meat	61.18
	0.19–0.38
Viruses	
Adenovirus (4 strains)	4.1–4.9

Adapted from Jay (2000).

0.75–2.5 kGy. This treatment is commonly used to enhance the shelf-life of fresh poultry, seafood, fruits and vegetables.

Similar to heat inactivation of microorganisms (described earlier), there are D-values for different microorganisms that are associated with particular radiation treatments (Table 9.2). Here, radiation dose and not time is used as the measuring unit. These values are useful in designing radiation treatments for different foods. As with heat treatment, spores are more resistant to radiation than non-spore-forming microorganisms. Once a toxin has been formed, a very high dose is required to inactivate it. With *S. aureus*, for example, the D-value for vegetative cells is 0.16 kGy, and for the toxin about 61 kGy. In the case of *C. botulinum*, there is an interesting difference from heat processing, where the toxin is fairly heat-sensitive and can be destroyed in five minutes at 85ºC, as opposed to the spores that require boiling for several hours. The reason is that the toxin is a small peptide that can be denatured and inactivated fairly easily by heat, but not by irradiation. As with heat treatment, viruses are more resistant to irradiation than bacteria, and different chemical additives and pH values can significantly affect microbial destruction. In a study involving frankfurters inoculated with five strains of *C. botulinum* at a level of 103 spores/g, Barbut *et al.* (1988) showed that increasing the salt concentration improved protection from toxin production under temperature-abuse conditions, when the product had been irradiated. Thus, a radiation exposure of 5 kGy or more, at either 1º or −30ºC, was sufficient to inhibit production of botulinum toxin for 40 days in turkey frankfurters containing 2.5% or more of NaCl. Neither 5 nor 10 kGy inhibited toxin production in products formulated with only 1.5% NaCl.

It is important to obtain actual dosimetry values in order to ensure that the product has been exposed to the desired treatment, and that the required pasteurisation/sterilisation level has been achieved. Two main dosimetry systems are commonly used. The first is based on colorimetry and is suitable for short periods of irradiation. The second is based on ceric sulphate, in which ceric ions, in acidic solution, are reduced by the action of ionising radiation to cerous ions. The change in ceric ions can be measured readily with a spectrophotometer. Secondary dosimetry systems are also used and are usually calibrated against one of the primary methods mentioned above. One such secondary system involves darkening of polymethyl methacrylate, when exposed to irradiation. The relative amount of darkening can be measured with a spectrophotometer.

Figure 9.3 shows the frequencies, wavelengths and photo energies of much of the electromagnetic spectrum. As can be seen, the shorter the wavelength, the greater the energy it carries (electromagnetic radiation occurs in units called quota or photons). When the quantity of energy in a quantum exceeds the energy that binds adjacent atoms in a molecule, the molecule can break and the chemical bond is cleaved off, resulting in smaller fragments that may be electrically charged (ions) or neutral. Ultraviolet, x-ray and gamma ray treatments are capable of breaking fairly stable bonds and even expelling electrons from atoms. Therefore, they are known as ionising radiation or ionising energy. Visible light, for example, has such a tendency, but to a much smaller degree, and it can only break weak bonds (CAST, 1986).

The depth to which ordinary visible light can penetrate most solids is of the order of a few microns. Gamma rays and x-rays can penetrate much deeper. Those with energy values of 0.15 to 4 million electron volts (eMv) can penetrate about 30 cm of water. Fast-charged particles such as electrons, alpha particles and protons also have enough energy to cleave molecules, as they penetrate the material. Accelerated electrons with an energy of 10 million eMv can penetrate to a depth of about 4 cm. However, accelerated alpha particles and protons do not have enough penetrating power to be of practical use in food applications.

There are two types of commercial food irradiation facility. The first uses a radioactive isotope (Fig. 9.7), and the second employs an electron-beam accelerator. Once the food has been treated, it has to be labelled, and a certain symbol should appear on the package to indicate that the food has been exposed to ionising radiation, letting the consumer decide if he/she wants to purchase it. Commercial irradiation of fresh poultry, beef and pork meat was approved in 1999 in the USA. In other countries, such as The Netherlands, food irradiation has been approved for many years, while in Canada, permits for experimental trials on poultry have been granted. Overall, food irradiation is becoming more acceptable today in different parts of the world. Among the reasons are the *Escherichia coli* O157:H7 problem in hamburger meat and attempts to market *Salmonella*- and *Campylobacter*-free poultry meat.

In terms of food safety, the World Health Organisation (WHO) concluded that 'no hazard is involved in processing any food with ionising energy up to an

RADIATION SHIELD

CONVEYOR SYSTEM

UNLOADED
PROCESSED
PRODUCT

IRRADIATION
ROOM

CONTROL CONSOLE

LOADING

STORAGE POOL

RADIATION SOURCE

IRRADIATION FACILITY
An industrial irradiator used for food
products consists of a room with concrete
walls two metres thick which contain the
radiation source (cobalt-60). A conveyor
system automatically moves the products
into the room for irradiation, and then removes
them. When personnel must enter the room,
the source is lowered to the bottom of a pool,
where water absorbs the radiation energy and
protects the workers.

Fig. 9.7   An industrial irradiator used for food products. Courtesy of Nordion Inc.

average dose of 10 kGy; hence, toxicological testing of food so treated is no longer required' (WHO, 1981). The WHO conclusion was based on the following three factors:

1. All the toxicological studies carried out on a large number of individual foods have produced no evidence of any adverse effect as a result of irradiation.
2. Radiation chemistry studies have shown that the radiolytic products of major food components are identical, regardless of the food from which they are derived. Moreover, for major food components, most of these radiolytic products have also been identified in foods subjected to other, acceptable methods of food processing. Knowledge of the nature and concentration of these radiolytic products indicates that there is no evidence of a toxicological hazard.
3. Supporting evidence is provided by the absence of any adverse effects resulting from the feeding of irradiated diets to laboratory animals, the use of irradiated feeds in livestock production and the practice of maintaining immunologically compromised patients on irradiated diets.

The conclusions of the WHO have been incorporated into an international standard under the procedure of the Codex Alimentarius Commission, which was adopted by 130 national governments in 1983. The standard has provided an important incentive for national authorities to introduce favourable regulations for food irradiation. Thayer (1994) reviewed the wholesomeness of irradiated

food, including data cited by the US Food and Drug Administration in support of their approval for irradiation of poultry meat, at 1.5–3.0 kGy, to control foodborne pathogens. Thayer (1994) concluded that neither short nor multi-generation feeding studies have produced evidence of toxicological effects in mammals due to ingestion of irradiated food. This supported the conclusion that properly processed, irradiated food is wholesome, and that radiolytic changes in the food are minimal and predictable.

Using irradiation to treat poultry meat at the radurisation level can assist in reducing foodborne diseases caused by bacteria such as *Salmonella* and *Campylobacter*, and levels of spoilage bacteria in the product, such as *Pseudomonas* and *Lactobacillus* spp. The effect of radiation dose on levels of microorganisms on freshly slaughtered chickens stored at 2ºC is presented in Table 9.3. Niemand *et al.* (1977) showed that non-irradiated controls stored at this temperature spoiled within 4–6 days, which would have occurred when counts reached about 10^7–10^8 bacteria/cm^2. Doubling the shelf-life, and reducing microbial counts by 3–4 logs, was achieved with a radiation dose of 2–5 kGy. A dose of 5 kGy more than tripled the shelf-life. The results are in agreement with experiments conducted both before and after 1977. Others have shown that irradiating eviscerated poultry with 2.5 kGy resulted in an essentially *Salmonella*-free product. In a study involving artificially-contaminated broiler skin, Mulder (1982) reported a range of D-values for irradiation at above and below the freezing point: for example, values of 0.54–0.68 for *Salmonella niloese* at +5ºC and 0.88–1.25 at −18ºC. The values are in agreement with those obtained for *E. coli* and *Salmonella* reported for other foods, where irradiating at −18ºC provides greater protection for the organisms and thus requires higher doses to achieve the same level of inactivation. Mulder (1982) indicated that the application of 2.5 kGy to Dutch poultry could not guarantee a *Salmonella*-free product, but would reduce the number of *Salmonella*-positive carcasses by a factor of 14. It should be mentioned that today the situation is likely to be different in The Netherlands, where a significant effort to eradicate *Salmonella* (with a farm-to-plate approach) has been made within the last decade.

Exposure of meat to medium or high levels of irradiation can result in the formation of 'off' flavours and odours. This is mainly the result of lipid

Table 9.3 Effects of irradiation dose on total plate counts (per cm^2) from chicken carcasses stored at 2ºC

| Days stored | Irradiation dose (kGy) | | | | |
	Control	2	3	4	5
1	0.2×10^5	$< 10^2$	~50	< 10	< 10
6	1.2×10^8	1.7×10^4	~50	< 10	< 10
12	–	4.5×10^6	3×10^3	1×10^2	< 10
20	–	–	5×10^6	2×10^5	5×10^3

From Niemand *et al.* (1977).

oxidation that can be accelerated by irradiation. Therefore, it is generally recommended that meat irradiated at medium to high levels be vacuum packed, especially when a high dose (20–70 kGy) is applied; a sub-freezing temperature is also recommended to minimise 'off' flavour formation. High-level radappertisation allows the product to be stored at room temperature without spoilage. For radappertisation, a mild heat treatment, at about 70–77ºC, is usually applied in order to inactivate proteolytic and lipolytic enzymes, which can cause flavour, odour and texture deterioration during storage (Josephson, 1983).

9.6   Future trends: emerging technologies

Over the past few years, several new technologies, usually requiring relatively sophisticated equipment, have been introduced and tried by the food industry. They include techniques such as high-pressure processing, instantaneously controlled decompression, oscillating magnetic-field treatment (ohmic heating, dielectric heating, microwaves), use of pulsed electric fields and high-intensity pulsed light (Hugas *et al.*, 2002; Heinz *et al.*, 2001). In this chapter, only high pressure and pulsed electric-field treatments will be discussed, since they are the closest to being used by the meat industry.

9.6.1   High-pressure processing

This is a non-thermal process that can be applied to fresh or fully-cooked products. The process uses an isostatic pressure, at room temperature, between 100 and 600 MPa. The pressure chamber is loaded, closed, degassed and the pressure is transmitted by a pump, through a liquid, to the food. Overall, the high pressure accelerates reactions involving a change of volume at the molecular level. This in turn can cause a destruction of microbial vegetative cells and inactivation of enzymes, without changing the organoleptic characteristics of the product, and leaving the vitamins intact. However, as with heat treatments (previously discussed), the resistance of microorganisms varies depending on the strain, meat-product composition, pressure, exposure time, temperature, etc. (Hugas *et al.*, 2002). It should be noted that there is a range of products already on the market, such as fruit juices, rice cakes, raw squid, oysters and guacamole that are processed in this way. The meat industry is currently experimenting with the process, but only a few companies currently attempt to use the technology. The inactivation of microorganisms by high pressure is probably the result of a combination of factors. High pressure does not inhibit or destroy unique cellular sites or functions, so cell death is likely to be due to multiple or accumulated damage inside the cell (Simpson and Gilmour, 1997). The cell membrane is the primary target for pressure damage, which acts mainly by altering membrane permeability as a consequence of phospholipid crystallisation. Other cellular features that are sensitive to pressure are: ribosome morphology, protein structure, DNA replicative complexes, fatty-acid composition, etc. In general,

cell death increases with pressure, but does not follow first-order kinetics (logarithmic death-rate), since there is a tailing of inactivation (Hugas *et al.*, 2002). Generally speaking, Gram-positive bacteria are more resistant to high pressure than Gram-negative types, and so are spores. It should be noted that, in a real-life situation, the different pressure-temperature-time profiles that occur in a commercial, high-pressure vessel may result in a pronounced, non-uniform pattern of microbial inactivation. Contrary to the situation with classical heat pasteurisation, the last area to be fully treated (or the coldest spot in a can) is located near the wall of a high-pressure vessel, because heat transfer occurs between the vessel wall and the bulk food, resulting in a lower temperature near the wall. Hugas *et al.* (2002) reported that a sliced, cooked-meat product processed at 600 MPa for 6 min at 30ºC in two separate machines, showed different results. For machine A, lactic acid bacteria were below the minimum detection level of 10^2 cfu per gram in products stored at 40ºC for 120 days, but only for 30 days in the case of machine B. The authors indicated that this highlights the need to establish validation protocols for high-pressure equipment.

The application of high-pressure treatment to fresh-meat products can result in a cooked appearance, and sometimes the product may develop a rubbery texture, whereas, after conventional cooking, no textural difference is likely to be detected. High-pressure treatment has been reported to extend the shelf-life of lightly-packaged, cooked-meat products by delaying the growth of spoilage microorganisms that can cause 'off' flavours and gas formation in the package (Hugas *et al.*, 2002). The packaging material should be able to provide a strong barrier (about 15% deformation at 600 MPa for a vacuum-packaged meat) and not migrate into the product. In recent consumer surveys, the acceptability level for this technology was reported as 74% in Germany, 71% in France and 55% in the UK. The average acceptability rate of 67% is above the threshold value of 60%, which is considered a positive indication for such a new technology.

9.6.2   High-intensity pulsed electric field

Microbial cells that are exposed to an external electric field for a few milliseconds (for example, a patented process called 'Cool Pure', in which a short burst of high-voltage current is passed through a fluid food placed in between two electrodes) show electrical disruption and structural changes in the cell membrane. A drastic increase in membrane permeability is observed and, when irreversible, results in a loss of viability. The use of non-thermal inactivation of microorganisms might be beneficial to product quality, when preservation processes of this kind are developed for meats. Although the technology was introduced in the 1960s, more recent developments, in particular the use of a continuous treatment chamber, which offers more possibilities for scaling-up applications, has stimulated renewed interest.

Overall, the mechanism of the inactivation of microorganisms by pulsed electric field has yet to be fully elucidated. The major factor seems to be

destabilisation of the membrane and formation of pores, a process called electroporation. Microbial inactivation also depends on many process parameters (electric-field strength, pulse length, pulse shape, number of pulses and start temperature), product parameters (type of food, water activity, pH) and the characteristics of the organisms themselves (type and strain). In general, Gram-positive and Gram-negative bacteria are more resistant than yeasts to this treatment.

9.7   References

BARBUT S (2002), *Poultry Products Processing – An Industry Guide*, New York, CRC Press.

BARBUT S and FINDLAY C J (1989), 'Sodium reduction in poultry products: a review', *CRC Critical Reviews in Poultry Biology*, 2, 59–95.

BARBUT S, MESKE L, THAYER D W, LEE K and MAURER A. J (1988), 'Low dose gamma irradiation effects on *Clostridium botulinum* inoculated turkey frankfurters containing various sodium chloride levels', *Food Microbiology,* 5, 1–7.

BAUTISTA D A, SYLVESTER N, BARBUT S and GRIFFITHS M W (1997), 'The determination of efficacy of antimicrobial rinses on turkey carcasses using response surface designs', *International Journal of Food Microbiology,* 34, 279–292.

CAST (1986), 'Ionizing energy in food processing and pest control', *Wholesomeness of Food Treated with Ionizing Energy*, Ames, Iowa, Council for Agriculture, Science and Technology, 7–28.

FAW R E and CHANG-MEI T Y (1987), 'Radiation preservation of poultry meat', *The Microbiology of Poultry Meat Products*, eds Cunningham, F E and Cox N A, New York, Academic Press, 235–271.

FELLOWS P (1988), *Food Processing Technology*, Cambridge, Ellis Horwood.

GARBUTT J (1997), *Essentials of Food Microbiology*, London, Arnold.

GRUNEWALD T (1961), 'Behandlung von Lebensmitteln mit energiereichen Strahlen', *Ernährungs-Umscha.* 8, 239–242.

HEINZ V, ALVAREZ I, ANGERSBACK A and KNORR D (2001), 'Preservation of liquid foods by high intensity pulsed electric field – basic concepts for process design', *Trends in Food Science and Technology,* 12, 103–111.

HUGAS M, GARRIGA M and MONFORT J M (2002), 'New mild technologies in meat processing: high pressure as a model technology', *Meat Science,* 62, 359–371.

JAY J M (2000), *Modern Food Microbiology* New York, Aspen Publishing.

JOSEPHSON E S (1983), 'Radapperization of meat, poultry, fin fish and special diets', in *Preservation of Food by Ionizing Radiation*, Vol. III, eds Josephson, E S and Peterson M S, Boca Raton, Florida, CRC Press.

LUND B M, KNOX M R and COLE M B (1989), 'Destruction of *Listeria monocytogenes* during microwave cooking', *Lancet*, I, 218–222.

MULDER R W A W (1982), *Salmonella Radicidation of Poultry Carcasses*, Report no. 363, Beekbergen, Netherlands, Spelderholt Institute for Poultry Research.

NIEMAND J G, HAAUSER G A M, CLARK I R and THOMAS A C (1977), *Radiation Processing of Poultry*, Report PER-16, Pelindaba, South Africa, Atomic Energy Board.

SHELEF L A (1983), 'Antimicrobial effects of spices', *Journal of Food Safety*, 6, 29–44.

SIMPSON R K and GILMOUR A (1997), 'The effect of high hydrostatic pressure on *Listeria*

monocytogenes in phosphate-buffered saline and model food systems', *Journal of Applied Micriobiology*, 83, 181–188.

THAYER D W (1994), 'Wholesomeness of irradiated foods', *Food Technology,* 48(5), 132–137.

WHO (1981), *Wholesomeness of Irradiated Food*, Report of Joint FAO/IAEA/WHO Expert Committee Tech. Rep. 65. Geneva, World Health Organization.

YUN J, SHAHIDI F, RUBIN L J and DIOSADY L L (1987), 'Oxidative stability and flavour acceptability of nitrite-free curing systems', *Canadian Institute of Food Science and Technology Journal,* 20, 246–251.

10

Production of turkeys, geese, ducks and game birds

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10.1   Introduction

According to the FAO (2003), world production of poultry amounted to 72 000 000 tonnes in 2002, which was five times greater than in 1970. These figures illustrate the dramatic increase in global poultry production during the last 30 years. With 62 000 000 tonnes produced in 2002, chicken remains the predominant species and its geographical distribution is virtually world-wide. Others types of poultry are mainly duck, goose and turkey, while certain gamebirds (quail, pigeon, pheasant, guinea fowl, etc.) also occur, although they represent a very small proportion of the total output and it is difficult to find exact production figures for them. Moreover, in developing countries, some of these birds are not raised on organized farms, but rather at a local level (to provide family income) and, again, it is impossible to account for them all.

In 2002, duck, goose and turkey represented the same proportion (around 15%) of total poultry production as in 1970 (see Table 10.1). While the overall situation has not changed, it is noticeable that, over this 30-year period, the proportion of turkey has slightly decreased and palmiped production has increased. A key factor in these changes could be the differing geographical distribution of the industries: turkey production is found mainly in developed countries (Europe and North America), while production of palmipeds is generally more common in Asia and South America. It is also apparent that, by the end of the twentieth century, the type of turkey being produced had been completely transformed to provide the modern lines that are suitable for further processing and manufacture of poultry products. On the other hand, production of smaller birds, to be sold as whole carcasses for traditional-type meals, has decreased.

Table 10.1   World production (in thousands of tonnes) of chickens, turkeys, ducks and geese in 1970 and 2002 (FAO, 2003)

	Total	Chickens	Turkeys	Ducks	Geese
1970	15 000	13 000	1200	488	226
1980	26 000	23 000	2000	700	282
1990	41 000	35 000	3700	1200	616
2002	74 000	63 000	5200	3000	2000

For all species, important steps have been taken to control the conditions of production and the quality and safety of the final product. This allows consumers in developed countries to find a very large diversity of poultry products in supermarkets. Because this type of consumer always wants something different, it is necessary to continue developing new products. These innovations could involve new processes adapted to deal with different kinds of poultry meat, or simply a widening of the choice available among the existing range of products.

10.2   Turkey production

Turkeys originate from Mexico, where they were first domesticated. The Spanish Conquistadors brought them to Europe and also introduced them to eastern North America. These birds bred freely with the local eastern turkey, *Meleagris gallopovo sylvestris*, giving hybrid birds that were much larger and more vigorous than the Mexican domestic parent (Crawford, 1995). This new breed (American bronze) rapidly replaced the original black European-Mexican bird. Selection for the broad-breasted trait in the bronze hybrid stock began in Canada at the beginning of the twentieth century. According to Crawford (1990), the entire world turkey industry is based largely on these two North American events: hybridization with the eastern wild turkey and selection for massive breast-muscle development.

Today, turkeys are commonly found in developed countries as meat-producing birds (Table 10.2). Nearly all the birds are produced under intensive conditions and are the result of selection programmes favouring high growth rate and meaty carcasses. Although most are white-feathered, there is still the smaller type of bird (black- or bronze-feathered), which is much closer to the original stock. These birds are traditionally bought as whole carcasses at Christmas, Easter or Thanksgiving and range from 2.5 to 5.0 kg dressed weight. While the tradition continues for these large family occasions, most of the actual market for turkey meat is in further-processed products, such as different cut portions, turkey ham, steaks and sausage (Bolla, 2001).

Male and female turkeys show considerable sexual dimorphism and are killed at different ages. To respond to the demands of both processors and consumers,

Table 10.2   Main countries producing turkeys in 2002 (FAO, 2003).

Country	Production*	Percentage
United States	2 533 000	49%
France	720 000	14%
Germany	375 000	7%
Italy	340 000	7%
United Kingdom	256 000	5%
Brazil	175 000	3%
Canada	150 000	3%
Hungary	120 000	2%
Others	523 974	10%
Total	5 192 974	100%

* Millions of tonnes.

the two main breeding companies, British United Turkeys and Nicholas, have developed several breeds with different growth characteristics (Table 10.3). With these different performance attributes, combined with different methods of production (stocking density, feeding programme, access to free range, etc.) and age at slaughter, farmers are able to cover all the market requirements. The duration of the egg incubation period is 28 days and, subsequently, the rearing period is classically divided into three stages: starting, growing and finishing. The feeding programme for these commercial birds is generally as follows:

- Starting diet (ME/kg): 3100 kcal and 27% crude protein
- Growing diet (ME/kg): 3000 kcal and 24.5% crude protein
- Finishing diet (ME/kg): 3000 kcal and 18% crude protein.

Table 10.3   Body weight and feed conversion ratio (FCR) for different breeds of turkey according to slaughter age (BUT, 2003; Nicholas, 2003)

Breeding company	Line	Sex	Age (weeks)	Body weight (kg)	FCR
Nicholas	300	M	18	14.83	2.35
		F	13	6.92	2.19
	700	M	22	20.54	2.92
		F	16	9.47	2.42
British United Turkeys	BUT 8	M	22	17.73	2.73
		F	16	8.19	2.54
	BUT 9	M	22	18.69	2.70
		F	16	8.79	2.48
	Big 6	M	22	20.72	2.73
		F	16	9.88	2.49
	BUT Bronze	M	22	16.77	2.72
		F	16	7.87	2.54

Turkey production can be highly integrated, but most French farmers obtain their day-old poults from specialized hatcheries. Thus, farmers usually own their poultry houses, but purchase the birds and the feed. At the end of the rearing period, they simply sell their complete stock of birds to a slaughterhouse, which will produce the processed carcasses. When compared with other kinds of poultry, turkeys present numerous advantages as meat producers (Shalev, 1995). From the sensory viewpoint, turkey meat is very close to that of chickens. The breast meat is white, while thigh meat is red, and, apart from size, very few differences can be found between the two kinds of poultry meat. Whole carcasses are purchased only when relatively large birds are required for special family meals, while hybrid birds (bigger than the original turkey) are dedicated to portioning or further processing. The latter represents more than 90% of the total world production. Turkeys contain very little fat and have a high protein content. They also have a very good growth rate that is associated with efficient feed utilization, leading to the lowest production cost per kg of edible protein for any type of poultry. These advantages are largely due to the success of genetic selection, which has been applied intensively to turkeys over the last 50 years. However, selecting animals for a high growth rate and an increased yield of breast meat has led to females with a low rate of egg production and males that are unable to mate naturally, making resort to artificial insemination essential.

According to Nixey (2002), the most significant trends in turkey production in recent years have included the following:

- Increasing body weight, but the rate of increase slowing down because processing plants do not want birds heavier than 21 kg.
- Reductions in killing age that will be difficult to sustain because age has a large influence on breast meat yield and breast muscle tends to develop relatively late. Also, when growth is too rapid, the health of the birds can be compromised, particularly in relation to the strength of the legs.
- Improvements in egg production by extending the laying period. Ten years ago, the norm would have been to plan for a 20-week laying period, whereas it is now 22 or 24 weeks for heavy and for heavy–medium strains, respectively.
- Installation of tunnel ventilation to facilitate heat loss from birds kept in hot climates.
- Increased use of whole wheat in combination with a balanced pellet diet.
- Development of specialized markets, such as free-range and organic production, which may demand different bird strains (Bentley, 2002).
- Development of new further-processed products that tend to imitate dishes or products that have traditionally used pork, beef or lamb.

Bentley (2002) suggested that, in the future, turkey breeders will have to focus more on meat quality, bird welfare and product safety. For meat quality, the main issue is the pale, soft, exudative (PSE) syndrome which is often assumed to be linked directly to genetic selection for increasing growth rate or breast meat yield. However, no direct evidence of this association has yet been

reported. The cause of the syndrome seems to be very uncertain and it is probably due to multiple factors, including genetic composition, bird management, stress before slaughter and rate of carcass cooling. Major turkey breeding companies (Bentley, 1999) also pay attention to other quality traits affecting processing economics, such as causes of carcass downgrading, including breast blemishes and blisters. Leg weakness and injurious pecking are areas where research is either being conducted or is a priority for the future, as is the case for understanding the genetics of disease resistance.

10.3   Duck and goose production

According to Crawford (1995), two distinct types of duck are raised commercially: the domestic, common or Peking duck (*Anas platyrhincos*) and the Muscovy duck (*Caïrina moschata*). By mating a Muscovy drake and a common duck dam, a sterile hybrid, the mulard (or mule duck), can be obtained. It has great commercial importance in South East Asia (meat production), and also in Europe, where it is the traditional bird used for force-feeding. The reciprocal crossbred bird (called a hinny) also exists, but is much more difficult to obtain.

There are two kinds of domestic geese: eastern breeds, which arise from the wild swan goose (*Anser cygnoides*), while western breeds come from the wild greylag goose (*Anser anser*).

In Asia, domestic ducks are preferred to chickens and turkeys as a source of meat and eggs, but have very minor importance elsewhere, where only the meat is usually consumed. Commercially bred domestic birds (Crawford, 1995) are produced in developed countries (Europe and North America), but there are no corresponding layer ducks. Major consumers of goose meat are China, Russia and Eastern European countries, but geese are generally of minor importance in this respect in more developed countries.

Consumers often consider duck and goose meat to be less than ideal from the nutritional standpoint. This view is confirmed by the fact that carcasses usually have a low content of crude protein and a relatively high proportion of fat (Shalev, 1995). The fat content of Muscovy duck is much lower than that of Peking duck and resembles more closely that of the goose (Pingel, 1990). This difference between Muscovy and Peking duck could explain why the former is preferred in Europe (for dietary reasons), while the second is appreciated in China because of its fatty skin. Another major difference between Muscovy and Peking duck is in the number of eggs laid over a given period. This is twice as high in Peking duck (180 per year). These eggs are largely marketed in Asia, and not in Europe, although no selected laying breed of duck actually exists.

Sexual dimorphism is slight in Peking duck, but is important in Muscovy duck (female body weight = 0.6 male body weight). In consequence, all Peking ducks are generally killed between seven and eight weeks of age while the Muscovy males are slaughtered at 12 weeks of age (mainly for cut portions) and
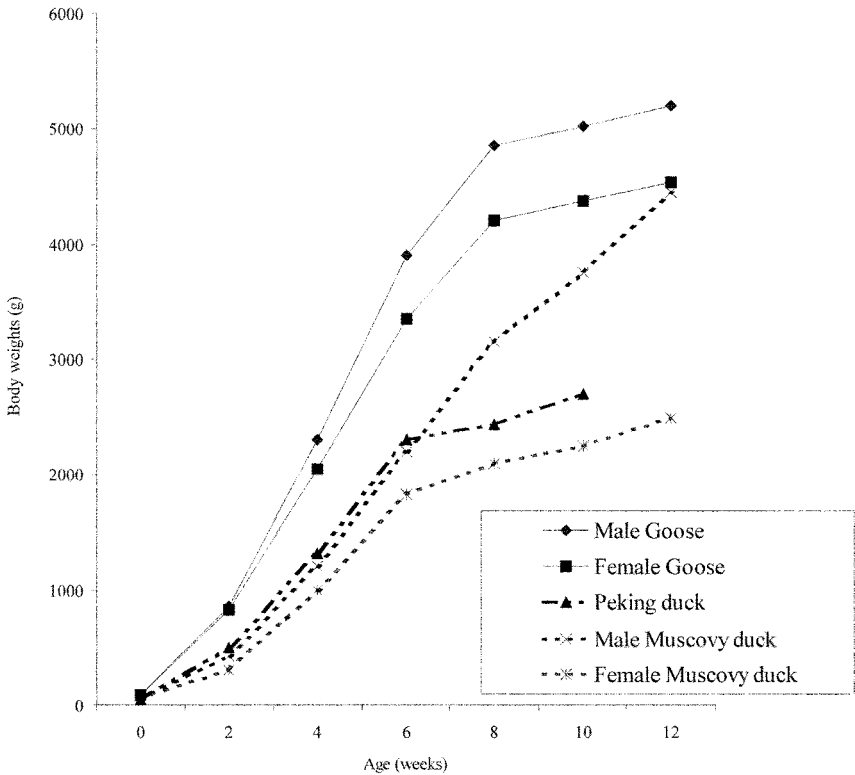
Fig. 10.1   Growth performance of various ducks and geese according to mean slaughter age.

females at 10 weeks of age for whole-carcass marketing. It is noticeable that very few further-processed products are prepared from duck or goose in comparison with chicken and turkey. This could be due to the fact that duck meat has a good natural flavour and does not require further processing to improve its appeal. When reared intensively, geese are generally slaughtered at 12 weeks of age and between five and six months of age for birds reared under more extensive conditions. (Figure 10.1 compares the growth performance of ducks and geese.) The gosling can be plucked by hand to harvest the down from eleven weeks of age onwards and again after an interval of six weeks. Each harvest of gosling down yields between 100 and 140 g.

Nutritional requirements for the two types of duck are very similar (Leclercq *et al.*, 1984) and feeding is generally in three main stages, involving the following:

- Starting diet = 2800 kcal ME/kg and 17.7% crude protein
- Growing diet = 2800 kcal ME/kg and 14% crude protein
- Finishing diet = 2800 kcal ME/kg and 13% crude protein.

For the goose, the recommended regimes are as follows (Leclercq *et al.*, 1984):

- Starting diet = 2700 kcal ME/kg and 17% crude protein
- Growing diet = 2800 kcal ME/kg and 15% crude protein
- Finishing diet = 2900 kcal ME/kg and 15% crude protein.

It is recommended that feed given to geese is supplemented with fresh grass, or access to pasture is allowed. This considerably limits cannibalism between birds and is almost essential with mature individuals. The meat of palmipeds is predominantly red (Pingel and Knust, 1993). In goose, the breast muscle is composed of 80% red and 20% white myofibres (Swatland, 1980), while, for Muscovy duck, these proportions are slightly different (90% red and 10% white), according to Zanusso *et al.* (2003). This high proportion of red myofibres confers on the meat certain organoleptic characteristics, especially flavour and juiciness, which are also associated with a higher lipid content in the breast muscle of approximately 1.5–2.5% of total muscle weight (Baeza *et al.* 1997). In geese, the proportion of fat in breast muscle is similar, but Friend *et al.* (1983) suggest that the Chinese strains tend to be slightly more fatty than the European strains. According to Pingel and Knust (1993), both carcass quality and the nutritional value of the meat have been modified considerably by selection, which tends to increase the proportion of muscle and decrease the fat content. This has been particularly so in Muscovy duck, which is mainly produced in developed countries, as shown by Baeza *et al.* (1997), who compared two strains of Muscovy duck selected for meat yield and fatness. Wezyk and Cywa-Benko (2002) state that the global trends in waterfowl production are mainly concerned with feed conversion and feeding costs, improvement of carcass quality and dressing percentages, and control of environmental pollution. The new trends in duck breeding are also concerned with reproductive traits that are of interest for production of both eggs and meat (Larzul, 2002).

10.4   The process of force-feeding palmipeds

The force-feeding of ducks and geese comes from a very ancient tradition that is illustrated in some paintings discovered on the walls of the pyramids in Egypt. From this origin, it seems that the Jewish people, who are not allowed to eat pork, have kept the tradition going as a means of obtaining fatty meat to savour on special occasions. Today, force-fed ducks and geese are still produced in Central Europe and Israel, but mostly in France (Table 10.4). For several years, however, the production of force-fed geese has been very low and most of the 'foie gras' produced now is from ducks (> 90% of the total production). As can be seen in Table 10.4, France is the main producer, but the quantity of 'foie gras' produced outside France increases slightly year by year. Before the beginning of the 1980s, the French producers were mainly located in the south-west of the country and force-fed small numbers of birds each year. In consequence, this

Table 10.4   World production (in tonnes) of 'foie gras' from ducks and geese (source CIFOG, 2003)

	1995	1999	2000	2001
France	10380	15017	15766	16430
Hungary	1900	1900	1900	1800
Bulgaria	900	800	1000	1000
Israel	300	300	350	300
Poland*	250	30	0	0
Others	250	250	300	350
Total	13980	18352	19336	19860

* Poland decided to stop the production of force-fed birds in 2000.

product had a very limited distribution and was mainly available in famous restaurants or for very special family events, such as Christmas and weddings. Since the early 1980s, some companies have invested in large production units and processing plants, with the goal of giving a more popular image to this luxury product. Some very large and specialized production units now exist in France and it is possible to buy raw 'foie gras' throughout the year, even from certain grocery stores. Nevertheless, the price of the product remains high and its consumption is restricted largely to special events.

Different types of bird can be used for the production of 'foie gras', but, in all cases, they are the males, because females tend to yield liver of a lower quality (venular liver). Most commonly used are mule ducks, which are infertile birds from the mating of a Muscovy male (*Caïrina moschata*) with a common female (*Anas plathyrincos*). Traditionally, pure Muscovy ducks and geese (*Anser anser*) are also used.

From zero to eight weeks, ducks are raised conventionally, with access usually to free-range conditions. From the eighth to the eleventh week of age, they are subjected to feed restriction (amount and time available) in order to prepare the crop to receive a large amount of feed in a restricted time. The force-feeding period generally starts between 11 and 12 weeks of age for ducks and between 12 and 18 weeks for geese.

Force-feeding continues for 12 days in ducks and between 14 and 21 days in geese. During this time, the birds are kept in cages and twice a day they receive a large amount of feed composed mainly of corn. The corn is given as stewed whole grains (traditional) or mixed with water and cornflour (modern method of force-feeding). Because more feed is used than that eaten spontaneously by the bird, farmers employ special machines to introduce the feed directly into the crop of each bird. Thus, it is easy to appreciate that this practice is laborious and time-consuming and largely explains why the final product is expensive to buy.

The development of steatosis in the liver has been studied by several research groups and the main biochemical events in its development are now well understood. During force-feeding, the bird receives very large amounts of corn that is particularly rich in energy, that is, it has a high carbohydrate content.

Because the energy provided is largely in excess, hepatic lipogenesis rapidly increases to maximize lipid production. The resultant lipid is first deposited in peripheral adipose tissue. In consequence, there is a large initial increase in abdominal and subcutaneous fat while liver weight increases only slightly. However, the liver's ability to transfer lipid, via lipoprotein, and the ability to store lipid in adipose tissue are soon saturated, and the newly-synthesized lipid then remains in the liver: this is the beginning of steatosis. At the end of the force-feeding period, the liver shows a ten-fold increase in weight, leading to final weights of approximately 600 and 1000 g in ducks and geese, respectively. To obtain these results, the technical expertise and experience of the farmer are very important. If the daily use of feed is too high, the liver will be heavier, but the risk of mortality in the birds increases rapidly. The technological quality of the product is also lower, because the lipid melts more rapidly during cooking. In contrast, if the amount of feed used is too low, the liver's ability to transfer lipid will not be saturated and all the synthesized lipid will be deposited in the peripheral tissues of the bird.

Consumer opinion varies on whether whole fatty liver from duck or goose is the most prized, but both liver itself and products made from it can be found on the market. Whole 'foie gras' contains more than 50% lipid and less than 10% protein per g of fresh product, so it is far from being a product for the diet-conscious! Moreover, 95% of the total lipid is in the form of triglycerides, and despite large amounts of unsaturated fatty acids (mainly oleic and palmitoleic acids), it is clear that 'foie gras' is not a well-constituted food. 'Foie gras paté' is often sold as a tinned food. The product is a mix of lean liver (from chicken) and fatty liver (from duck or goose). It can be presented with or without the inclusion of whole pieces of true 'foie gras', but, in any case, to qualify as 'foie gras' on the label, the final product must contain more than 50% fatty liver.

As well as being used to produce 'foie gras', the meat of force-fed birds is sold as fresh cut portions (breast, thigh) or in a preserved form. The latter product results from a lengthy period of cooking in fat and the meat can be kept for several months in the fat. Because of the dramatic increase in lipid production during the force-feeding period, the meat from fat ducks is richer in lipid than that from lean ducks, but this confers a very specific taste, flavour and texture on the final product (also called 'confit').

The welfare of palmipeds during force-feeding has been widely discussed in recent years. The first point to decide is whether or not the steatosis developed by the birds is a pathological condition. Investigations have demonstrated that this steatosis is different from that of a pathological liver, because changes, such as necrosis or haemorrhage of the tissue, are not observed during fattening and the hepatic state reverts to normal after force-feeding is stopped (Babilé *et al.*, 1998). Another important issue concerns the fact that most of the birds are force-fed in individual cages, mainly to facilitate their daily handling by the farmer. Recently, the European Commission decided that, at the beginning of 2004, no new individual cages should be installed in either existing or new premises for force-feeding.

10.5   Guinea fowl production

The guinea fowl originates from Africa, where it can still be found as a wild bird. Although it is known that guinea fowl was appreciated by the Romans and the Greeks, it is only since the end of the Second World War that this type of production has really begun to be organized. The most important producers are located in Western Europe and are represented by France, Italy and to a lesser extent, Belgium. According to Eurostat (2003), over 69 million guinea fowl were raised in the European Union (EU) during 2001. Approximately 78% of these birds were produced in France, 20% in Italy and 2% in Belgium. Linked to its position in the EU, France is the primary world supplier of guinea fowl. In consequence, it is also the only country to develop a rigorous selection programme for this bird, which is positioned half way between traditional poultry and game birds (CIP, 2003). The principles for raising guinea fowl are similar to those for chickens. However, due probably to only recent, complete domestication, guinea fowl reared indoors are very noisy, nervous and gregarious, which does not permit easy management. Guinea fowl can be reared in closed poultry houses (intensive production) or preferably with access to free-range conditions (extensive production) via an aviary. In all cases, it is important to remember that guinea fowl are able to fly to some extent. To limit this, a bone is broken in one of the wings of the day-old bird.

The eggs of guinea fowl are slightly less heavy ($< 50\,g$) than those of chickens. The duration of incubation is 28 days and a day-old bird usually weighs 32–34 g. Very young birds are highly sensitive to the prevailing temperature and are generally raised at a density of 40 birds/m^2. The growth pattern of the guinea fowl is very similar to that of the chicken, except that the growth rate of the standard chicken is twice as fast. The birds are killed when they are between 70 and 77 days old, with a body weight of about 1800 g (Fig. 10.2). Throughout their entire rearing period, guinea fowl require no particular attention, except that the stocking density has to be carefully controlled (never more than 15 birds/m^2), because of the gregarious behaviour of the birds. However, it is not unusual to observe birds huddling together when a human being enters the poultry house, and this can lead to the death of some individuals by suffocation, or to significant damage, such as claw marks, thus affecting carcass quality.

The feed of guinea fowl is mainly based on cereals and provides sufficient nutrients for good overall development, with a slight general fattening during the finishing period. Commonly used values are those given by Leclercq *et al.* (1984):

- Starting diet: 3050 kcal ME/kg and 24% protein
- Growing diet: 3150 kcal ME/kg and 20% protein
- Finishing diet: 3100 kcal ME/kg and 14% protein.

This must lead to a final product with a carcass weight (ready-to-cook) between 1.1 and 1.5 kg, showing a thin, uniform layer of subcutaneous fat, no visible
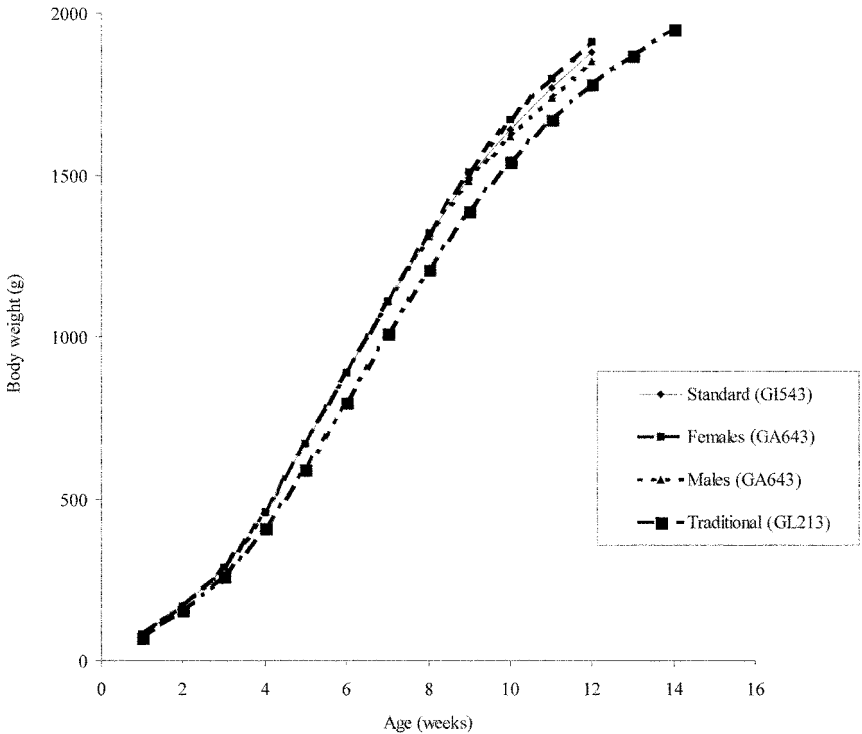
Fig. 10.2   Growth curves of various commercial lines of guinea fowl (Galor, 2003).

carcass damage (haematomas, claw marks, bloody wings), an angular breast and a yellow, uniform skin.

These birds can be produced in four different ways:

- Standard: slaughtered at 77 days (65% of the total production).
- Certified: slaughtered at 82 days (5% of the total production).
- Organic: representing as little as 1% of the total production.
- Label Rouge: reared out in the open with plenty of space, slaughtered on average at 94 days (27% of the total French production in 2002).

The overall chemical composition of the meat of guinea fowl makes it a good source of nutrients for humans and not only a meat with a particular taste. It is interesting to note that 100 g of chicken contains 154 calories (109 for turkeys), whereas 100 g of guinea fowl contains only 134 calories. Meat of guinea fowl contains more protein than red meat and as much as other types of poultry meat (around 22.5%). It also contains relatively large amounts of iron and vitamins E, B1, B2 and pyrophosphate.

Few scientific papers have been published to describe the characteristics of guinea fowl meat, probably because it represents only a small part of overall poultry production and is produced in a very restricted number of countries. Kiessling (1977) described several characteristics of muscle from game birds. In

Table 10.5   Carcass composition (% of body weight) for male and female standard guinea fowl (from Baeza *et al.*, 2001)

Sex	Abdominal fat	Breast muscle	Wing	Thigh and shank
Male	2.45 ± 0.5	16.07 ± 0.92	7.87 ± 0.36	24.34 ± 0.54
Female	3.30 ± 1.00	15.94 ± 1.56	7.69 ± 0.35	23.01 ± 0.92

this paper, the histochemical profile of the muscle fibres of the *M. pectoralis major* (PM) of guinea fowl indicates that 75% of the myofibres are white. This observation places the guinea fowl in a quite different category from chicken or turkey, in which the PM contains 100% white muscle fibres, and is also different from the quail, where the PM contains 75% red fibres. In consequence, the PM of the guinea fowl can be considered as an intermediate meat between the red (duck, goose, quail) and the white (chicken, turkey) breast meats. According to Rémignon *et al.* (1999), the chemical composition of the breast meat, as a percentage of the fresh weight, is:

Dry matter   = 26.50
Minerals   = 1.33
Protein (N*6.25) = 23.66
Total fat   = 1.52

Concerning carcass composition, Leterrier *et al.* (1999) have reported that the carcass weight of females is heavier (+5.58%) than that of males. Females seem to be more compact according to their breast-angle value. Baeza *et al.* (2001) found that females were fatter than males (Table 10.5), but the male did not tend to be meatier. These differences were mainly explained by the earlier body growth and sexual development in the female (Ricard, 1986).

Concerning the sensory quality of the meat, guinea fowl is often compared with chicken, but most consumers recognize that guinea fowl has a particular taste that distinguishes clearly between these two products. Guinea fowl was mainly eaten on special occasions, but this is no longer the case. In consequence, guinea fowl becomes 'more poultry and less game bird'. This is reinforced by the fact that, in France, it is possible to find the meat in almost all supermarkets throughout the year and, increasingly, as cut portions like chicken.

10.6   Japanese quail production

The Japanese quail originates from South-East Asia, where it can still be found as the wild type. Japanese quail should not be confused with other *Coturnix* species, such as Bobwhite quail (*Coturnix virginianus*), which is very popular in the United States (Mills *et al.,*1999). Originally, the Japanese quail was appreciated for its song and it seems that from only around 1940 onwards were these birds selected for increased egg and meat production. Today, the selection

of commercial lines is commonplace and generally based on the approach used for chickens: some specific lines are selected for the meat market, while others are selected for egg production. This section focuses on the production conditions for Japanese meat quail but it is important to remember that the production of quail eggs increases significantly every year. A female can now lay more than 400 eggs in a year!

The Japanese quail has been widely used in animal science, especially by geneticists as a bird model, because it is inexpensive, easy to keep and the birds mature very quickly (between six and seven weeks of age). The eggs are a mottled brown colour and weigh about 10 g. The chicks hatch after 17–18 days of incubation and weigh 8–10 g. Then, the birds grow very rapidly, such that the hatch weight is doubled by five days and tripled by eight days of age (Mills *et al.* 1999). After 5–6 weeks, the birds reach their maximum weight (160–300 g), depending on sex and strain (Gerken and Mills, 1993). Adult females are heavier than the corresponding males. For meat production, birds are killed at about 40 days.

Japanese quails are social birds and they must always be raised in large groups. However, they can be kept under husbandry conditions as diverse as battery cages and outdoor aviaries. A male will react vigorously to the presence of other males and, in breeding flocks, it is necessary to maintain the ratio of males to females at a low level (1:3 respectively). Quails have high nutritional requirements throughout their lives and particularly so during the growing period (Mills *et al.*, 1999). For good development, it is necessary to give the birds different diets, according to their requirements (Leclercq *et al.*, 1984) (see Table 10.6).

At present, there is very little information on body composition for the quail. Oguz *et al.* (1999) reported that the carcass represents approximately 68% of the live weight, while breast and thigh represent respectively 26 and 19% of carcass weight. From a nutritional point of view, carcass composition appears to be similar to that of chicken:

Table 10.6   Feed composition and food intake for male and female quails at different ages

Age (days)		0–20		21–40		> 40	
Diet type		Starter		Grower		Breeder	
ME (kcal/kg)		3000		3000		2800	
Crude protein (%)		25		19		19	
Sex	Male	Female	Male	Female	Male	Female
Food consumption per day (g)	14	15	11	16	15	20

Data from Leclerq *et al.* (1984).

Dry matter   = 27% of wet weight (ww),
Crude protein = 19% of ww
Fat   = 0.6% of ww
Ash   = 0.2% of ww.

According to Kiessling (1977), of all the birds reared artificially, including goose, pheasant, guinea-hen, turkey and chicken, quail is the one with the reddest breast muscle. This indicates that the meat will be very juicy and tasty. Japanese quails are generally sold as fresh whole carcasses, but with different types of presentation. In traditional markets, they can be found with feathers and viscera present, while in supermarkets they will be sold like other poultry, without feathers, viscera, head, etc.

10.7   Pigeon production

The pigeon industry developed mainly in Europe and the United States. However, it is important to distinguish between the keeping of pigeons for racing and show purposes, which are very popular hobbies in many parts of the world, and the rearing of pigeons for meat. In this section, only the last-mentioned activity will be described briefly. The raising of pigeons is different from other kinds of poultry or game bird production, because only very young birds (also called squabs) are produced for the meat market. The main feature of pigeon rearing is that young squabs are raised with their parents, and also fed by them, until slaughter. At present, squabs ready for slaughter are 28–30 days old and weigh between 500 and 700 g depending on their genetic type and method of rearing.

The adults are sexually mature between five and seven months of age, and then are ready to mate. The birds are strictly monogamous and, for this reason, the moment of mating at the beginning of the rearing period is very important for the future success of the production process. Females generally lay one or two eggs in a nest and the total duration of incubation is 17 or 18 days, depending on the season. During this period, the male and the female take turns at sitting on the eggs. At hatching, the nestlings are unable to feed themselves and the so-called 'crop milk' is given alternately by the two parents, following regurgitation. During the first 15 days of life, the squabs are very sensitive to the cold and, because of their poor feathering, they must stay in the nest, covered by the wings of the parents. After this time, the parents will leave them alone in the nest and only help them to feed. Two or three days after the parents have begun to leave the nest regularly, mating will begin again and the female will lay one or two new eggs in a second nest installed in the cage. This alternation of successive laying, hatching and feeding is generally carried out for three whole years before the adults are replaced by a new pair. In good sanitary conditions and with adequate lighting and feeding programmes, a pair of adult pigeons would be expected to produce 14–15 squabs in a year.

Table 10.7   Characteristics of commercial squabs (Europigeons, 2003).

	Line		
	MIRTHYS Hybrid	MIMAS Hybrid	TITAN Hybrid
Productivity			
No. of squabs/pair/year	15.4	16–17	12–13
Birth weight (g)	15	15	15
Weaning age (days)	28	28	28
Body weight (g) at 30 days	610	580	700
Eviscerated yield (% of body weight)	78.4	78.4	78.4
Ready-to-cook yield (% of body weight)	65.6	65.6	65.6

When 30 days old, the squabs begin to fly and are able to feed themselves, so they are ready to leave the nest. It is at this time that the farmer must catch them for killing in a dedicated slaughterhouse. After this point, it will be much more difficult to do so. At the slaughterhouse, the operations include electrical stunning, bleeding, dry plucking, wax plucking (to remove small feathers and down), evisceration and then cooling of carcasses for several hours.

A typical feed for pigeon generally comprises 50% maize, 25% corn and 25% of another protein-rich grain such as pea. Pigeons prefer whole-grain feed and their main nutritional requirements are as described by Leclercq *et al.* (1984):

Crude protein: 13.5%
Carbohydrate: 65%
Crude fibre: 3.5%
Fat: 3%
Energy: 2900 kcal/kg

In addition to a grain ration, pigeons require minerals, vitamins and grit, which is needed for grinding of food in the gizzard. Usually, the feed components are presented separately and the pigeons choose what they want. A pair of pigeons will consume 50 to 55 kg of feed in a year and 200 ml of water in a day.

Because they are mainly sold as whole carcasses, and increasingly as cut portions, meat pigeons are first selected for growth rate and laying performance, which are known to be conflicting interests. Skin colour is important in squabs and the young birds must have a pale, rosy skin. The breast meat is plump, juicy and tender, but must not be overcooked, because, in doing so, it tends to lose flavour. Table 10.7 gives the main characteristics of three selected French lines of pigeon.

10.8   Pheasant production

There are nine different genera of pheasants, but *Phasianus* is the most important in the present context. Despite their Asian origin, wild pheasants are

common in Europe and North America. They have been hunted by humans for a long time and are mainly bred in captivity to ensure adequate stocks. An exception exists in North America where white pheasants are reared artificially and marketed as traditional poultry. In Europe, more than 95% of pheasants are reared for hunting and selection is more concerned with flying capability and capacity for survival in the wild than productivity or growth performance (Gavard-Gongallud, 2000). According to restocking requirements, different types of production can be found.

- Production of pheasants for hunting. The birds are kept for 20 weeks and then sold during the hunting period.
- Production of young pheasants. These birds are between 7 and 16 weeks of age and are sold during the summer. By the following spring, when hunting begins again, they are expected to be fully adapted to their new environment.
- Production of adults. These are sexually mature birds and are sold for introducing new stock into the wild, or to breeders who require new breeding birds.

These types of production represent respectively about 85, 15 and 1% of the total birds produced. Production of pheasants for the meat market is not highly organized, except in North America, where pheasants can be reared only for their meat. In Europe, meat birds usually come from unsold stocks of breeders at the end of the summer. They are usually killed in poultry slaughterhouses and sold as whole carcasses in traditional markets or supermarkets, or used in restaurants. A slight increase in consumer demand is observed towards the end of the year.

There is an important dimorphism in pheasants. The males are highly coloured (depending on species), while the females have a uniform sandy-coloured feathering. The birds are usually raised in small or medium-sized units, where the farmer controls mating, hatching operations and final rearing conditions. The total duration of the incubation period is 24.5 days. For the first three weeks, the chicks must be kept in a closed poultry house, because they are sensitive to temperature changes. From three to five weeks of age, the birds become progressively more accustomed to external conditions, and they are allowed to enter a small, covered area outside. From five to eight weeks of age, the birds have access to an aviary, which has features similar to their natural environment, including trees, bushes, hedges, etc. From eight weeks onwards, the birds have become well adapted to these conditions. Usually, cereals such as wheat, maize and sunflowers are grown in the aviary to further accustom the birds to their future wild environment. At every stage of rearing, human contact must be restricted, so that the birds develop a natural aversion to humans.

The recommended feed values from Leclercq et al. (1984) are:

- Starting diet (0–4 weeks): 2900 ME kcal/kg and 27% crude protein.
- Growing diet (5–12 weeks): 2770 ME kcal/kg and 16% crude protein.
- Finishing diet (after 12 weeks): 2700 ME kcal/kg and 15% crude protein.
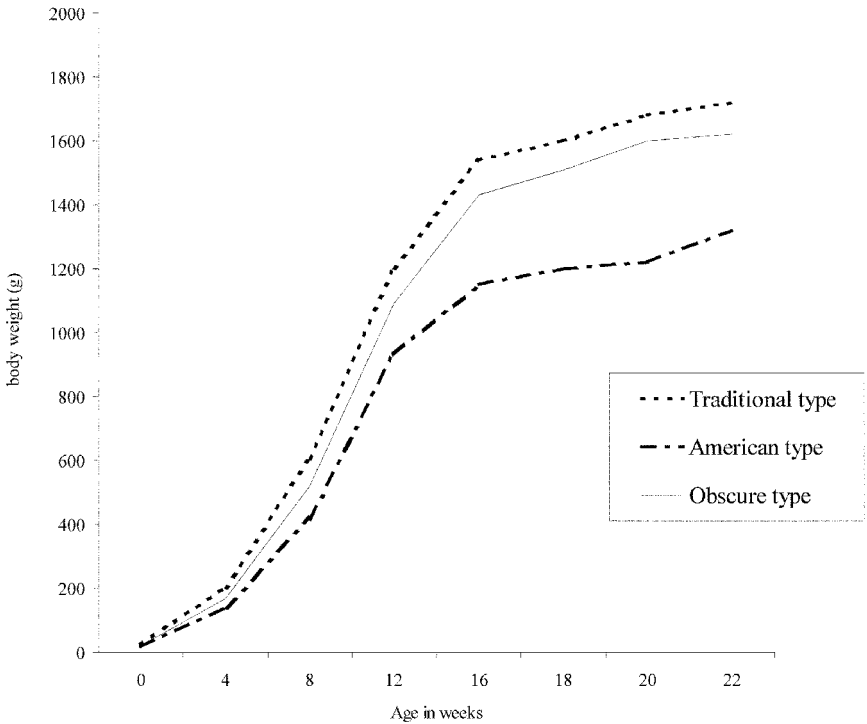
Fig. 10.3   Growth curves of different types of commercial male pheasants (Gibovendée, 2003).

The growth performance of the pheasant is generally followed for a 22-week period, because it is the maximum age at which the birds can be successfully reintroduced into the wild. After this, the chances of survival are less and it is difficult to follow their growth. Figure 10.3 gives growth curves for several types of pheasant, selected or unselected, for flying capability and/or heavy body weight.

In most cases, carcass yield is around 70–75%, with a PM muscle yield of 15%. According to Kiessling (1977), the structure of the PM muscle of the pheasant is very close to that of the guinea fowl. The muscle is composed of one third red and two thirds white muscle fibres. This provides a muscle that is not easily fatigued and is good for long flights, and a red meat that contains a relatively high proportion of intramuscular fat.

10.9   Future trends

Over the last 15 years, poultry production has changed and more and more poultry products are sold as value-added items. This tendency began with turkeys and now many of these birds are produced only for further processing. In

future, the trend is likely to continue, because consumer demand for meat is always focussed on greater innovation, more diversity and more 'ready-to-heat–ready-to-eat' products. It seems that meat technologists have understood this message well, at least for turkey meat, and they will continue to develop many more further-processed turkey products. This includes products that are brine-cooked or marinated and those like frankfurters or sausages, in which mechanically deboned meat is utilized. These products are generally associated with new and different 'tastes' (Tex-Mex, Indian, Mediterranean, for example), due to the use of specific spices and other aromatic ingredients. In consequence, the initial taste and aroma of the raw meat tend to be less important. Although the development of these products is a good way of giving added-value to the raw meat, there are also some specific problems, such as poor processing yield, low water-holding capacity, variation in colour, need for longer shelf-life and new types of packaging. All these new problems are largely related to the technology of the process, but are also linked to the initial properties of the meat (colour, protein composition, pH) and breeding companies, farmers and processors must work together to improve the quality of manufactured products.

In France, relevant studies are being made at the Institut National de la Recherche Agronomique, the Centre Technique de la Salaison de la Charcuterie et des Conserves de Viande, the Centre Technique de la Conservation des Produits Agricoles, the Comité Interprofessionnel de la Dinde Française, the Institut Technique Avicole, the Office National Interprofessionnel des Viandes, de l'Elevage et de l'Aviculture, etc.

For duck and goose, it is important to distinguish clearly between the situation for lean birds and that of those being force-fed. For the force-fed palmiped (either duck or goose), few major technical innovations are anticipated, because this type of production is typically a traditional one and most consumers would wish the tradition to be maintained, regardless of any new products. Some special ways of cooking this luxury product are known to exist, but are generally carried out only in fine restaurants.

France is the world's most important producer and consumer of 'foie gras', but is opposed in this respect by countries from the northern part of the EU because of questions about the welfare of the birds. Nevertheless, for most French people, the 'foie gras' is a typical part of their history and culture and, at present, it is inconceivable that anyone should consider prohibiting this product. Nevertheless, animal rights associations from all over the world claim that force-feeding practices must be stopped immediately because of injury to the bird. In reality, it is not easy to demonstrate what really affects the bird during the force-feeding period: is it the twice-daily manipulation of the bird, restriction of movement or ingestion of very large quantities of feed? So far, only modification of cage size has been imposed on producers by the European Commission, but no new individual cages can be installed, and in 2010 all force-feeding cages must be communal, to accommodate five or six birds. The very specialized production of force-fed palmipeds and the final price of the 'foie gras' will probably limit its future expansion, both within France and elsewhere.

At the research level, work on this topic is done at the Ecole Nationale Supérieure Agronomique de Toulouse and the Institut National de la Recherche Agronomique in collaboration with the Comité Interprofessionnel du Foie Gras.

Concerning lean palmipeds, the new selected lines of ducks are very meaty and give highly reproducible rearing results. Consumers seem to like this red type of poultry meat and the production has slightly increased. Nevertheless, because the price of duck meat is usually higher than that of chicken or turkey, this often discourages people from buying it more often. Only an increase in production would lead to any decrease in price and such an expansion could be linked to the manufacture of further-processed products, which are increasingly popular as tastier counterparts to those from chicken or turkey.

Guinea fowl is in a different position, because it is well known to French consumers, and consumption is more or less stagnant. This is probably due to the price of the carcass, associated with its small size, which discourages people from buying it more often. The higher price is largely justified by the length of the rearing period, the slower growth of the birds, poorer feed conversion, higher mortality rate, etc. Because the raw product is sometimes difficult to sell, the development of new products has been unattractive. In future, French producers (linked by the Comité Interprofessionnel de la Pintade) are unlikely to promote any new developments and will prefer to defend the natural image of guinea fowl by producing more organic and Label Rouge birds that are different from any kind of intensive production.

For other game birds, such as pigeon, quail and pheasant, the market level is very low, and no major product development is anticipated, because producers must first improve their production methods. Eventually, this would reduce the price of the product and lead to better information for consumers on the choice of meat available in the market place.

10.10   Conclusions

For all types of poultry described above, apart from turkey, the meat is rarely subjected to any further processing. This is probably due to the fact that these birds produce a meat that is clearly different from that of the chicken and is appreciated as such by the consumer. The unique character of the meat is supported by the fact that all the products described here are usually much more expensive than either a standard or a traditional chicken. In contrast, turkey producers have readily accepted that their product is too close to chicken meat to be clearly distinguished from it on any basis other than size. In consequence, they have developed new processed products that can be produced at a very low cost. These products have been highly successful and are even copied by the chicken industry. There have been some attempts to develop the same type of products for guinea fowl, duck and quail, but such products have been difficult to promote. This is partly due to the high price of the raw material – the meat – and is associated with less efficient or well-organized production systems.

10.11   References

BABILÉ R., AUVERGNE A., DUBOIS J-P., BÉNARD G. and MANSE H. (1998), 'Réversibilité de la stéatose hépatique chez l'oie', *Proceedings of the 3èmes Journées de la Recherche sur les Palmipèdes Gras, Cigof-Inra, Paris*, 45–48.

BAEZA E., DE CARVILLE H., SALICHON M-R., MARCHÉ G. and LECLERCQ B. (1997), 'Effects of selection, over three and four generations, on meat yield and fatness in Muscovy ducks', *British Poultry Science* 38, 359–365.

BAEZA E. JUIN H. REBOURS G. CONSTANTIN P. MARCHÉ G. and LETERRIER C. (2001),'Effect of genotype, sex and rearing temperature on carcass and meat quality of guinea fowl', *British Poultry Science* 42, 470–476.

BENTLEY J.S. (1999), 'Meat characteristics of turkeys: a breeder perspective' *Proceedings of the Fourteenth European Symposium on the Quality of Poultry Meat*, Bologna, Italy, eds Cavalchini L.G. and Baroli D., Milano, Associazione Italiana di Avicoltura Scientifica, Milan (Italy), 9–28.

BENTLEY J.S. (2002), 'Breeding for future market trends in the turkey meat', in *Proceedings of the Eleventh European Poultry Conference*, Bremen, Germany. Full papers are only available on CD ROM (German Branch of the World's Poultry Science Association).

BOLLA G. (2001), 'Raising turkeys' Agfact A5.0.9, third edition, April 2001. Available at http://www.agric.nsw.org.au

BUT (2003), http://www.but.co.uk

CIFOG (2003), http://www.cirad.fr/itavi.cifog.htm

CIP (2003), http://www.pintade.com

CRAWFORD R.D. (1990), 'Poultry genetic resources: evolution, diversity, and conservation', *Poultry Breeding and Genetics*, ed. Crawford, R.D., Amsterdam, Elsevier Science Publishers, 27–52.

CRAWFORD R.D. (1995), 'Origin, history and distribution of commercial poultry', *Poultry Production – World Animal Science,* ed. Hunton P., Amsterdam, Elsevier, 1–20.

EUROPIGEONS (2003), http://www.grimaud.fr

EUROSTAT (2003), http://europa.eu.int

FAO (2003), http://apps.fao.org.

FRIEND D.W., KRAMER J.K.G. and FORTIN A. (1983). 'Effect of age, sex and strain on the fatty acid composition of goose muscle and depot fats', *Journal of Food Science* 48, 1442–1444.

GALOR (2003), http://www.galorfrance.com

GAVARD-GONGALLUD N. (2000), *L'Elevage du Gibier à Plumes*, Paris, Editions France Agricole.

GERKEN, M. and MILLS, A.D., (1993), 'Welfare of domestic quail', *Proceedings of the Fourth European Symposium on Poultry Welfare*, eds Savoy C.J. and Hughes B.O., Potters Bar, Universities Federation for Annual Welfare 158–176.

GIBOVENDÉE (2003), http://www.gibovendee.com

KIESSLING K-H. (1977), 'Muscle structure and function in the goose, quail, pheasant, guinea hen and chicken', *Comparative Biochemistry and Physiology* 57B, 287–292.

LARZUL C. (2002). 'New tendencies in duck breeding', *Proceedings of the Eleventh European Poultry Conference*, Bremen, Germany. Full papers are only available on CD-ROM (German Branch of the World's Poultry Science Association).

LECLERCQ B., BLUM J-C., SAUVEUR B. and STEVENS P. (1984), 'Recommandations

alimentaires pour les volailles', in *L'Alimentation des Animaux Monogastriques: Porc, Lapin, Volailles*, Paris, Institut National de la Recherche Agronomique, 86–145.

LETERRIER C., BAEZA E., REBOURS G., CONSTANTIN P., MARCHÉ G. and JAMENOT P. (1999), 'Label production of guinea-fowl and carcass quality', *Proceedings of the Fourteenth European Symposium on the Quality of Poultry Meat,* Bologna, Italy, eds Cavalchini L.G. and Baroli D., Milano, Associazione Italiana di Avicoltura Scientifica, 265–270.

MILLS A.D., FAURE J-M. and RAULT P. (1999), 'The japanese quail', *The UFAW Handbook on the Care and Management of Laboratory Animals – Volume 1*, London, Blackwell Science, 697–713.

NICHOLAS (2003). http://www.nicholas-turkey.com

NIXEY C. (2002). 'Trends in turkey production', *Proceedings of the Eleventh European Poultry Conference*, Bremen, Germany. Full papers are only available on CD ROM (German Branch of the World's Poultry Science Association).

OGUZ I., AKBAS Y., KIRKPINAR F. and ALTAN, O. (1999), 'Carcass characteristics and carcass composition in lines of Japanese quail (*Coturnix coturnix japonica*), unselected and selected for four-week body weight. *Journal of Applied Animal Research* 15, 175–180.

PINGEL H. (1990), 'Genetics of growth and meat production in waterfowl', *Poultry Breeding and Genetics*, Amsterdam, Elsevier, 691–704.

PINGEL H and KNUST, U. (1993), 'Review on duck meat quality', *Proceedings of the Eleventh European Symposium on the Quality of Poultry Meat* , eds Colin P., Culioli J. and Ricard F, Tours, Institut National de la Recherche Agronomique, 26–38.

RÉMIGNON H., APPIA E., MANSE H. and BABILÉ R., (1999), 'Comparisons of muscle parameters in two lines of Guinea-fowl reared at two temperatures', *Proceedings of the Fourteenth European Symposium on the Quality of Poultry Meat,* Bologna, Italy, eds Cavalchini L.G. and Baroli D., Milano, Associazione Italiana di Avicoltura Scientifica, 301–307.

RICARD F-H., (1986), 'Composition anatomique de la carcasse du canard mulard comparée aux deux types parentaux', *Proceedings of the Seventh European Poultry Conference*, Paris, ed. Larbier M., World's Poultry Science Association (French Branch), 3, 47–64.

SHALEV B.A. (1995), 'Comparative growth and efficiency of various avian species' Poultry Production – World Animal Science, ed. Hunton P., Amsterdam, Elsevier, 53–78.

SWATLAND H.J. (1980), 'Muscle fiber histochemistry in breast and leg meat of geese'. *Canadian Institute of Food Science and Technology*, 13(3), 135–136.

WEZYK W and CYWA-BENKO K. (2002), 'Global trends in waterfowl production and science', *Proceedings of the Eleventh European Poultry Conference*, Bremen, Germany. Full papers are only available on CD-ROM (German Branch of the World's Poultry Science Association).

ZANUSSO J, RÉMIGNON H., GUY, G., MANSE H. and BABILÉ R, (2003),'Effects of overfeeding on myofiber characteristics and metabolical traits of the breast muscle in Muscovy ducks'. *Reproduction, Nutrition and Development*, 43, 105–115.

11

Microbial hazards in production and processing

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11.1 Introduction

Global demand for poultry meat continues to grow year by year (Bilgili, 2002). Throughout the world, however, production methods vary from that of the free-range village chicken of developing countries to the highly intensive systems used in other regions, where poultry production is one of the most technologically advanced sectors of agriculture. In many of the larger companies, the operation is partly or completely integrated and a single organisation may own breeding farms, hatcheries, feed mills, growing units and primary and further processing plants. Over the years, there have been continuous improvements in bird growth performance and feed conversion, and considerable economies of scale in both production and processing. In addition, increasing mechanisation of processing has reduced the need for plant personnel to a minimum. Despite all these advances, microbiological hazards remain at all stages of the production chain and this chapter will consider the principal microbial agents that are relevant to product safety and quality, their behaviour on the farm and in the processing plant, and the means available for control purposes.

Live poultry carry many different kinds of microorganisms on the skin, among the feathers and in the alimentary tract, and any of these organisms may ultimately become contaminants of processed products (Mead, 1989; Waldroup, 1996). The presence of the organisms and their spread over the outside of each bird is related to the conditions of rearing and transportation to the processing plant, during which the birds are in continuous contact with their droppings and those of their cohorts. The organisms of concern include foodborne human pathogens discussed in Chapter 1 and spoilage organisms, the properties of

which are described by Garcia-Lopez *et al*. (1998) and Holzapfel (1998). Organisms that can spoil chill-stored, raw poultry products include, principally, *Pseudomonas* spp., certain lactic acid bacteria and yeasts. These and other psychrotrophic microbes may originate in the farm environment, or even some water supplies used in processing and, once in the processing plant, will be capable of multiplying on all wet surfaces.

On the farm, increasing attention is being given to the control of foodborne pathogens, although the organisms do not usually cause disease in the birds themselves. While modern conditions of intensive rearing can put many birds at risk, if pathogens of any kind gain access to the flock, the use of controlled-environment housing in temperate countries does provide the possibility of maintaining flock biosecurity (see below), which is a key element in pathogen control. By reducing the risk of infection on the farm, any subsequent problem in the processing plant is also diminished, although total elimination of pathogens from the farm environment cannot be achieved at present by any practicable, cost-effective means.

During processing, hygiene control measures act to limit levels of microbial contamination on carcasses, but do not entirely prevent any hazardous organisms present from spreading among the carcasses. Controls are hampered by the nature of modern mechanised processing systems, which are geared primarily to speed of operation, efficiency and maintaining product yield. Only in the case of manufactured products is it possible to use treatments that can effectively eliminate undesirable organisms and prevent re-contamination. A particular problem in primary processing is that microbial contaminants readily become attached to carcass surfaces and are not easily removed by subsequent washing procedures. The possible mechanisms of attachment or entrapment in the skin were reviewed by Mead (1989) and practical consequences, such as enhanced resistance to heat and chlorine, were considered by Notermans *et al*. (1991) and Lillard (1993). No entirely effective means of detaching the organisms has yet been developed.

11.2   Microbial hazards on the farm: *Salmonella* and *Campylobacter*

Of the foodborne pathogens described in Chapter 1, those that are currently most important in the poultry industry are *Salmonella* and *Campylobacter* spp. and, in many countries, live poultry are recognised as a major reservoir of these bacteria. Some of the organisms present will become contaminants of processed carcasses, and handling and consumption of raw or undercooked poultry are potential risk factors in human food poisoning. Among the large number of *Salmonella* serotypes that are known to exist, relatively few are associated with poultry, but almost all appear capable of causing gastroenteritis in man, and need to be controlled in poultry operations. The emphasis now being given to on-farm control relies on the application and refinement of appropriate

biosecurity measures. This concept involves the effective use of hygiene precautions and can be defined as 'a set of management practices which, when followed, collectively reduce the potential for the introduction or spread of disease-causing organisms onto and between sites' (Lister, 2002). In an epidemiological study from hatchery to slaughterhouse, Heyndrickx *et al.* (2002) showed that horizontal transmission of *Salmonella* to broilers during the rearing period and contamination in the processing plant were key factors in determining the *Salmonella* status of the end-product and were clearly more important in this respect than the early stages of production. Furthermore, significant associations were found between the contamination level of a flock and hygiene control of the broiler house and its feed and water supplies. Deficiencies in hygiene management of crates used to transport birds to the processing plant were also highlighted as a problem.

Throughout the supply chain, much is known about the sources of *Salmonella* infection in poultry and product contamination, as well as the measures needed for control purposes. The possible on-farm sources can be summarised as follows:

- use of contaminated feed
- vertical transmission from infected breeding stock to their progeny via the hatchery
- horizontal transmission during rearing from a variety of potential animal vectors, including rodents, insects and wild birds, via the stockman and other individuals that enter the house, and through items of equipment, etc., that were previously contaminated and not effectively cleaned and disinfected prior to reuse.

Although measures are taken at feed mills to eliminate salmonellas and maintain appropriate hygiene standards, feed is manufactured from ingredients that are sometimes contaminated with salmonellas, especially the protein component. The effectiveness of any heat treatment used depends not only on the temperature and time of heating, but also on the moisture content of the feed, which should be sufficient to allow destruction of vegetative bacteria. After the heating process, recontamination with *Salmonella* can sometimes occur during cooling of the feed in air containing dust or during subsequent handling, storage or transportation of the final product. In modern, well-controlled feed mills, contamination of finished feed is likely to be at a low level; nevertheless, even small numbers of *Salmonella* can be significant, because young chicks may become colonised by as few as one colony-forming unit per gram of feed (Williams, 1981). With breeder feeds in particular, addition of certain short-chain organic acids, such as formic and propionic acids, has been associated with a reduction in *Salmonella* colonisation in birds given the treated feed (Hinton and Linton,1988). The acids do not eliminate salmonellas from the dry feed, but kill the organisms in the crop of the bird, when the feed has been moistened following consumption. Other possible methods of feed treatment have been reviewed by Davies and Hinton (2000) and van Immerseel *et al.* (2002).

Serotype Enteritidis is an outstanding example of an invasive salmonella that can be vertically transmitted via an infection of the reproductive tract of the hen and contamination of egg contents. Within the European Union (EU), both hatcheries and breeder flocks are subject to statutory monitoring for salmonellas and any flocks found to be carrying the invasive serotypes Enteritidis or Typhimurium must be destroyed by law. This strategy, coupled with the voluntary use of vaccines by, for example, the UK poultry industry, whether in the form of attenuated or inactivated preparations, has led to a steady decline in the isolation of Enteritidis from chickens since 1994 (VLA, 2002). The importance of horizontal transmission, which applies to all salmonellas capable of colonising poultry, has been highlighted above and various potential sources are implicated. Any type of poultry flock is susceptible to a *Salmonella* challenge from the rearing environment, and hence the importance of comprehensive biosecurity measures, including control of rodents, insects and wild-birds, and limiting visitor access to the house. Elimination of salmonellas after the rearing of a positive flock can be difficult, since the organisms survive well outside the avian host and intensive sampling of residual house-dust after routine cleaning and disinfection may reveal their continuing presence (Davies and Wray, 1996). One possible means of reducing horizontal transmission is the use of so-called 'competitive exclusion' treatment. This is based on the fact that commercial chicks are slow to develop the complex intestinal microflora of older birds, because they are produced and reared initially under highly sanitised conditions, and have no contact with the mother hen. In the first few weeks of life, chicks are particularly prone to *Salmonella* colonisation due to the lack of microbial competition in the alimentary tract. Early establishment of an adult-type flora greatly increases the resistance of the chicks to a *Salmonella* challenge (Nurmi and Rantala, 1973), and the protection appears to be unaffected by the breed, sex or immune status of the recipient birds, while being active against all food-poisoning salmonellas studied so far (Mead, 2000a). Various commercial treatment products of this type are available for use and are given orally to the birds. Like vaccines and anti-salmonella feed additives, however, the treatment is not usually given routinely to broiler flocks, largely because of cost.

It is clear that *Salmonella* and *Campylobacter* are very different from one another in their growth requirements and general properties, and they respond differently to environmental pressures. Campylobacters, for example, have a relatively high optimum growth temperature, require a reduced oxygen tension and are much more sensitive to dry conditions than salmonellas. Whereas young birds are more prone to *Salmonella* infections, *Campylobacter* can infect birds of any age, the minimum infective dose being approximately 10 cells per bird. In practice, poultry flocks are rarely colonised by *Campylobacter* before 2–3 weeks of age, due, possibly, to the presence of maternal antibodies (Sahin *et al*., 2001). Once present in a flock, however, they spread rapidly and colonisation persists at a high level ($> 10^6$/g of faeces) for the life of the flock. Up to 90% of commercial broiler flocks become colonised at some point in the rearing period. Although campylobacters appear to survive less well outside the host than

Table 11.1   Transmission and control potential compared for *Salmonella* serotypes and thermophilic *Campylobacter* spp.

Characteristic	Salmonella	Campylobacter
Mainly young birds susceptible	+	-
Potential for vertical transmission	+	+
Environmental persistence	+	?*
Possible horizontal transmission from:		
feed	+	-
rodents	+	+
wild birds	+	+
insects	+	+
contaminated water supply	+	+
external environment via footwear of stockman	+	+
Availability of vaccines, competitive exclusion treatment	+	-

* Apparently poorer survival than *Salmonella,* but existence of viable, non-culturable forms.

Salmonella, viable, but non-culturable forms are known to occur (Rollins and Colwell, 1986). Any role that they may have in relation to flock infection is presently unknown, and may be overshadowed by the large numbers of normal vegetative cells that are shed by infected birds, as well as the fact that many different animal hosts can become colonised. Nevertheless, being quite fragile organisms, campylobacters are readily destroyed during routine cleaning and disinfection of poultry houses, and it might be expected that flock biosecurity would be more effective as a control measure than appears to be the case.

Similarities and differences in the transmission potential of *Salmonella* and *Campylobacter* are shown in Table 11.1. While vertical transmission of *Campylobacter* used to be regarded as unlikely, because of poor survival in eggs, there is evidence now that it can occur (Pearson *et al*., 1996; Cox *et al*., 1999), albeit more rarely than the horizontal route. In contrast to *Salmonella*, there would be no prolonged survival under the dry conditions of manufactured feed and therefore feed is not implicated in the transmission of campylobacters to poultry. What makes control of *Campylobacter* infection difficult at the present time is that no specific intervention measures are available for commercial use (Table 11.1).

11.3   Feed withdrawal and transportation of live poultry

Before transporting birds from the farm to the processing plant, feed is usually withdrawn from the flock for several hours. This is a means of reducing the potential for spreading faeces from the caeca and colon among the birds being transported, and then again during carcass processing. Thus, there is a gradual emptying of the alimentary tract. A disadvantage of feed withdrawal is the effect on conditions in the crops of the birds, which are a possible reservoir of both *Salmonella* and *Campylobacter* (Hargis *et al*., 1995; Byrd *et al*., 1998; Corrier *et*

al., 1999). Without exogenous nutrients, the ability of the crop to suppress these foodborne pathogens declines, as populations of lactic acid bacteria diminish, along with concentrations of inhibitory volatile fatty acids, while the pH of the crop contents increases (Hinton *et al*., 2000). The net effect may be to increase the frequency of pathogen colonisation.

Placing birds in transport crates subjects them to close confinement and further faecal contamination of skin and feathers during transport. It is debatable, however, whether the stress of transportation significantly increases the proportion of birds in an infected flock that are shedders of salmonellas, although there may be increased shedding in infected individuals and even translocation of such organisms to the viscera in some cases (Pezzotti *et al*., 1998). With *Campylobacter*, Stern *et al*. (1995) showed that the proportion of externally contaminated birds increased from 12.1 to 56.0% and levels of *Campylobacter* contamination were raised more than a hundred-fold during commercial transport. Part of the problem is due to inadequate cleaning and disinfection of the crates at the processing plant prior to being re-used on the farm. Rigby *et al*. (1982) reported that 99% of crates tested for *Salmonella* before loading were found to be positive and 46% of birds from a *Salmonella*-free flock became contaminated when placed in crates. Cleaning of the plastic crates requires a multi-stage operation that often involves inversion of the crates to remove loose material, soaking to loosen dried-on faeces, and appropriate washing steps prior to the application of a disinfectant solution. Persistence of salmonellas on crates following the cleaning process was attributed by Corry *et al*. (2002) to poor practices that included

- insufficient cleaning
- inadequate use of disinfectant
- use of recycled flume-water in the soak-tank.

Bolder (1998) recommended spraying the crates with disinfectant and allowing it to remain on the crate surfaces to ensure an adequate kill.

11.4   The effects of processing on carcass contamination

11.4.1   General considerations

Details of the processing operation, from live bird to oven-ready carcass, are given in Chapter 5. The primary process can be divided into four phases that have particular microbiological implications and should be physically separated from one another. These are:

1. unloading and shackling of the birds, in which there is considerable aerial dispersion of microbes
2. stunning, killing, scalding and plucking – the so-called 'dirty' stages of the process
3. evisceration and carcass cleaning, the latter resulting in many of the microbes present being removed

4. chilling to control microbial growth, followed by grading and packaging of carcasses, where required.

Although processing tends to change the predominant microflora of carcasses from one in which the principal organisms are Gram-positive rods and cocci to a flora dominated by Gram-negative rods (McMeekin and Thomas, 1979), the microbial condition of the end-product is largely determined by the microbial load of the live bird. This is particularly true of *Salmonella* and *Campylobacter* that need to be controlled on the farm, since there can be no guarantee that they will be eliminated during processing. On the other hand, some organisms may even be acquired by carcasses in the processing plant. Included here are certain strains of *Staphylococcus aureus*, reviewed by Mead and Dodd (1990), and psychrotrophic organisms, such as *Listeria monocytogenes* and *Pseudomonas* spp., that are capable of multiplying in the processing environment.

Mechanisation of processing in the larger plants facilitates the use of high line-speeds – up to about 9000 birds per hour for chickens and 3000 per hour for turkeys and ducks – and leads to greater uniformity in product quality and microbiological condition. However, while individual machines must be safe to use and easy to clean and disinfect, with no adverse effect on product quality (Hupkes, 1996), there has been no attempt to set performance criteria in microbiological terms, and such an approach would be impossible without much more data for different stages of the process. Over the years, developments in mechanised processing have resulted in labour-saving, operational improvements and greater control of product yield, but have had little impact on the spread of microbial contaminants that is seen at virtually all stages of the process, and for which control measures are presently limited. This problem occurs in spite of overall reductions in carcass contamination, as carcasses pass through the process, and generally increases the incidence of any carcasses that are contaminated with minority pathogens such as *Salmonella*. Further development and application of cleaning-in-place systems for processing lines would help to limit the spread of foodborne pathogens from one batch of carcasses to another, but would not entirely solve the cross-contamination problem.

11.4.2   Unloading and shackling of live birds

Because of improvements in crate design and in ease of access to the birds, unloading of birds at the processing plant can be carried out in a less stressful manner. Also, the use of appropriate lighting has a calming effect, as birds are transferred to the shackles. Despite these improvements, some wing-flapping still occurs and aerial dispersion of dust and microorganisms is inevitably associated with the shackling operation and the hanging period before birds reach the stunner. In fact, experience suggests that the hanging-on bay has the highest atmospheric concentration of microorganisms in the plant, as shown by Zottola *et al*. (1970) at seven US turkey operations (Table 11.2). In this study,

Table 11.2 Airborne microorganisms at seven US turkey processing plants (adapted from Zottola *et al.*, 1970)

Processing stage	Aerobic plant count, 32ºC	Coliform bacteria
Shackling	* 3.7–6.9	NF–4.1
Defeathering	NF–5.2	NF–3.2
Evisceration	1.5–4.8	NF–3.0

* Range of counts ($\log_{10}$ cfu per m^3) for all plants in each case.
NF – not found.

Salmonella was regularly isolated from air samples and underlines the importance of effective physical isolation of this part of the process.

11.4.3   Stunning and slaughter

There are some microbiological implications for these stages. Where water-bath stunning is used, certain birds do appear to inhale a small amount of contaminated water, which may penetrate the lung cavity (Gregory and Whittington, 1992), but the exact consequences of this are unknown. Making a cut in the neck, whether by hand or with a rotating blade, to allow bleeding of the carcass, can cause cross-contamination and may introduce bacteria into the blood-stream. Cross-contamination can be reduced, however, by regular heat treatment of the slaughter-knife or, in the case of a rotating blade, by irrigating it with a continuous stream of chlorinated water (Mead *et al.*, 1994).

11.4.4   Scalding

Although the primary purpose of scalding is to loosen the feathers prior to plucking, the process does have important microbiological effects. Not only are the birds carrying large numbers of microbes on the skin and feathers, as they enter the tank, but there will be some degree of involuntary defaecation that adds many faecal bacteria to the water. Control of microbial levels in the water depends upon water usage and temperature. Conditions should be such that, after an initial build-up, the numbers of organisms present will be relatively constant, both in the water and on the skin of birds passing through the system (Mercuri *et al.*, 1974). In the USA, there is a requirement for an overflow of almost one litre per bird, but, in many other countries, the addition of fresh water is merely to replace that retained by the feathers, as birds leave the tank. Due to the use of hot water, which is in a state of constant agitation, many organisms are removed from the carcass surface and their subsequent rate of destruction depends on the water temperature and the type of organism concerned. Spoilage pseudomonads appear to be readily inactivated at any scald temperature (Mead *et al.*, 1993), Enterobacteriaceae less so and spores of *Clostridium perfringens* probably not at all (Mulder and Dorresteijn, 1977). Bacteria that remain attached to the skin tend

to show greater heat resistance than those in the water (Notermans and Kampelmacher, 1975).

Scald temperatures range from 50 to 63ºC, depending on the type of bird and whether the product will be sold fresh or frozen. Turkeys and ducks require the use of higher temperatures ('hard' scalding) to loosen the more difficult feathers. Temperatures in the range of 50 to 52ºC ('soft' scalding) are necessary for chicken carcasses that will be air-chilled, because higher temperatures would affect the cuticle and cause it to be partially removed during plucking. Dry chilling would then lead to unsightly areas on the carcass surface, termed 'barking'. 'Hard' scalding is suitable, however, for carcasses that will be frozen, since the surface appearance is less important in this case. As might be expected, 'hard'-scald temperatures have a greater effect in reducing the microbial load of the scald-water, total viable counts and Enterobacteriaceae being 100–1000-fold lower than in 'soft' scalding (Mulder and Dorresteijn, 1977), but with no such benefit in reducing *Salmonella* and *Campylobacter* contamination of carcasses (Slavik *et al*., 1995). Survival of bacteria in scald-water is also affected by pH, which is usually about pH 6.0, due to dissociation of ammonium urate present in the faeces. This is close to the optimum pH for heat resistance of salmonellas, which is influenced by the organic material that accumulates in the water (Humphrey, 1981). Adjusting the pH value to 9.0 under laboratory conditions lowered the decimal reduction time (DRT) for a strain of *S*. Typhimurium from 34.5 min to 1.25 min. Also, subsequent trials in a processing plant led to substantial reductions in total viable counts and levels of coliforms, both in the scald-water and on scalded carcasses (Humphrey *et al*., 1984). Unfortunately, the use of sodium hydroxide or sodium carbonate to adjust the pH of scald-water made the carcasses slippery and difficult to handle.

The microbial load of scald-water is important for two reasons. Firstly, there is a possibility that some birds could inhale a small amount of the water, which may then contaminate the blood and respiratory systems of the bird (Thomson and Kotula, 1959; Lillard, 1973), thereby allowing organisms of public health concern, including spores of *Cl. perfringens*, to reach the heart and liver. It is important, therefore, that the birds are always adequately stunned prior to slaughter and allowed to bleed for a sufficient length of time before entering the scald-tank. The second reason why microbial contamination of scald-water is of concern is the opportunity for cross-contamination between carcasses during the scalding process. The potential for this to occur was amply demonstrated by Mulder *et al*. (1978), using carcasses artificially inoculated with an easily identifiable 'marker' organism (*Escherichia coli* K12, resistant to nalidixic acid). Transmission of the marker during scalding was mainly derived from organisms on the surface of the carcass rather than those inoculated into the contents of the colon, and the phenomenon contributed significantly to the extent of cross-contamination in processing as a whole. The possibility of transferring any foodborne pathogens from one batch of birds to another would clearly depend on survival time in the scald-water. With *Campylobacter*, at least, the death rate

Table 11.3   Changes in microbial contamination of carcasses at different stages of processing (rinse method of sampling) (adapted from Berrang and Dickens, 2000)

Processing stage	Aerobic plate count, 37ºC	Coliform bacteria*	*Campylobacter* spp.*
After:			
bleeding	6.8 ± 0.1**	5.0 ± 0.2	4.7 ± 0.5
scalding	5.0 ± 0.2	2.9 ± 0.2	1.8 ± 0.3
plucking	5.0 ± 0.1	3.4 ± 0.3	3.7 ± 0.3
evisceration	4.5 ± 0.1	3.1 ± 0.1	3.4 ± 0.3
washing	3.6 ± 0.2	2.2 ± 0.1	2.3 ± 0.3
chilling	2.9 ± 0.3	1.9 ± 0.2	1.5 ± 0.4

* Mean values from positive samples only (30 samples tested in each case). Results expressed as $\log_{10}$ cfu/ml of rinse fluid.
** ±95% confidence interval.

appears to be relatively rapid, and Bolder (1998) reported DRTs at 52ºC of <2–3 min over a range of pH values.

Partly because of the cross-contamination problem, alternatives to immersion scalding have been sought and have included spray-scalding and the use of steam (Bolder, 1998). For both operational and carcass-quality reasons, however, these methods are not currently popular in the industry. A more successful development is a modification of the existing process in the form of multi-stage, counter-flow immersion scalding, as described by Veerkamp (1991). This means that carcasses are moved through the tanks in a direction opposite to that of the in-coming water. Because the system comprises up to three separate tanks in series, the microbial load of the water is progressively diluted. In consequence, there is a marked reduction in carcass contamination (3.0–3.9 $\log_{10}$ reduction per carcass), even at 'soft'-scald temperatures. At comparable temperatures in conventional, single-tank systems, the reductions were less than one log unit per gram of neck skin and sometimes non-existent (Mead *et al*., 1993). With a three-stage process operating at 55ºC, and including super-chlorination of the water, Berrang and Dickens (2000) noted significant reductions in aerobic plate counts, coliforms, *E. coli* and campylobacters. Some of the data obtained are shown in Table 11.3. Most of the removable bacteria appear to be washed off the carcasses in the early part of the process (Cason *et al*., 2000). When scalding was changed to the counter-flow configuration, with only a single tank and a post-scald, hot-water rinse, James *et al*. (1992b) noted an improvement in the microbiological condition of carcasses, but emphasised the need to maintain good hygiene control at later stages of processing in order to retain this benefit.

11.4.5   Defeathering
The defeathering process involves high-speed rotation of multiple metal discs bearing rubber 'fingers', and causes considerable scattering of microbes from

carcass surfaces, so that cross-contamination is an obvious hazard. Several studies have demonstrated the spread of salmonellas by this means (Bryan *et al*., 1968; Morris and Wells, 1970; Notermans *et al*., 1975; Clouser *et al*., 1995). In the last study, there was a three-fold increase in the proportion of salmonella-positive carcasses during plucking, which appeared to be related to feather contamination. While overall levels of carcass contamination also tend to increase (Mead, 1989), this is not always the case. In a survey of five UK processing plants, Mead *et al*. (1993) reported slight reductions in total viable counts from neck-skin samples as a result of defeathering. On the other hand, being warm and moist, conditions inside the machines are sometimes favourable for microbial growth and appear to support multiplication of some staphylococci, notably *Staphylococcus aureus* and *Staph. sciuri* (Mead and Dodd, 1990; Mead and Scott, 1994), which adhere to the rubber 'fingers'. Some of the *Staph. aureus* strains show an unusual clumping morphology, extracellular slime formation and enhanced resistance to chlorine (Mead and Dodd, 1990). Although the *Staph. aureus* strains rarely produce enterotoxin, numbers on carcasses may increase up to a thousand-fold (Dodd *et al*., 1988), leading to possible rejection of meat required for further processing. Avoidance of the staphylococcal problem may require better cleaning and disinfection of the equipment, more regular replacement of worn plucker 'fingers' and operating conditions that do not allow excessive feather accumulation in the machines. Other measures to improve the microbiological condition of carcasses during plucking have included chlorination of water used in the pluckers at 40 mg per litre of free available chlorine (Mead *et al*., 1995) and development of the so-called 'closed-loop' washing system (Veerkamp and Pieterse, 1993). This involves spraying carcasses during plucking with water at 50ºC, which is partly recycled into the scald tank after being pasteurised. However, a possible problem with incorporating a spray-wash in the plucking process is the likelihood of spreading salmonellas and other undesirable organisms via aerosols (McDermid and Lever, 1996).

Defeathering of duck carcasses involves water-immersion scalding at 60ºC followed by immersion of carcasses in molten wax at about 90ºC. When the wax has set, it is stripped off by hand, thereby removing the finer feathers ('down'). Following subsequent water chilling, Barnes *et al*. (1979) obtained total viable counts at 20ºC of only 10^3 cfu per cm^2 or less, and $<10^2$ cfu per cm^2 of coliform bacteria.

11.4.6   Evisceration and related processes

Included here are a number of stages at which the head is removed, the abdominal cavity is opened and both edible and inedible viscera are taken out. (What is classed as inedible is not the same in all countries!) Necks are among the organs that are used to prepare giblet packs, where required. The various steps in evisceration may be carried out either manually or by means of machines. When the latter are used, they must be set carefully to avoid excessive

breakage of the intestines. With most machines, some degree of breakage is inevitable, because of natural variation in bird-size, and spillage of intestinal contents occurs. The newer types of machine avoid any prolonged contact between carcass and viscera by immediately transferring the viscera to a separate, parallel line, although there is little evidence of any consequent decrease in carcass contamination (Bolder, 1998).

If evisceration is carried out badly, then microbial levels on carcasses will increase significantly. In practice, any increase is usually small. For example, Mead *et al*. (1993) found that total viable counts and coliforms on carcasses increased by less than 0.5 log during evisceration, while Abu-Ruwaida *et al*. (1994) reported no increase at all at the evisceration stage. Evisceration is usually a relatively wet process and washing carcasses at points along the line where contamination is known to occur will remove bacteria before they can become attached to carcass surfaces (Notermans *et al*., 1980). Nevertheless, cross-contamination is always likely via implements, equipment and hands of operatives, and the proportion of salmonella-positive carcasses has been shown to increase more during evisceration than at other stages of processing (Sarlin *et al*., 1998). In addition, salmonellas and campylobacters can be transmitted through spillage of crop contents, and crops are considered 86 times more likely than caeca to rupture during processing (Hargis *et al*., 1995; Byrd *et al*., 2002).

Contamination of carcasses with psychrotrophic spoilage bacteria also occurs during evisceration (Lahellec *et al*., 1973) and, because pseudomonads are often present in large numbers on rubber gloves worn by operatives, excessive handling of carcasses is to be avoided. Therefore, automatic transfer of carcasses from the slaughter line to the evisceration line and, where possible, onto the chilling line is to be recommended from the hygiene viewpoint. The psychrotrophic pathogen, *Listeria monocytogenes*, can sometimes be found on evisceration machinery (Ojeniyi *et al*., 1996) and could multiply in the relatively warm environment of the eviscerating area. To eliminate this organism from processing equipment, particular attention may need to be given to post-processing cleaning and disinfection.

11.4.7   Post-evisceration washing and chilling

Once evisceration and other manipulations involved in preparing finished carcasses are complete, it is usual to clean the carcasses before they are transferred to the chilling process. This is necessary to remove blood spots and other organic debris, and it is carried out by spray-washing. In doing so, levels of microbial contamination may be reduced, but the extent of the reduction will depend upon washer design, water-pressure and the degree of carcass washing at earlier stages of the process, which could have removed most of the unattached microbial cells beforehand. Experience suggests that reductions in total viable counts and coliform bacteria will be less than one log unit (Mead *et al*., 1993) at this particular stage. Moreover, the use of an inside/outside washer is no more effective in this respect than a fixed-nozzle system (Mulder and Bolder, 1981).

Hot water at temperatures up to 71ºC was used for the final spray-wash by Thomson *et al*. (1974), but had little additional effect and could lead to changes in carcass appearance. In relation to subsequent water immersion chilling, adequate cleaning of carcasses is important to minimise the introduction of organic material and microbes into the chill-water. At this stage, and sometimes during chilling, it is possible in countries outside the EU to use a chemical decontamination treatment that will further reduce the microbial load on carcasses. Available methods are discussed in Chapter 9.

After final spray-washing, carcasses still retain a considerable amount of body heat and prompt and efficient chilling is essential to control microbial growth. The methods in common use are continuous, mechanical, immersion chilling and air-blast chilling, with or without the incorporation of water-sprays to maintain product yield and enhance cooling by evaporation. The choice of method is related to the type of product, whether fresh or frozen, and marketing requirements. In the EU, for example, only products intended for freezing are water-chilled. With this method, movement of carcasses through cold, agitated water has a washing effect that removes some of the remaining organisms on the outer surface of each carcass and inside the abdominal cavity. Therefore, it is important to prevent a build-up of microbes in the chiller and this depends upon water usage and temperature. Constant addition of fresh water not only aids the carcass cooling process, but prevents the temperature of the chill-water from reaching a point where bacterial growth becomes a problem. EU regulations specify both the amount of water needed for a particular size of carcass and the maximum permitted temperature in different parts of the system. There is also a requirement for the counterflow mode of operation, so that carcasses meet progressively cleaner water as they pass through the final stages of chilling. In a well-controlled system, total viable counts and coliform bacteria are reduced by 50–90% (Surkiewicz *et al*., 1969; Mead and Thomas, 1973b), regardless of whether or not the water in the chiller is super-chlorinated. Surkiewicz *et al*. (1969) found that the proportion of *Salmonella*-contaminated carcasses remained at 20.5% during chilling, but others have reported increases in positive carcasses, even when carcass contamination was reduced by the chilling process (James *et al*., 1992a,b; Mikolajczyk and Radkowski, 2002).

Air chilling, whether as a batch process in a chill-room or by continuous air-blast, does not have the benefit of any washing effect and air-chilled carcasses are likely to carry more organisms than those that are water-chilled. Several studies have supported this contention, although the differences are relatively slight and usually less than one log unit (Büchli *et al*., 1966; Mulder, 1971; Mead, 1975; Thomson *et al*., 1975). Allen *et al*. (2000) confirmed that there was little effect on levels of skin contamination, but reported that counts from the abdominal cavity were reduced by one log. In contrast, air chilling with water sprays increased counts from the cavity, especially for *Pseudomonas* spp. The possibility that prolonged air chilling would have an adverse effect on campylobacters, which are sensitive to drying, was examined by Mead and

Hudson (1987). Holding naturally contaminated carcasses at 1ºC overnight had virtually no effect on campylobacter contamination of neck skin or on the proportion of positive samples from the abdominal cavity; however, only one breast sample was positive out of 30, compared with 12 samples from unstored carcasses of the same batch. It was concluded that some parts of the carcass retained sufficient moisture during storage to avoid the lethal effect of drying. Although air chilling should be less favourable to cross-contamination than water immersion chilling, recent work involving a marker organism (Mead *et al*, 2000) showed that dispersion of the organism occurred in all directions in the chill tunnel. With the incorporation of water-sprays, there is the added problem of dispersion via aerosols (Stephan and Fehlhaber, 1994).

11.4.8   Grading, packaging and post-chilling handling

To ensure an adequate shelf-life for fresh, chilled poultry, carcasses must be cooled to 0–2ºC during a further period of refrigeration, following grading, weighing and packaging. These handling stages should be completed without delay to safeguard the keeping quality of the product and only minimal increases in microbial levels are to be expected (Mead *et. al*, 1993). However, cross-contamination can still occur from product handling and contact with contaminated surfaces. Packaging is important to protect the meat, prevent weight-loss by evaporation from the surface and avoid the spread of microbes from the product to other items. Any marked variation in environmental temperature would be undesirable, partly because development of condensation within the pack could favour growth of spoilage bacteria. On the other hand, subjecting carcasses to blast-freezing causes significant reductions in numbers of faecal organisms, including campylobacters, and psychrotrophic spoilage bacteria (Reddy *et al.*, 1978; Stern *et al.*, 1984).

11.4.9   Super-chlorination of process water

Process water was first treated with chlorine in the USA in the 1950s to extend the shelf-life of chilled, oven-ready chickens. Since that time chlorine has been widely used in processing as a hygiene aid, although it is not permitted everywhere. EU Directive 92/116/EEC, for example, states that 'potable water must be used for all purposes' in processing. In those countries that favour chlorination, it is often used in the plant water supply ('in-plant' chlorination) and chlorine may be added at generally higher levels to scald tanks and water immersion chillers. For 'in-plant' chlorination, chlorine gas is often the preferred form, while other applications usually involve liquid hypochlorite. As an antibacterial, chlorine is most active in the form of undissociated hypochlorous acid, which occurs under acid conditions, and its efficacy is also affected by the concentration of chlorine used and the prevailing temperature. In scald tanks and water chillers, much of the added chlorine is completely inactivated by the organic matter present, but some may persist in combined

form as chloramines, and even as free residual chlorine, if the organic loading is low enough. Chloramines are less effective against bacteria than free chlorine, but still sufficiently active to be of value in this respect. Thus, the situation is complex and different approaches have been used for chlorine dosing. For example, Mead and Thomas (1973a) chose to maintain a *total* residual (free + combined chlorine) in chill-water of 45–50 mg per litre, while Waldroup *et al*. (1992) preferred to ensure a *free* residual of 1–5 mg per litre in the chiller overflow. Studies have shown that different types of bacteria vary in chlorine sensitivity, with *Pseudomonas* spp. being more resistant that *E. coli*, while *C. jejuni* is less resistant (Blaser *et al*., 1986). In the case of *Salmonella*, strains of differing sensitivity were obtained from a processing plant by Mokgatla *et al*. (1998).

In practice, chlorine has little direct effect on carcass contamination, whether used in spray-washing or water chilling, because of the rapid rate of chlorine inactivation when in contact with carcasses. Furthermore, Lillard (1993) showed that attached/entrapped salmonellas are not readily accessible to chlorine and therefore are relatively unaffected by it. Even the more sensitive *C. jejuni* is virtually unharmed when attached to chicken skin, whereas the organism is easily destroyed on stainless steel (Table 11.4). Although the washing effect of immersion chilling may be slightly enhanced by adding hypochlorite, because this contains alkali as a stabiliser and may have a more surface-active effect, the chlorine itself is unlikely to contribute much.

Table 11.4   Effect of chlorine treatment on attached cells of *Campylobacter jejuni*

Strain	Initial nos	Free chlorine conc. (mg/l)		
		250	50	10
Stainless steel discs				
CS–21	5.2	< 1.2	< 1.2	< 1.2
CS–30	4.6	< 1.2	< 1.2	< 1.2
CS–34	5.4	< 1.2	< 1.2	< 1.2
Chicken skin portions				
CS–21	6.2	5.4	5.9	6.1
CS–30	5.3	4.8	5.0	5.1
CS–34	4.9	4.6	4.6	4.5

Counts expressed as $\log_{10}$ cfu/ml or g
Geometric mean of three trials in each case.
Chlorine contact time (ambient temp): discs – 5 min; skin – 20 min.

- Strains isolated from poultry carcasses and tested separately.
- Material immersed in a 24 h broth culture of the test strain. After draining, inoculated material left for 5 min and then subjected to a standard washing procedure to remove unattached cells.
- Attached cells recovered from stainless steel by mechanical agitation and collected in diluent. Recovery from skin by means of 'stomacher'.

(G C Mead, unpublished data.)

The main benefit from chlorination of process-water lies in its ability to control microbial contamination of the processing environment, both with respect to organisms in the water and those that contaminate processing equipment. Potable water supplies may sometimes contain appreciable numbers of spoilage bacteria (Fries and Graw, 1999) and these can be eliminated by 'in-plant' chlorination. In water chilling, continuous addition of chlorine can be used to keep the chill-water virtually free from viable bacteria, including clostridial spores (Mead and Thomas, 1973a), thus reducing the opportunity for cross-contamination of carcasses via the cooling medium. For continuous spraying of evisceration equipment, Bailey *et al*. (1986) found that a chlorine concentration of at least 40 mg per litre was required for the purpose. In an attempt to reduce contamination of processed carcasses with *Campylobacter,* Mead *et al*. (1995) used chlorinated water sprays at various stages of processing and increased chlorine concentrations being used in the chilling system. In consequence, a statistically significant reduction in campylobacters was obtained.

A possible alternative to chlorine is chlorine dioxide, which acts as a gas in solution, and is seven times more effective than chlorine itself (Lillard, 1979). The antimicrobial activity of chlorine dioxide is not impaired by high pH, as in some hard water supplies, and it is less affected than chlorine by organic matter in the water. Concentrations of 1–5 mg per litre appear to be appropriate for use in water immersion chilling.

11.4.10   Portioning of carcasses

With increasing demand for cut portions and deboned meat, this has been an expanding sector of processing operations in many of the larger companies. As with carcass processing, there are fully or partly mechanised portioning systems, which allow high line-speeds, and those that are entirely manual, involving large numbers of personnel, especially for turkeys. Despite the importance of portioning, few studies have been made of modern systems. It might be expected that microbial contamination would increase during the manipulations involved, due to contact with soiled hands and equipment, but this is not necessarily the case. Holder *et al*. (1997) studied a largely mechanised line and showed that microbial numbers on different meat surfaces were generally related to the time of exposure to contamination. However, they concluded that only high standards of factory and operative hygiene would avoid any significant increase in the numbers of microbes present on the meat. There was some evidence that *Staph. aureus* had accumulated on certain items of equipment, thus emphasising the importance of plant cleaning and disinfection. It is also important to keep equipment and working surfaces as dry as possible, and the working environment cool, to minimise any growth of psychrotrophic spoilage bacteria. Maintaining the microbial quality of the product depends upon prompt transfer of freshly cut portions to a chill room or blast-freezer.

The machines used to harvest residual meat from the bones are conducive to microbial cross-contamination. They are relatively difficult to clean and some of

the older models can cause an increase in product temperature during operation. The bones themselves must be refrigerated and stored hygienically prior to use, and the recovered meat must be chilled promptly or frozen. The meat is in a finely divided state and highly favourable for microbial growth.

11.5   Microbiological testing in the processing plant

Testing is carried out in the processing plant for a number of purposes:

- to ensure that the end-product meets customer specifications
- for validation and verification of Hazard Analysis Critical Control Point programmes
- to determine the effects of any changes in the processing operation
- as a check on the effectiveness of plant cleaning and disinfection.

In relation to the product, it is first necessary to decide on the method of sampling. While most contaminants of processed carcasses will be on the skin, they are not evenly spread, and some sites, such as the thighs and neck skin, tend to be more heavily contaminated than others, for example the breast area. Microbial attachment or entrapment in the skin is another factor, because the organisms are then more difficult to remove without a destructive method of sampling. This usually involves relatively small skin samples and may sometimes result in minority organisms like salmonellas being overlooked.

All sampling is a compromise, and two methods in particular are widely used, although both are known to have advantages and disadvantages. One involves taking about five grams of neck skin, which can be done while the carcass is on the processing line and without causing any damage to the product. For routine purposes, the neck-skin method is only relevant to eviscerated carcasses in which the neck-flap is freely accessible. The skin sample obtained is usually processed in a 'stomacher' prior to testing, and this method gives a higher recovery of microorganisms than any non-destructive method. The principal alternative is the whole-carcass rinse method (Simonsen, 1971). Although not all the organisms present are recovered by this means, it is more appropriate for minority pathogens, because all surfaces of the carcass, inside and out, are subjected to the rinsing process. The carcass is removed from the processing line and placed in a waterproof plastic bag, followed by an appropriate amount of diluent. After closing the bag, it is shaken vigorously, usually for 30–60 s. A portion of the rinse water is then examined for the required organisms. The method is more time-consuming and less convenient than taking neck-skin samples, and it is unsuitable for larger carcasses, such as those of turkeys; however, a mechanical shaker has been developed (Dickens *et al*., 1985), which makes the method less tiring to use. Giblets, cut portions and mechanically recovered meat are usually sampled by taking an appropriate amount of material for maceration or 'stomaching'. With portions, both skin and cut muscle should be included in the sample.

The swab method of sampling is of limited value for carcasses or portions, because the recovery of organisms is quite low, but the method is suitable for sampling equipment and working surfaces, because it can reach those niches that are most difficult to clean and disinfect properly. Swabbing and other methods of sampling processing equipment, including use of agar contact plates and ATP and impedance measurement, were reviewed by Russell *et al.* (1997a). These methods are appropriate for monitoring the cleaning process, although microbiological testing is usually confined to total viable counts, using agar plates incubated at 30ºC, to allow recovery of faecal bacteria and spoilage organisms that generally fail to grow at 37ºC. The medium can be in the form of pre-prepared agar contact plates or plates that are surface-inoculated with appropriate sample dilutions to avoid killing heat-sensitive spoilage bacteria by exposure to molten agar, as in pour-plates.

For some purposes, indicator organisms are used as a measure of faecal contamination, and possible candidates are *E. coli*, coliforms and Enterobacteriaceae. However, faecal contamination of carcasses post-scalding may be difficult to distinguish from that occurring initially on the skin, especially when 'soft' scalding is used. Undoubtedly, *E. coli* is the most specific indicator of faecal contamination and most coliforms isolated from carcasses during processing belong to this species (Mead *et al*., 1982), but there is a preference in the EU for the Enterobacteriaceae test, involving a pour-plate method, because of its wider scope. Whatever test is used, there is no predetermined correlation between levels of carcass contamination and the presence of enteric pathogens, but if the pathogens are present in the in-coming birds, control of faecal contamination will clearly be an important factor in limiting the spread of these organisms. Also, there are no universally accepted microbiological standards for poultry meat products, and counts will depend on various factors in production and processing, as well as on the method of product sampling.

11.6   Future trends

While improvements in the control of microbial hazards will continue to be made by the poultry industry, these are likely to occur gradually rather than through major, rapid technological changes. The main reason for this is cost, in an industry that is globally competitive and needs to maintain high throughputs in order to compensate for low profit margins. In any individual company, improving the control of foodborne human pathogens would not immediately increase profitability, although it may confer competitive advantage. Nevertheless, consumers are demanding ever-safer food and the industry is obliged to respond. A strategy of gradual improvement was recommended for the UK by the Government's Advisory Committee on the Microbiological Safety of Food (ACMSF) in Report (1996). In relation to the production of feed, there was a perceived need to raise the microbiological status of feed milling, premises, plant and equipment. The Committee believed that it was 'technologically possible and

economically feasible for the feed industry to produce *Salmonella*-free poultry feed' and a number of improvements in milling practices were specified, including more effective heat treatment and better control of re-contamination at the various post-treatment stages. In the longer term, however, feed production may need to make some basic technological changes, if *Salmonella* is to be eliminated. These could involve the processing, handling and delivery of feed via closed systems, as is necessary for pasteurised milk. In other words, animal feed would be produced and marketed under the same conditions as human food. The ACMSF also expressed a view on necessary improvements to the broilerhouse environment, which would include replacing older houses with new ones made of food-grade materials and providing surfaces that are smooth, hard and impervious, to facilitate cleaning and disinfection. Other recommendations included improved rodent-proofing of houses and better systems for disposing of spent litter. Although not specifically mentioned by the ACMSF, comparable changes could be made in hatcheries, so that, for example, hatching cabinets would always be individually ventilated and provision made for the eggs from one breeder flock to be incubated separately from those of another, thus reducing opportunities for flock-to-flock transmission of pathogens. Such changes would need to be made across the entire production chain to ensure that there was no weak link at any stage (Mead, 1998). For the live-bird sector, control of pathogens may well be enhanced in the future by the development of new, more powerful vaccines and other preparations, capable of combating a range of disease agents.

At present, the most problematical area is poultry processing, where the various stages are still conducive to the spread of any pathogens carried by incoming flocks, and there are no Critical Control Points at which the organisms can be eliminated. Some of the more recent developments in processing technology, aimed at improving hygiene, were discussed by Mead (2000b). Not all of them have yet been taken up by the industry and, in any case, they do not overcome the basic deficiencies in the process in relation to hygiene control. Only a drastic re-design of the processing operation would solve the problem, but unless there are clear economic advantages to the processor, the motivation for change would be lacking. Because of this, attention will continue to be focussed in the foreseeable future on live-bird production, since elimination of pathogens at this stage, if it becomes possible, would pre-empt the need to change the nature of carcass processing.

11.7   Sources of further information

For more detailed accounts of *Salmonella* serotypes, their involvement in livestock production and importance in food microbiology, Wray and Wray (2000) and the review of D'Aoust (1997) should be consulted. Further information on *Campylobacter* spp. is contained in Nachamkin and Blaser (2000), and aspects relating specifically to poultry production and processing are discussed by Corry and Atabay (2001). This review also mentions other

campylobacteria that are common on poultry carcasses, for example *Arcobacter* and *Helicobacter* spp., and their possible public health significance. In contrast, the detection of pathological and other conditions, which is the responsibility of poultry meat inspectors, is described in Bremner and Johnston (1996). The book has other sections on the design and construction of poultry plants and cutting premises in relation to hygiene, and operational requirements for smaller producers. Within the EU, these include producers of less than 10 000 birds per year that are exempt from the hygiene directive, 92/116/EEC. Methods for microbiological sampling of poultry carcasses and parts are given by Russell *et al.* (1997b), while sampling and testing of processing equipment, which is particularly important in ensuring adequate cleaning and disinfection prior to re-use, is described by Russell *et al.* (1997a), as mentioned previously. General principles for the establishment of microbiological criteria for foods can be found in CAC (1997).

11.8   References

ABU-RUWAIDA A S, SAWAYA W N, DASHTI B H, MURAD M and AL-OTHMAN H A (1994), 'Microbiological quality of broilers during processing in a modern commercial slaughterhouse in Kuwait', *Journal of Food Protection* 57, 887–892.

ALLEN V M, CORRY J E L, BURTON C H, WHYTE R T and MEAD G C (2000), 'Hygiene aspects of modern poultry chilling', *International Journal of Food Microbiology* 58, 39–48.

BAILEY J S, THOMSON J E, COX N A and SHACKELFORD A D (1986), 'Chlorine spray washing to reduce bacterial contamination of poultry processing equipment', *Poultry Science* 65, 1120–1123.

BARNES E M, IMPEY C S and GRIFFITHS N M (1979), 'The spoilage flora and shelf-life of duck carcasses stored at 2º or −1ºC in oxygen-permeable or oxygen-impermeable film', *British Poultry Science* 20, 491–500.

BERRANG M E and DICKENS J A (2000), 'Presence and level of *Campylobacter* spp. on broiler carcasses throughout the processing plant', *Journal of Applied Poultry Research* 9, 43–47.

BILGILI S F (2002), 'Poultrymeat processing and marketing – what does the future hold?', *Poultry International,* September, 12–22.

BLASER M J, SMITH P F, WANG W-L L and HOFF J C (1986), 'Inactivation of *Campylobacter jejuni* by chlorine and monochloramine', *Applied and Environmental Microbiology* 51, 307–311.

BOLDER N M (1998), 'The microbiology of the slaughter and processing of poultry', in *The Microbiology of Meat and Poultry*, eds Davies A and Board R, London, Blackie Academic & Professional, 158–173.

BREMNER A and JOHNSTON M (eds) (1996), *Poultry Meat Hygiene and Inspection*, London, W B Saunders.

BRYAN F L, AYRES J C and KRAFT A A (1968), 'Contributory sources of salmonellae on turkey products', *American Journal of Epidemiology* 87, 578–591.

BÜCHLI K, VAN SCHOTHORST M and KAMPELMACHER E H (1966), 'Untersuchungen über die hygienische Beschaffenheit von mit Wasser resp. Luft gekühltem Schlachtgeflügel', *Archiv für Lebensmittelhygiene* 17, 97–99.

BYRD J A, CORRIER D E, HUME M E, BAILEY R H, STANKER L H and HARGIS B M (1998), 'Effect of feed withdrawal on the incidence of *Campylobacter* in crops of preharvest broiler chickens', *Avian Diseases* 42, 802–806.

BYRD J A, HARGIS B M, CORRIER DE, BREWER R L, CALDWELL D J, BAILEY R H, McREYNOLDS J L, HERRON K L and STANKER L H (2002), 'Fluorescent marker for the detection of crop and upper gastrointestinal leakage in poultry processing plants', *Poultry Science* 81, 70–74.

CAC (1997), *Principles for the Establishment and Application of Microbiological Criteria for Foods,* Rome, Codex Alimentarius Commission.

CASON J A, HINTON A Jr and INGRAM K D (2000), 'Coliform, *Escherichia coli*, and salmonellae concentrations in a multiple-tank, counterflow poultry scalder', *Journal of Food Protection* 63, 1184–1188.

CLOUSER C S, DOORES S, MAST M G and KNABEL S J (1995), 'The role of defeathering in the contamination of turkey skin by *Salmonella* species and *Listeria monocytogenes',* *Poultry Science* 74, 723–731.

CORRIER D E, BYRD J A, HARGIS B M, HUME M E, BAILEY R H and STANKER L H (1999), 'Presence of *Salmonella* in the crops and ceca of broiler chickens before and after preslaughter feed withdrawal', *Poultry Science* 78, 45–49.

CORRY J E L and ATABAY H I (2001), 'Poultry as a source of *Campylobacter* and related organisms', *Journal of Applied Microbiology* 90, 96S–114S.

CORRY J E L, ALLEN V M, HUDSON W R, BRESLIN M F and DAVIES R H (2002), 'Sources of salmonella on broiler carcasses during transportation and processing: modes of contamination and methods of control', *Journal of Applied Microbiology* 92, 424–432.

COX N A, STERN N J, HIETT K L and BERRANG M E (1999), 'Transmission of *Campylobacter jejuni* from breeders to commercial broiler chickens', in *Abstracts of the 10th International Workshop on Campylobacter, Helicobacter and Related Organisms, Baltimore, USA,* eds Mobley H L T, Nachamkin I and Gee D, Abstract no CF1, 61.

D'AOUST J-Y (1997), 'Salmonella species', in *Food Microbiology Fundamentals and Frontiers*, Washington DC, ASM Press, 129–158.

DAVIES R H and HINTON M H (2000), '*Salmonella* in animal feed', in *Salmonella in Domestic Animals*, eds Wray C and Wray A, Wallingford, Oxford, CABI Publishing, 285–300.

DAVIES R H and WRAY C (1996), 'Studies of contamination of three broiler breeder houses with *Salmonella enteritidis* before and after cleansing and disinfection', *Avian Diseases* 40, 626–633.

DICKENS J A, COX N A, BAILEY J S and THOMSON J E (1985), 'Automated microbiological sampling of broiler carcasses', *Poultry Science* 64, 1116–1120.

DODD C E R, MEAD G C and WAITES W M (1988), 'Detection of the site of contamination by *Staphylococcus aureus* within the defeathering machinery of a poultry processing plant', *Letters in Applied Microbiology* 7, 63–66.

FRIES R and GRAW C (1999), 'Water and air in two poultry processing plants' chilling facilities – a bacteriological survey', *British Poultry Science* 40, 52–58.

GARCIA-LOPEZ M L, PRIETO M and OTERO A (1998), 'The physiological attributes of Gram-negative bacteria associated with spoilage of meat and meat products', in *The Microbiology of Meat and Poultry*, eds Davies A and Board R, London, Blackie Academic & Professional, 1–34.

GREGORY N G and WHITTINGTON P E (1992), 'Inhalation of water during electrical stunning in chickens', *Research in Veterinary Science* 53, 360–362.

HARGIS B M, CALDWELL D J, BREWER R L, CORRIER D E and DELOACH J R (1995), 'Evaluation of the chicken crop as a source of *Salmonella* contamination for broiler carcasses', *Poultry Science* 74, 1548–1552.

HEYNDRICKX M, VANDEKERCHOVE D, HERMAN L, ROLLIER I, GRIJSPEERDT K and DE ZUTTER L (2002), 'Routes for salmonella contamination of poultry meat: epidemiological study from hatchery to slaughterhouse', *Epidemiology and Infection* 129, 253–265.

HINTON A JR, BUHR R J and INGRAM K D (2000), 'Physical, chemical and microbiological changes in the crop of broiler chickens subjected to incremental feed withdrawal', *Poultry Science* 79, 212–218.

HINTON M and LINTON A H (1988), 'Control of *Salmonella* infections in broiler chickens by the acid treatment of their feed', *Veterinary Record* 123, 416–421.

HOLDER J S, CORRY J E L and HINTON M H (1997), 'Microbial status of chicken portions and portioning equipment', *British Poultry Science* 38, 505–511.

HOLZAPFEL W H (1998) 'The Gram-positive bacteria associated with meat and meat products', in *The Microbiology of Meat and Poultry*, eds Davies A and Board R, London, Blackie Academic & Professional, 35–84.

HUMPHREY T J (1981), 'The effects of pH and levels of organic matter on the death rates of salmonellas in chicken scald-tank water', *Journal of Applied Bacteriology* 51, 27–39.

HUMPHREY T J, LANNING D G and LEEPER D (1984), 'The influence of scald water pH on the death rates of *Salmonella typhimurium* and other bacteria attached to chicken skin', *Journal of Applied Bacteriology* 57, 355–359.

HUPKES H (1996), 'Automation and hygiene in relation to poultry processing', in proceedings of a meeting on *Microbial Control in the Meat Industry, Perugia, Italy*, eds Hinton M H and Rowlings C, Bristol, University of Bristol Press, 95–98.

JAMES W O, WILLIAMS W O JR, PRUCHA J C, JOHNSTON R and CHRISTENSEN W (1992a), 'Profile of selected bacterial counts and *Salmonella* prevalence on raw poultry in a poultry slaughter establishment', *Journal of the American Veterinary Medical Association* 200, 57–59.

JAMES W O, PRUCHA J C, BREWER R L, WILLIAMS W O JR, CHRISTENSEN W A, THALER A M and HOGUE A T (1992b), 'Effects of countercurrent scalding and postscald spray on the bacteriologic profile of raw chicken carcasses', *Journal of the American Veterinary Medical Association* 201, 705–708.

LAHELLEC C, MEURIER C and CATSARAS M (1973), 'La flore psychrotrophe des carcasses de volailles II. Évolution au cours de l'éviscération', *Annales de Recherches Vétérinaires* 4, 499–512.

LILLARD H S (1973), 'Contamination of blood system and edible parts of poultry with *Clostridium perfringens* during water scalding', *Journal of Food Science* 38, 151–154.

LILLARD H S (1979) 'Levels of chlorine and chlorine dioxide of equivalent bactericidal effect in poultry processing water', *Journal of Food Science* 44, 1594–1597.

LILLARD H S (1993), 'Bactericidal effect of chlorine on attached salmonellae with and without sonication', *Journal of Food Protection* 56, 716–717.

LISTER S A (2002), 'Hygiene and disinfection in poultry management', in *Poultry Diseases*, Fifth Edition, eds Jordan F, Pattison M, Alexander D and Faragher T, London, W B Saunders, 43–54.

MCDERMID A S and LEVER M S (1996), 'Survival of *Salmonella enteritidis* PT4 and *Salmonella typhimurium* Swindon in aerosols', *Letters in Applied Microbiology* 23, 107–109.

McMEEKIN T A and THOMAS C J (1979), 'Aspects of the microbial ecology of poultry processing and storage: a review', *Food Technology, Australia*, January 31, 35–41.

MEAD G C (1975) 'Hygiene aspects of the chilling process', *Proceedings of the 2nd European Symposium on Poultry Meat Quality'*, *Oosterbeek, Netherlands*, Paper no 35.

MEAD G C (1989), 'Hygiene problems and control of process contamination, in *Processing of Poultry*, ed Mead G C, London, Chapman & Hall, 183–220.

MEAD G C (1998), *'The Safety of Poultry Products: Present Trends and Future Developments'*, Temperton Fellowship Report no 7, Newport, Shropshire, Harper Adams Agricultural College.

MEAD G C (2000a), 'Prospects for competitive exclusion treatment to control salmonellas and other foodborne pathogens in poultry', *Veterinary Journal* 159, 111–123.

MEAD G C (2000b), 'HACCP in primary processing: poultry', in *HACCP in the Meat Industry*, ed Brown M, Cambridge, Woodhead Publishing, 124–153.

MEAD G C and DODD C E R (1990), 'Incidence, origin and significance of staphylococci on processed poultry', *Journal of Applied Bacteriology Symposium Supplement*, 81S–91S.

MEAD G C and HUDSON W R (1987), 'Survival of campylobacters on air-chilled broiler carcasses held under different conditions', *British Poultry Science* 28, 776.

MEAD G C and SCOTT M J (1994), 'Coagulase negative staphylococci and coliform bacteria associated with mechanical defeathering of poultry carcasses', *Letters in Applied Microbiology* 18, 62–64.

MEAD G C and THOMAS N L (1973a), 'Factors affecting the use of chlorine in the spin-chilling of eviscerated poultry', *British Poultry Science* 14, 99–117.

MEAD G C and THOMAS N L (1973b), 'The bacteriological condition of eviscerated chickens processed under controlled conditions in a spin-chilling system and sampled by two different methods', *British Poultry Science* 14, 413–419.

MEAD G C, ADAMS B W and HAQUE Z (1982), 'Studies on the incidence, origin and spoilage potential of psychrotrophic Enterobacteraceae occurring on processed poultry' *Fleischwirtschaft* 62, 1140–1144.

MEAD G C, HUDSON W R and HINTON M H (1993), 'Microbiological survey of five poultry processing plants in the UK', *British Poultry Science* 34, 497–503.

MEAD G C, HUDSON W R and HINTON M H (1994), 'Use of a marker organism in poultry processing to identify sites of cross-contamination and evaluate possible control measures', *British Poultry Science* 35, 345–354.

MEAD G C, HUDSON W R and HINTON M H (1995), 'Effect of changes in processing to improve hygiene control on contamination of poultry carcass with campylobacter', *Epidemiology and Infection* 115, 495–500.

MEAD G C, ALLEN V M, BURTON C H and CORRY J E L (2000), 'Microbial cross-contamination during air chilling of poultry', *British Poultry Science* 41, 158–162.

MERCURI A J, COX N A and THOMSON J E (1974), 'Microbiological aspects of poultry scalding', in *Proceedings of the 15th World's Poultry Congress, New Orleans, USA*, Washington DC, World's Poultry Science Association, 543–545.

MIKOLAJCZYK A and RADKOWSKI M (2002), '*Salmonella* spp. on chicken carcasses in processing plants in Poland', *Journal of Food Protection* 65, 1475–1479.

MOKGATLA R M, BRÖZEL V S and GOUWS P A (1998), 'Isolation of *Salmonella* resistant to hypochlorous acid from a poultry abattoir', *Letters in Applied Microbiology* 28, 379–382.

MORRIS G K and WELLS J G (1970) 'Salmonella contamination in a poultry processing

plant', *Applied Microbiology* 19, 795–799.

MULDER R W A W (1971), 'Hygiënische aspecten van de koeling van geslacht pluimvee', *Vlees* 6, 11–13.

MULDER R W A W and BOLDER N M (1981), 'The effect of different bird washers on the microbiological quality of broiler carcasses', *Veterinary Quarterly* 3, 124–130.

MULDER R W A W and DORRESTEIJN L W J (1977), 'Hygiene beim Brühen von Schlachtgeflügel', *Fleischwirtschaft* 57, 2220–2222.

MULDER R W A W, DORRESTEIJN L W J and VAN DER BROEK J (1978), 'Cross-contamination during scalding and plucking of broilers', *British Poultry Science* 19, 61–70.

NACHAMKIN I and BLASER M J (eds) (2000), *Campylobacter*, 2nd edn, Washington DC, ASM Press.

NOTERMANS S and KAMPELMACHER E H (1975), 'Heat destruction of some bacterial strains attached to broiler skin', *British Poultry Science* 16, 351–361.

NOTERMANS S, VAN LEUSDEN F M, VAN SCHOTHORST M and KAMPELMACHER E H (1975), 'Salmonella-contaminatie van slachtkuikens tijdens het slachtprocess in enkele pluimveesschlachterijen', *Tijdschrift voor Diergeneeskunde* 100, 259–264.

NOTERMANS S, TERBIJHE R J and VAN SCHOTHORST M (1980), 'Removing faecal contamination of broilers by spray-cleaning during evisceration', *British Poultry Science* 21, 115–121.

NOTERMANS S, DORMANS J A M A and MEAD G C (1991), 'Contribution of surface attachment to the establishment of micro-organisms in food processing plants', *Biofouling* 5, 21–36.

NURMI E and RANTALA M (1973), 'New aspects of *Salmonella* infection in broiler production', *Nature* 241, 210–211.

OJENIYI B, WEGENER H C, JENSEN N E and BISGAARD M (1996), '*Listeria monocytogenes* in poultry and poultry products: epidemiological investigations in seven Danish abattoirs', *Journal of Applied Bacteriology* 80, 395–401.

PEARSON A D, GREENWOOD M H, FELTHAM R K A, HEALING T D, DONALDSON J, JONES D M and COLWELL R R (1996), 'Microbial ecology of *Campylobacter jejuni* in a United Kingdom chicken supply chain: intermittent common source, vertical transmission and amplification of flock propagation', *Applied and Environmental Microbiology* 62, 4614–4620.

PEZZOTTI G, MIGLIORATI G, TOSCANI T, SEMPRINI P and CONTE A M (1998), 'Influence of transportation stress on *Salmonella* spp. contamination in broiler carcasses', in *Prevention of Contamination of Poultry Meat, Eggs and Egg Products*, eds Franchini A and Mulder R W A W, Luxembourg, Office for Official Publications of the European Communities, 7–9.

REDDY K V, KRAFT A A, HASIAK R J, MARION W W and HOTCHKISS D K (1978), 'Effect of spin-chilling and freezing on bacteria on commercially processed turkeys', *Journal of Food Science* 43, 334–336.

REPORT (1996), *Report on Poultry Meat*, Advisory Committee on the Microbiological Safety of Food, London, HMSO.

RIGBY C E, PETTIT J R, BENTLEY A H, SPENCER J L, SALOMONS M O and LIOR H (1982), 'The relationships of salmonellae from infected broiler flocks, transport crates or processing plants to contamination of eviscerated carcasses', *Canadian Journal of Comparative Medicine* 46, 272–278.

ROLLINS D M and COLWELL R R (1986), 'Viable but nonculturable stage of *C. jejuni* and its role in survival in the natural aquatic environment', *Applied and Environmental Microbiology* 52, 531–538.

RUSSELL S M, COX N A and BAILEY J S (1997a), 'Microbiological methods for sampling poultry processing plant equipment' *Journal of Applied Poultry Research* 6, 229–233.

RUSSELL S M, COX N A and BAILEY J S (1997b), 'Sampling poultry carcasses and parts to determine bacterial levels', *Journal of Applied Poultry Research* 6, 234–237.

SAHIN O, ZHANG Q, MEITZLER J C, HARR B S, MORISHITA T Y and MOHAN R (2001), 'Prevalence, antigenic specificity and bactericidal activity of poultry-anti-*Campylobacter* maternal antibodies', *Applied and Environmental Microbiology* 67, 3951–3957.

SARLIN L L, BARNHART E T, CALDWELL D J, MOORE R W, BYRD J A, CALDWELL D Y, CORRIER D E, DELOACH J R and HARGIS B M (1998), 'Evaluation of alternative sampling methods for *Salmonella* critical control point determination at broiler processing', *Poultry Science* 77, 1253–1257.

SIMONSEN B (1971), 'Methods for determining the microbial counts of ready-to-cook poultry', *World's Poultry Science Journal* 27, 368.

SLAVIK M F, KIM J W and WALKER J T (1995), 'Reduction of Salmonella and Campylobacter on chicken carcasses by changing scalding temperature', *Journal of Food Protection* 58, 689–691.

STEPHAN F and FEHLHABER K (1994), 'Untersuchungen zur Hygiene des Luft-Sprüh-Kühlverfahrens', *Fleischwirtschaft* 74, 870–873.

STERN N J, GREEN S S, THAKER N, KROUT D J and CHIU J (1984), 'Recovery of *Campylobacter jejuni* from fresh and frozen meat and poultry collected at slaughter', *Journal of Food Protection* 47, 372–374.

STERN N J, CLAVERO M R S, BAILEY J S, COX N A and ROBACH M C (1995), '*Campylobacter* spp. in broilers on the farm and after transport', *Poultry Science* 74, 937–941.

SURKIEWICZ B F, JOHNSTON R W, MORAN A B and KRUMM G W (1969), 'A bacteriological survey of chicken eviscerating plants', *Food Technology, Champaign* 23, 1066–1069.

THOMSON J E and KOTULA A W (1959), 'Contamination of the air sac areas of chicken carcasses and its relationship to scalding and method of killing', *Poultry Science* 28, 1433–1437.

THOMSON J E, COX N A, WHITEHEAD W K and MERCURI A J (1974), 'Effect of hot spray washing on broiler carcass quality', *Poultry Science* 53, 946–952.

THOMSON J E, COX N A, WHITEHEAD W K, MERCURI A J and JUVEN B J (1975), 'Bacterial counts and weight changes of broiler carcasses chilled commercially by water immersion and air-blast', *Poultry Science* 54, 1452–1460.

VAN IMMERSEEL F, CAUWERTS K, DEVRIESE L A, HAESEBROUCK F and DUCATELLE R (2002), 'Feed additives to control *Salmonella* in poultry', *World's Poultry Science Journal* 58, 501–513.

VEERKAMP C H (1991), 'Multi-stage scalding', *Poultry International* 30, 62–67.

VEERKAMP C H and PIETERSE C (1993), 'Cleaning of broiler carcasses using a closed loop washing system during plucking', *Proceedings of the 11th Symposium on the Quality of Poultry Meat, Tours, France,* 576–579.

VLA (2002), 'Reports of *Salmonella* in poultry', in *Salmonella in Livestock Production in GB,* New Haw, Addlestone, Surrey, Veterinary Laboratories Agency, 83–122.

WALDROUP A L (1996), 'Contamination of raw poultry with pathogens', *World's Poultry Science Journal* 52, 7–25.

WALDROUP A L, RATHGEBER B M and FORSYTHE R H (1992), 'Effects of six modifications on the incidence and levels of spoilage and pathogenic organisms on commercially processed postchill broilers', *Journal of Applied Poultry Research* 1, 226–234.

WILLIAMS J E (1981), 'Salmonella in poultry feeds – a worldwide review', *World's Poultry Science Journal* 37, 97–105.

WRAY C and WRAY A (eds) (2000), *Salmonella in Domestic Animals*, Wallingford, Oxford, CABI Publishing.

ZOTTOLA E A, SCHMELTZ D L and JEZESKI J J (1970), 'Isolation of salmonellae and other air-borne microorganisms in turkey processing plants', *Journal of Milk and Food Technology* 33, 395–399.

12

Chemical residues in poultry

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12.1 Introduction: chemical residues

The residues discussed in this chapter include the following major groups:

- veterinary drugs including coccidiostats
- pesticides
- heavy metals
- other environmental contaminants (dioxins, etc.)
- mycotoxins.

The origins of the substances and the manner in which poultry are exposed to them vary considerably. Residues can be caused by either intentional use, as with veterinary drugs and pesticides, the undesirable result of human agency, as with polychlorinated biphenyls (PCB) and dioxins or natural processes of other living organisms (fungi) resulting in the production of mycotoxins. Sometimes their presence can be avoided but, more often, industry, government and society in general are faced with the fact that their occurrence is universal and simply has to be accepted. Exposure of poultry to the chemicals can be either through feed (all of the groups discussed), through drinking water (drugs, pesticides and heavy metals), through the air (pesticides and other contaminants), through injections (drugs) or through the materials used for housing (PCBs in paints, pesticides in wood, heavy metals and other contaminants in soil).

Some of the above substances, such as various drugs, are not very toxic to the birds themselves and can often be broken down easily by the bird; others like dioxins and mycotoxins can either be harmful to the chick or resistant to metabolism and thus pose a threat to human consumers. This wide variety of exposure routes and possible consequences for human health make it impossible

to use one single approach, whether preventive or curative, for all the substances discussed.

Generally, the lowest concentrations of any chemical residue are found in muscle tissue. On the other hand, the excretory organs, liver and kidney, quite often contain the highest concentrations of chemical contaminants. The exceptions are the fat soluble organohalogen contaminants which often reach the highest concentrations in fatty tissues, including abdominal, intramuscular and subcutaneous fat.

12.2   Safety and regulatory issues of chemical residues

Food safety involves both the real and perceived risks from the food itself and the ingredients and chemicals that it contains – whether there for a purpose or by accident – and the communication of risk in relation to those substances. Perception and acceptability of risk can differ widely between individuals and among groups of consumers, and even more between food 'professionals' and consumers, the 'truth' being very different for each category. Risk analysis generally consists of the following: risk assessment, risk management and risk communication. The first two are generally dealt with by the professional community and are based on 'hard' evidence. A pertinent example of such a technical approach has recently been discussed by Parzefall (2002). In this case, the outcome of a risk assessment was that the actual exposure of man to dioxins via food is far less than the level at which overt toxicity in normal humans can be expected. In the same paper, however, a warning is given against repeated intake of dioxins, and this seems rather contradictory. Another approach to risk assessment has been taken by Ma (2002), who considered the dioxin impact from a municipal waste incinerator in Taiwan as a means of prioritising information on residues in food items, using a stochastic risk assessment model. In this approach the variability in exposure, and not the exposure itself, is the point of interest. From the work of Ma (2002) it emerges that eggs and poultry are a large contributory factor to variability in the total risk estimate. It remains to be proved, however, that this model and its underlying assumptions are also applicable in Western Europe and elsewhere.

Risk communication is more subjective and value-laden, and Trautman (2001) has recently summarised some basic points about the process. The main points in this paper are: include all major stakeholders, be open and honest, recognise biases and differences and ask for professional help in risk communication. Consumers are, or at least should be, protected from harmful amounts of chemical substances in their food by international or national regulations. The tolerances for intentionally applied chemicals (for example, pesticides and drugs) are derived from thorough toxicological investigations combined with knowledge of good agricultural practice. Tolerances for environmental contaminants and mycotoxins are also based on toxicological knowledge, but sometimes the inevitable presence of these substances in food

must be taken into account. This implies that lower margins of safety for specific consumer groups may have to be accepted.

The Food and Agricultural Organisation of the United Nations (FAO) and the World Health Organisation (WHO) play an important role at the international level in proposing maximum levels of environmental contaminants, pesticides and veterinary drugs. The Codex Alimentarius Commission of FAO/WHO has laid down the principles of this procedure in CODEX STAN 193–1995 (revised in 1997) for contaminants. The whole procedure for setting maximum levels or Codex Guideline levels is outlined in that document. The overriding principle is that contaminant levels should be as low as are reasonably achievable. These should be attained by preventing food contamination, applying appropriate technology to limit contamination and taking measures for decontamination, where possible. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) evaluates the safety of food additives, naturally occurring toxicants and residues of veterinary drugs. However, the proposed limits of both Codex and JECFA are not binding on member states and have sometimes shown signs of compromise between different countries or areas of the world. For that reason, the maximum residue levels set in various countries can differ. Also, the assessment of risk does not always have an outcome.

Tolerances in the European Union (EU) for the different chemicals are dealt with in a number of Directives. An informal compilation of residue limits for pesticides in agricultural products has been produced by the EU services at europa.eu.int/comm/food/fs/ph_ps/pest/09-99-3.pdf. This document provides information on the commodity, the substance, the maximum residue limit (MRL), the limit of detection (LOD) and the Directive involved. Nasreddine and Parent-Massin (2002) have recently reviewed the risk to consumers of pesticide residues in food and concluded that there is no reason for concern over this issue for foods in the EU. The MRLs for veterinary medicinal products in the EU are laid down in the Annexes of Council Regulation (EC) 2377/90. The Council Directive 96/23/EC, which prescribes national residue monitoring plans for products of animal origin in all member states, is also a valuable source of information on the MRLs of all chemicals mentioned and in all products involved. The Commission Services of the EU report annually on the results obtained from implementing these plans, as in document SEC (2002) 1278, giving data for the year 2000.

Every year, the Food Safety and Inspection Service (FSIS) in the USA (www.fsis.usda.gov) publishes data concerning the national residue program for products of animal origin in its so-called 'Red Book'. This publication also contains the MRLs for veterinary drugs, unavoidable contaminants and pesticides in animal products.

Di Corcia and Nazzari (2002) recently compiled some MRL data for veterinary drugs in the EU and USA and, from this work, it is clear that a number of marked discrepancies still exist. MRL values for tetracyclines feature prominently in this category; this coincides with the continuing use of tetracyclines as feed additives in the USA but restriction to therapeutic use in the EU.

12.3   Sources of residues in poultry meat

12.3.1   Intentionally used substances

Antimicrobials are used intentionally to prevent or cure infectious diseases in poultry and still, to some extent, to enable maximum growth or laying performance of poultry. Both therapy and prophylaxis are of prime importance for the well-being of the birds and the economic viability of the poultry-production chain. However, not all diseases can be prevented or cured by this means. Avian influenza is a recent and very dramatic example of this. Viral diseases, in particular, are insensitive to most drugs and sometimes vaccines are either not available or their use is prevented by trade-associated rules. Diseases of metabolic origin, ascites for example, can seldom be cured or prevented by antimicrobials or other chemicals. EU legislation makes a distinction between feed additives (performance enhancers, coccidiostats and related substances) and veterinary drugs. Feed additives are regulated at the EU level but, to a large extent, veterinary drugs are still controlled on a national basis. The EU has not yet linked any MRL values to the use of feed additives. Withdrawal periods of 0 to about 10 days should ensure the absence of hazardous amounts of these substances; however, Directive 2001/79 prescribes that a MRL value and withdrawal period should be calculated. Feed additives can be used for particular target animals without a veterinary prescription. However, both target animals and permitted additives have been defined clearly in EU legislation (70/524).

Residue limits for veterinary drugs can be found in the annexes of EU Council Regulation 2377/90. Annexes I and III contain the substances assigned a permanent or temporary MRL value, while Annex II lists the substances which are not considered to pose, under practical conditions, any threat to human health from residues in products of animal origin. Annex IV contains those substances for which the experts have not been able to lay down a safe level in products for human consumption. Most substances in this group are known carcinogens or are strongly suspected to have carcinogenic potential. Veterinary drugs should be used only on a veterinary prescription but experience has shown that such prescriptions are sometimes very easily obtained.

12.3.2   Unintentional exposure to pesticides, environmental contaminants and mycotoxins

The main route of exposure to these substances is still via animal feed but air, soil, housing material and water should not be neglected. In this respect, the use of pesticides is often regarded as essential for the large-scale production or storage of plant materials. Appropriate use such as that indicated by good agricultural practice and development and selection of less persistent substances should prevent the occurrence of pesticide residues above MRL values. High values for organochlorine pesticides in poultry products were not uncommon in the 1970s (Kan, 1991), but these substances have largely vanished in recent years. (See also Section 12.4.2.)

Mycotoxins are substances produced mainly by fungi of the genera *Aspergillus, Fusarium* and *Penicillium* and their occurrence is still sometimes difficult to prevent. Weather conditions, especially high rainfall, during critical phases of plant growth cannot be controlled and may lead to mycotoxin formation. In principle, storage is more controllable but on-farm storage conditions, in particular, sometimes leave much to be desired. The main hazard from mycotoxins is an adverse effect on the birds, although broilers and laying hens are quite insensitive to most mycotoxins. Residues of mycotoxins are seldom found in poultry products, because the bird is a relatively efficient filter and detoxifier of these substances (see also Dänicke, 2002).

Environmental contaminants like PCBs, dioxins, heavy metals and radioactive fall-out are the result of human and industrial activity. High levels of these contaminants are often of a very sporadic nature and therefore difficult to control. Furthermore, intestinal absorption from contaminated feed or ingested soil, or through the lungs or skin by the birds and resultant tissue residues can be quite variable and difficult to assess from laboratory analyses alone.

12.4   Types, levels and effects of residues in poultry meat

12.4.1   Recent residue data for poultry in the EU and the USA
The residue data given in the following tables should be viewed bearing in mind certain general principles.

The national residue monitoring plans of EU member states, as prescribed by Council Directive 96/23/EC, start from the principle of targeted monitoring. Thus the samples must be taken from animals or situations where the chances of finding violative levels of residues are higher than in a random-testing sampling scheme. This has the advantage that available resources are used for situations where only zero values will not be found. However, general conclusions about exposure of the public to toxic substances cannot be drawn from these data.

In contrast, the US monitoring programmes cited here involve random sampling with the disadvantage of many low or zero values but the benefit of providing a basis for calculating general exposure. In special cases, however, the US authorities also carry out targeted surveys. Tables 12.1 to 12.7 give the data from residue control programmes in Belgium, Germany, Ireland and the UK over different years. Tables 12.8 and 12.9 give an overview of production figures, numbers of samples and those found positive as reported by the EU. Tables 12.10 and 12.11 give data from the random-monitoring programmes in the USA during 1999 and 2000.

12.4.2   Hormonal residues
The results given in Tables 12.1–12.7 show that none of the samples contained violative amounts of hormonal substances such as stilbenes, thyreostatics, steroids

Table 12.1 Random control of poultry in Belgium

	1998 http://139.165.180.63/ostc/ MonitoringIEV/98iev.htm			1999 http://139.165.180.63/ostc/ MonitoringIEV/99iev.htm			2000 http://139.165.180.63/ostc/ MonitoringIEV/00iev.htm		
	N	Positive	Remarks	N	Positive	Remarks	N	Positive	Remarks
Hormonal residues	120	0		120	0		240	0	
Antibiotics	450	13		461	26		673	20	
Chloramphenicol	90	0		86	0		223	0	
Florfenicol/ thiamfenicol				86	0		223	0	
Nitrofurans	85	0		92	1	Turkey sample	101	0	
Ronidazole dimetridazole	95	0		90	5	Guinea fowl samples	147	1	Chicken/ sample
Acetylsalicylacide	30	0		30	0		74	1	
Coccidiostats	150	1	Lasolacide	150	1	Lasolacide	139	1	Monensin
Beta-agonists	179	0		92	0		222	0	
Anti-hormonal residues	31	0		31	0		50	0	
Anthelmintics							110	0	

Table 12.2 Sampling of poultry in Germany in 2000 http://www.bvl.bund.de/lebensmittel/dateien/Internet_2000_ges.pdf

EU Code	Group identification	Broilers N	Broilers Positive	Layers N	Layers Positive	Turkeys N	Turkeys Positive	Other poultry N	Other poultry Positive
A1	Stilbenes	71	0	6	0	74	0	6	0
A2	Thyreostatics	47	0	6	0	41	0	12	0
A3	Steroids	95	0	10	0	83	0	11	0
A4	Resorcylic acid lactones incl. zeranol	85	0	11	0	63	0	14	0
A5	Beta-agonists	639	0	20	0	491	0	39	0
A6	Annex IV substances according 2377/90	583	1	95	0	521	1	65	0
B1	Antibacterials	1007	0	102	0	790	1	46	0
B2a	Anthelmintics	30	0	0	0	15	0	2	0
B2b	Coccidiostats incl. nitroimidazoles	634	0	76	0	434	0	52	0
B2c	Pyrethroids and carbamates	38	0	14	0	5	0	0	0
B2d	Sedatives	1	0	0	0	0	0	0	0
B2e	Non-steroidal anti-inflammatory drugs	8	0	0	0	0	0	7	0
B2f	Other pharmacologically active agents	9	0	0	0	0	0	0	0
B3a	Organochlorine compounds incl. PCB	167	0	14	0	33	0	6	0
B3b	Organophosphorus compounds	14	0	1	0	0	0	0	0
B3c	Chemical elements (heavy metals)	17	0	1	0	13	0	0	0
B3d	Mycotoxins	10	0	0	0	4	0	1	0
B3e	Colouring agents	0	0	0	0	0	0	0	0
B3f	Other substances	180	0	14	0	24	0	5	0

Annex IV positives; 2 × chloramphenicol.
Antibacterials: 1 × quinolones.

Table 12.3 Sampling of poultry in Germany in 2001 http://www.bvl.bund.de/lebensmittel/dateien/Internet_2001_ges.pdf

EU Code	Group identification	Broilers N	Broilers Positive	Layers N	Layers Positive	Turkeys N	Turkeys Positive	Other poultry N	Other poultry Positive
A1	Stilbenes	41	0	8	0	43	0	6	0
A2	Thyreostatics	62	0	8	0	65	0	4	0
A3	Steroids	57	0	6	0	42	0	6	0
A4	Resorcylic acid lactones incl. zeranol	44	0	8	0	40	0	4	0
A5	Beta-agonists	329	0	6	0	313	0	30	0
A6	Annex IV substances according 2377/90	547	0	90	0	505	0	42	0
B1	Antibacterials	903	0	59	0	762	0	38	0
B2a	Anthelmintics	76	0	2	0	61	0	4	0
B2b	Coccidiostats incl. nitroimidazoles	449	0	48	0	429	0	36	0
B2c	Pyrethroids and carbamates	37	0	3	0	35	0	1	0
B2d	Sedatives	0	0	0	0	0	0	0	0
B2e	Non-steroidal anti-inflammatory drugs	60	0	1	0	47	0	7	0
B2f	Other pharmacologically active agents	0	0	0	0	0	0	0	0
B3a	Organochlorine compounds incl. PCB	61	1	9	0	27	0	4	0
B3b	Organophosphorus compounds	7	0	0	0	3	0	0	0
B3c	Chemical elements (heavy metals)	38	0	4	0	30	0	2	0
B3d	Mycotoxins	23	0	1	0	11	0	2	0
B3e	Colouring agents	0	0	0	0	0	0	0	0
B3f	Other substances	67	0	9	0	27	0	4	0

Organochlorines: 1 × PCB 52.

Table 12.4   Sampling of poultry in Ireland in 2001 http://www.gov.ie/daff/Pressrel/ 2002/213-2002.htm

EU Code	Group identification	N	Positive
A1	Stilbenes	61	0
A2	Thyreostatics	16	0
A3	Steroids	63	0
A4	Resorcylic acid lactones incl. zeranol	55	0
A5	Beta-agonists	57	0
A6	Annex IV substances according 2377/90	131	0
B1	Antibacterials	2550	2
B2a	Anthelmintics	72	0
B2b	Coccidiostats incl. nitroimidazoles	88	0
B2c	Carbamates and pyrethroids	18	0
B2d	Sedatives	0	0
B2e	Non-steroidal anti-inflammatory drugs	11	0
B2f	Other pharmacologically active agents	0	0
B3a	Organochlorine compounds incl. PCB	45	0
B3b	Organophosphorus compounds	0	0
B3c	Chemical elements (heavy metals)	18	0
B3d	Mycotoxins	0	0
B3f	Others	0	0

or zeranol. Absence of these substances, which is often not the case with other farm animals, has been predicted (Kan, 1996) since these substances are generally inactive in poultry when given via the feed and they do not provide a financial benefit for the farmer.

12.4.3   Beta-agonist residues

In the UK, only one sample was reported positive in 1999 (Table 12.5) and the substance was described merely as a β-agonist in broiler liver. The virtual absence of residues of β-agonists was also predicted (Kan, 1996) because these substances have only marginal effects on poultry performance.

12.4.4   Substances banned according to Annex IV of 2377/90

Two main groups of veterinary drugs fall into this category: chloramphenicol and nitrofurans. Both types of compound were occasionally found in poultry samples from Belgium and Germany (Tables 12.1 and 12.2). Table 12.9 shows that the total number in the EU of positive samples for all the above groups taken together was 51 in 1998 and 32 in 1999. It is more than likely that all the positive samples were in this banned category. The data may show a declining trend, but the illegal use of these drugs has certainly not ceased in all EU member states. On 10 March 2003 the EU reported that 47 poultry farms in Portugal were blocked by the authorities following positive results in residue testing. It should be noted, however, that most, if not all, of the results obtained

Table 12.5 Statutory surveillance of poultry in the UK in 1999 http://www.vet-residues-committee.gov.uk/

EU Code	Group identification	Broilers		Layers		Turkeys		Other poultry	
		N	Positive	N	Positive	N	Positive	N	Positive
A1	Stilbenes	266	0	9	0	61	0	15	0
A2	Thyreostatics	9	0	0	0	1	0	0	0
A3	Steroids	235	0	11	0	81	0	14	0
A4	Resorcylic acid lactones incl. zeranol	189	0	14	0	54	0	6	0
A5	Beta-agonists	258	1	8	0	78	0	20	0
A6	Annex IV substances according 2377/90	2662	0	148	0	560	0	64	0
B1	Antibacterials	1761	0	119	0	479	0	70	0
B2a	Anthelmintics	483	0	57	0	136	0	50	0
B2b	Coccidiostats incl. nitroimidazoles	553	48	71	0	166	0	38	0
B2c	Pyrethroids and carbamates	133	0	21	0	44	0	11	0
B2e	Non-steroidal anti-inflammatory drugs	55	0	20	0	17	0	9	0
B3a	Organochlorine compounds incl. PCB	386	0	24	0	92	1	20	0
B3c	Chemical elements (heavy metals)	76	0	66	9	69	0	62	0
B3d	Mycotoxins	16	0	5	0	5	0	5	0

Coccidiostat positives: all nicarbazin in broiler liver.
Heavy metal positives: all cadmium in hen liver.

Table 12.6 Statutory surveillance of poultry in the UK in 2000 http://www.vet-residues-committee.gov.uk/

EU Code	Group identification	Broilers		Layers		Turkeys		Other poultry	
		N	Positive	N	Positive	N	Positive	N	Positive
A1	Stilbenes	332	0	9	0	84	0	18	0
A2	Thyreostatics	11	0	0	0	1	0	0	0
A3	Steroids	249	0	12	0	70	0	15	0
A4	Resorcylic acid lactones incl. zeranol	125	0	14	0	24	0	5	0
A5	Beta-agonists	261	0	9	0	80	0	18	0
A6	Annex IV substances according 2377/90	2442	0	113	0	478	0	58	0
B1	Antibacterials	1853	1	129	0	451	5	77	0
B2a	Anthelmintics	464	0	53	0	179	0	44	0
B2b	Coccidiostats incl. nitroimidazoles	565	29	61	0	158	0	34	0
B2c	Pyrethroids and Carbamates	126	0	21	0	40	0	12	0
B2e	Non-steroidal anti-inflammatory drugs	20	0	12	0	8	0	3	0
B3a	Organochlorine compounds incl. PCB	438	3	8	0	62	0	10	0
B3c	Chemical elements (heavy metals)	69	0	54	3	61	0	22	0
B3d	Mycotoxins	38	0	5	0	5	0	5	0

Antibacterial positives: chlortetracycline in broiler liver and turkey liver and kidney.
Coccidiostat positives: lasolacide and nicarbazin in liver.
PCB positives: all in broiler fat.
Heavy metal positives: all cadmium in hen liver.

Table 12.7 Statutory surveillance of poultry in the UK in 2001 http://www.vet-residues-committee.gov.uk/

EU Code	Group identification	Broilers N	Broilers Positive	Layers N	Layers Positive	Turkeys N	Turkeys Positive	Other poultry N	Other poultry Positive
A1	Stilbenes	265	0	9	0	65	0	8	0
A2	Thyreostatics	115	0	5	0	26	0	5	0
A3	Steroids	255	0	10	0	68	0	9	0
A4	Resorcylic acid lactones incl. zeranol	196	0	8	0	52	0	7	0
A5	Beta-agonists	371	0	13	0	116	0	13	0
A6	Annex IV substances according 2377/90	2655	0	136	0	556	0	135	0
B1	Antibacterials	2165	3	45	1	778	16	99	0
B2a	Anthelmintics	459	0	66	0	181	0	32	0
B2b	Coccidiostats incl. nitroimidazoles	624	35	65	0	137	0	21	0
B2c	Pyrethroids and Carbamates	119	1	44	0	45	0	14	0
B2e	Non-steroidal anti-inflammatory drugs	34	0	6	0	11	0	5	0
B3a	Organochlorine compounds incl. PCBs	470	0	12	0	66	0	12	0
B3c	Chemical elements (heavy metals)	68	0	20	0	44	0	14	0
B3d	Mycotoxins	32	0	5	0	11	0	6	0

Antibacterial positives: chlortetracycline in broiler, hen and turkey kidney and tylosin in turkey kidney.
Coccidiostat positives: nicarbazin in liver.
Carbamate positive: propoxur in broiler liver.

Table 12.8   EU poultry production and numbers of targeted poultry samples

	Poultry production (tonnes)	Number of targeted samples	Number of positives
1998	7,795,000	36,206	252
1999	8,179,637	40,264	205
2000	8,372.378	48,487	

relate to protein-bound metabolites of the nitrofurans and not to the parent substances themselves. The latter substances are very susceptible to metabolic breakdown and can hardly ever be found in products of animal origin, with the possible exception of eggs. The metabolites, on the other hand, can persist for quite a long time (Kan & Brüll, 2003 unpublished results).

12.4.5   Residues of antibacterials

Quite a number of antibiotic-positive samples were reported in Belgium over the years (Table 12.1). These were probably detected by microbiological tests, which are not always specific, and the identity of the antibiotic often cannot be ascertained. As would be expected, the few positive samples in Germany and the UK contained mainly the old, cheap and widely used tetracyclines and sulfonamides. No information on identity was given for the positive samples in Ireland. The analysis of antibiotic residues in the USA (Tables 12.10 and 12.11) also revealed a few violations. Streptomycin and penicillin were found in kidney, a matrix that is not taken in the EU for residue testing, because consumption of poultry kidney on its own does not occur.

12.4.6   Anthelmintic residues

No samples were found to contain violative amounts of anthelmintics. This can be explained by the fact that the majority of poultry is still kept indoors and infection by helminths is usually an outdoor problem.

Table 12.9   EU subdivison of postive samples

	Group A substances	Group B substances	Total number of positives
1998	51	201	252
1999	32	173	205

http://europa.eu.int/comm/food/fs/sfp/fcr/reports/reports_en.html

Table 12.10 Sampling of poultry in the USA, reported by FSIS, 1999 www.fsis.usda.gov

	Young chicken		Mature chicken		Young Turkey		Mature turkey		Duck	
	N tested	Violations	N tested	Violations	N tested	Violations	N tested	Violations	N tested	Violations
Antibiotics	408	0	293	0	411	1	170	0	327	0
Arsenic	410	0	217	0	274	0	53	0	259	1
Chlorinated hydrocarbons	418	0	305	0	449	0	131	0	334	0
Organophosphates	418	0	305	0	449	0	131	0	334	0
Phenylbutazone	418	0	305	0	449	0	131	0	334	0
Sulfonamides	410	1	225	0	412	2	128	0	249	0

Antibiotic positive: oxytetracycline in kidney.
Sulfonamide positives: Sulfadimidine in chicken liver, sulfadimethoxine and sulfadoxine in turkey liver.
Arsenic was determined in liver.

Table 12.11 Sampling of poultry in the USA, reported by FSIS, 2000 *www.fsis.usda.gov*

	Young chicken		Mature chicken		Young Turkey		Mature turkey		Duck	
	N tested	Violations	N tested	Violations	N tested	Violations	N tested	Violations	N tested	Violations
Antibiotics	444	1	242	1	441	0	138	0	328	0
Arsenic	1155	1	240	0	455	1	46	0	259	2
Chlorinated hydrocarbons	446	0	317	0	452	2	132	0	332	0
Organophosphates	446	0	317	0	452	0	132	0	332	0
Fluoroquinolones	227	0	22	0	0	0	0	0	0	0
Phenylbutazone	446	0	317	0	452	0	132	0	332	0
Sulfonamides	418	0	50	0	453	0	170	0	256	0

Antibiotic positives: streptomycin and penicillin in kidney.
Chlorinated hydrocarbons: lindane in fat.
Arsenic was determined in liver.

12.4.7   Residues of coccidiostats, including nitroimidazoles

The number of samples found positive for coccidiostats and nitroimidazoles is quite low in Belgium, Germany and Ireland. The substances found are in line with known usage patterns in feed in the years in question. The rather high number of UK broiler liver samples that occasionally contained considerable amounts of nicarbazin raises a number of questions. The persistence of nicarbazin in litter and poultry tissues has been known for some time (Kan *et al.*, 1995). For many years, therefore, the EU has not allowed this substance to be incorporated in broiler feed for longer than 28 days. Therefore, liver samples that contained high amounts of nicarbazin must have been taken while the birds were still being given the nicarbazin-containing feed or after a very short withdrawal period. Cross-contamination between different batches of feed and lack of an appropriate withdrawal period were among the reported reasons for the findings. Further action was being taken by a special working group.

12.4.8   Residues of sedatives and non-steroidal anti-inflammatory drugs

Residues of sedatives or non-steroidal anti-inflammatory drugs have not been reported in either the EU or the USA. Kan (1996) has suggested that control of these substances would be superfluous for poultry.

12.4.9   Residues of organochlorine compounds, including PCBs

The number of samples containing violative amounts of organochlorine pesticides including PCBs was low both in the EU survey and in data from the USA. Since systematic control started in the 1970s, the joint efforts of governments and industry have accomplished a major reduction in this area. The declining trend shown by Kan (1991) for residue data in the Netherlands can now be observed for all industrialised countries.

12.4.10   Residues of organophosphates

The low number of samples tested in the EU for organophosphate residues and the much higher number tested in the USA did not reveal any violations of residue limits. The result is not unexpected, because, usually, these compounds are rapidly metabolised by warm-blooded animals.

12.4.11   Heavy metal residues

Cadmium and lead were found in livers in the UK sampling scheme (Tables 12.5 and 12.6). The cadmium in hen liver is in accordance with the earlier finding that levels are generally higher in birds exposed for longer periods (Vos *et al.*, 1990). The arsenic residues reported in US liver samples (Tables 12.10 and 12.11) are probably related to the use of arsenic-containing performance promoters, such as Roxarsone, which are still permitted in the USA, but not in EU.

12.4.12   Mycotoxin residues
The few samples analysed for mycotoxin residues showed no violative residues, as was predicted by Dänicke (2002).

12.4.13   Hormones, etc.
Steroid hormones and thyreostatics compounds are not effective for improving the profitability of poultry farming and thus their use should be negligible. The residue data on these substances confirm their continuing absence from poultry products. β-agonists may marginally improve the performance of broilers, but their clearance from the body is very rapid (Haasnoot *et al.*, 1991) so, even if they are used, any residues are very unlikely, which is clear from the reported data.

12.4.14   Veterinary drugs
In most cases, the use of veterinary drugs will result in residues, especially in the excretory organs liver and kidney, but residues may also persist in skin for some time. Residues in muscle tissue are usually low and clearance after cessation of therapy is generally rapid. Data on skin residues, however, are sometimes compromised by cross-contamination. Market permission for a veterinary drug to be used nearly always includes an MRL value and a withdrawal period to ensure that the MRL can be achieved. The relatively low number of violative samples indicates that this approach gives adequate protection to the consumer against high residues of drugs via foods of animal origin.

12.4.15   Coccidiostats
Coccidiostats are considered to be essential in the rearing of broilers. Although they are intended to work only in the gastrointestinal tract and may be also in excreta, coccidiostats also give rise to residues in edible tissues. Consequently the EU has prescribed withdrawal times in Council Regulation 70/524, while MRL values have been specified in the USA. Nicarbazin has proved to be quite persistent in the birds and their excreta (Kan *et al.*, 1995), as well as being involved in cross-contamination. This could explain how inadequate on-farm handling or faulty usage procedures have been responsible for the considerable number of nicarbazin-positive broiler livers reported in the UK. The apparent absence of nicarbazin in other surveys indicates either better practices in those countries or lower usage of this particular coccidiostat. The number of violative residues of other coccidiostats is quite low, indicating good adherence to specified withdrawal periods. Such practices could be encouraged by the knowledge that some coccidiostats can impair performance when given to healthy animals (Kan *et al.*, 1998). Thus, farmers might be inclined to use them only during the first few weeks, when the birds are most susceptible to coccidiosis, thereby ensuring an adequate withdrawal period.

12.4.16   Sources of environmental contaminants

Kan (2002) has discussed the different routes that may lead to contamination of poultry. Feed is by far the largest contributor, especially through fatty ingredients. However, specific incidents have shown that environmental factors cannot be ruled out. In Michigan, USA, coating of farm silos resulted in a rather high PCB concentration in silo material due to leaching (Willett *et al.*, 1985) as did the use of ceiling vapour-seal in turkey houses (Hansen *et al.*, 1989). Contaminated landfills – not uncommon in some parts of the world – may also be a source of PCBs and dibenzofurans in soil and dust (Hansen *et al.*, 1997) thus influencing levels of these contaminants in free-range poultry.

12.4.17   Carry-over of PCBs and some related compounds

Hansen *et al.* (1983) gave feed with added Arochlor 1254 either directly or after passage through pigs to broilers for about 20 days. Concentrations of 18 individual chlorobiphenyls in liver and body fat were determined. The highest level of accumulation in body fat was found for the congeners 118, 128, 138, 153 and 180. Levels in liver followed a similar trend, but there were some differences between isomers. No marked differences in pattern were found between the 'native' mixture and the PCBs that first passed through the pig. Ueberschär and Vogt (1986) determined the accumulation ratios of the congeners 28, 52, 101, 135, 153 and 180 in broilers and layers. Congeners 52 and 101 were much less persistent than the other four.

Hoogenboom and co-workers (unpublished results, 2002) fed diluted feed originating from the Belgian dioxin crisis for one week to laying hens and broilers and followed residue patterns in eggs and abdominal fat for several weeks, both using a biological (CALUX) test and gas chromatography/mass spectrometry (GC/MS). The PCB pattern in this feed resembled a 50/50 mixture of Aroclors 1254 and 1260 (van Larebeke *et al.*, 2001). The results are not yet completely available, but, of the seven marker components, congener 101 proved to be much more actively metabolised than congeners 118, 138, 153 and 180. Congeners 28 and 52 were also metabolised quite extensively as can be expected for these lesser chlorinated congeners. These results concur with the comparison of congener patterns in feed and eggs from Belgium in 1999 (van Larebeke *et al.*, 2001). The observed decline in PCB residues in broiler fat during the withdrawal period could be almost completely explained by dilution during growth of the birds. Metabolism, if it occurred, was not a major contributory factor in this experiment.

De Vos *et al.* (2003) fed PCBs to broilers for 42 days in diets with differing amounts of added fat. Variation in dietary fat level had no influence on the accumulation of PCBs in abdominal adipose tissue or fat of breast and thigh muscle. The levels of PCBs varied among the different fat fractions indicating an uneven distribution within the body. However, the number of birds in each group was relatively small, so variation between animals, which can be quite large (Kan, 1978), may have played a major role in this finding. Toxaphen, a

multi-component mixture of chlorinated terpenes, was once a widely used insecticide but is now considered more as an environmental contaminant. Being a mixture of many congeners, it bears some resemblance to PCBs. Ueberschär *et al.* (2001) looked for indicator congeners and carry-over from feed to fat in a broiler trial, but found accumulation only in body fat and suggested some legal limits for feedstuffs in order to comply with food regulations. Mineral oil hydrocarbons have not yet received much attention, although Grob *et al.* (2001) have shown their presence in both animal feed and foods of animal origin.

12.4.18   Dioxins

Zabik *et al.* (1998) fed a low level of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) to male leghorn chicks for 14 days. Residues of the dioxin were absent from brain, heart, fat, plasma, muscle, kidney or skin and residues were found only in liver samples, occurring 21 days after administration had stopped. Inclusion of mineral oil in the diet did not increase the rate of excretion of TCDD. However, one can only speculate about the results, had a much faster-growing type of broiler chicken been tested. Hoogenboom and co-workers (unpublished results, 2002) found that 2,3,7,8 TCDD was only a minor component (about 1.5% of total dioxins and dibenzofurans) in the feed that originated from the Belgian dioxin crisis. By far the largest contributor to the Toxic EQuivalent (TEQ) level (*c.* 68%) was 2,3,4,7,8-pentachlorodibenzofuran (PeCDF); other major components (> 5%) were 2,3,7,8-tetrachlorodibenzofuran (TCDF), 1,2,3,4,7,8-hexachlorodibenzofuran (HxCDF) and 1,2,3,7,8-pentachlorodibenzofuran (PeCDD). Similar results from other feed analyses have recently been published (van Larebeke *et al.*, 2001). The levels in eggs and fat after cessation of administration decreased naturally due to excretion with the eggs, but the four above-mentioned congeners were about equally stable. The percentage contribution to the total residue slightly increased during the washout period. The overall picture from these studies is that the more chlorinated congeners are metabolically more stable and accumulate to a greater extent. However, even between congeners with the same degree of chlorination, there are considerable differences.

Recently Iben *et al.* (2003) fed mixtures of dioxins and dibenzofurans to broilers for 2, 4 or 6 weeks and grew them for a total of 6 weeks. Particular attention was given to the mass balance and it was found that about 21% of the dioxin/dibenzofuran intake could be recovered from the edible tissue. The data show almost no metabolism during the withdrawal period. A limit value for feed was suggested in order to meet the accepted limits in human food, but there was no mention of the fact that different mixtures of dioxins/dibenzofurans, with a similar TEQ value, might well show a different pattern of accumulation.

The biotransfer of dioxins and dibenzofurans from soil has been studied extensively by Stephens *et al.* (1995) but the conclusions reached for laying hens may not apply to meat-type birds. The bioavailability of the substances could be similar but not the mass balance, which might be obscured by events like the

apparent synthesis of hepta- and octachlorodioxins observed by Fries *et al.* (2002) in cattle.

General control programs do not yet cover dioxin residues. Overviews can be found in a large document from an EU advisory committee (SCAN, 2000) and a paper from the USA by Huwe (2002). Following the Belgian food contamination incident, specific data for recent years have been published by Covaci *et al.* (2002). They conclude that human exposure to dioxins/dibenzofurans might be greater from consumption of chicken than from consumption of pork assuming the same feed is given to both types of animal. However, this conclusion seems to be based on the analysis of only three fat samples from chicken, two fat samples from pork and one feed sample. Thus, the basis for the conclusion seems quite weak and should be substantiated by proper comparative studies such as those carried out by Hoogenboom and co-workers (unpublished results, 2002). Data from the Swiss Dioxin Monitoring Program (Schmid *et al.*, 2002) show no major difference in contamination level between chicken and pork fat. The mean reported levels are higher for chickens but the maximum level is higher for the pork samples.

12.5   Factors affecting absorption of residues in poultry meat

Factors affecting absorption of harmful substances from the digestive tract of poultry and their levels in poultry products have been discussed previously (Kan, 1994). Generally, bioavailability of the chemical is the prime determining factor. Lipophilic compounds present in the oil phase of feed may have a much greater bioavailability or absorption potential than those embedded in other feed ingredients. The difference in digestibility of PCBs between the basal diet and that containing the added material in the broiler trial of de Vos *et al.* (2003) illustrates the point. Attempts to measure such bioavailability *in vitro* have produced conflicting results so far (Wittsiepe *et al.*, 2001). Any reduction in absorption of fat-soluble organochlorine pesticides or enhancement of their elimination from the body is not easy to accomplish. Some volatile substances might be eliminated by freeze-drying the product, while removing the fat by baking, for example, will reduce the level remaining in the product. The absorption of heavy metals in the intestine is also largely influenced by their speciation and hence their bioavailability. Water- or fat-soluble entities are generally well absorbed but minerals present in a highly insoluble salt are not. Specific absorbents can prevent the absorption of some mycotoxins via the intestinal tract, but Dänicke (2002) points out that the general application of this approach still has technical and economic barriers to overcome. The largest residues – as already stated in Section 12.1 – are generally found in liver and kidney. Persistent organohalogen compounds are mainly found in fatty tissues and muscle tissue usually contains the lowest amounts of any contaminants.

12.6   Detection and control of residues in poultry meat

12.6.1   Detecting residues

Depending on their purpose, the analytical methods used to determine chemical residues in meat can be divided into screening and confirmatory methods. Screening methods must be fast, reliable and cheap, and produce no false negatives. They are required to deal with large numbers of samples, even on the farm or the slaughter line, and to be able to identify those in which a violative residue may be present. Methods that can detect more than one substance at a time (also called multi-methods) are preferred for this purpose. Often they are based on a common biological principle, such as inhibition of growth of a microorganism that indicates the presence of an antimicrobial or the binding to a receptor such as the Ah receptor for dioxins and dibenzofurans in the CALUX test mentioned previously. Confirmatory methods, on the other hand, do not need to be fast or cheap necessarily, but they should not produce false positives. Their purpose is to establish unequivocally whether or not a particular substance is present and, if an MRL exists for the substance, whether the value has been exceeded. High sample throughputs are seldom required. Substances that are closely related chemically can often be handled by the same method. The methods usually include a two-step process: firstly separation, often by gas liquid chromatography (GLC) or high pressure liquid chromatography (HPLC) of the substance of interest from other interfering compounds, and then identification, which is frequently done by mass-, infrared- or even ultraviolet-spectrometry.

The consequences of banning certain foods from the marketplace and the relatively severe penalties involved have resulted in considerable attention to the establishment of decision criteria. Many legal actions have centred on the question of how certain the legal body must be of the results of the analyses in order that firm conclusions can be drawn and action taken. Is 99% certainty acceptable or should it be 99.99999%? When can the analyst be confident that the compound has been properly identified and is not another, as yet unforbidden substance? Good overviews on these topics can be found in the proceedings of the residue symposia (Euroresidue and the symposia on hormone residues), which are held bi-annually in The Netherlands and Belgium (e.g. Antignac *et al.*, 2003; Hoffmann *et al.*, 2002). The control programmes of the different EU member states and of the FSIS in the USA also contain extensive descriptions of the methods used.

12.6.2   Controlling residues

The prevention and control approach (Hazard Analysis Crititical Control Point, HACCP) has been developed primarily for controlling microbiological and physical hazards in food production. Ropkins and Beck (2002) have recently discussed the specific points to be taken into account when the HACCP system is applied to organic chemical hazards. They specifically consider the

identification and assessment of chemical hazards, the limited use of chemical contaminant analytical inspection and the possible effectiveness of control measures. Generally, individual companies have to rely much more on external advice on chemical hazards, while effects of processing on contaminant levels are not always well known. Last but not least, analytical methods that are rapid, robust, user-friendly and economical to use have yet to be developed for most chemicals and matrices. It is also considered that chemical HACCP procedures are unlikely to be as efficient or effective as those for microbiological hazards which usually ensure safety with only a limited number of Critical Control Points (CCPs). This is because it is usually possible to reduce the microbial load by appropriate procedures, whereas reduction of the chemical load is hardly possible at all (Kan, 1994). Prevention and control of chemical contaminants in the poultry production chain have been discussed by Kan (2002). It was concluded that pesticide residues have been tackled successfully in recent years, a view substantiated by the data presented in this chapter. The control of other environmental contaminants is much more difficult. Prevention and control of mycotoxins in the poultry production chain has been summarised by Dänicke (2002). Because the weather is such an important factor in this case, prevention is not always simple, if at all possible. Removal from or inactivation of mycotoxins in feedstuffs needs further development with regard to cost and scale of application.

Animal feed is a major source of undesirable substances. The EU has regulated some of them in Council Directive 1999/29/EC; this regulation now has the following groups: ions or elements (for example, cadmium or lead), toxic products (for example, aflatoxin or DDT) and botanical impurities (for example, Brassica or Croton). An updated document from the Scientific Committee on Animal Nutrition (March 2003) deals at length with possible adverse effects on animals and formation of residues by all the aforementioned substances. This is the first step in a revision and most likely expansion of the Council Directive.

12.7   Future trends

What is likely to happen in the field of residues in poultry and the reactions of the general public to perceived risks from residues in food? A further downward trend in both the proportion of samples with amounts above tolerated levels and in average or median levels of the chemicals in question can be anticipated for those chemicals that can be controlled during poultry production. This downward trend certainly should be observed for veterinary drugs and pesticides, but there is doubt about other contaminants (heavy metals, dioxins, PCBs, etc.), as well as mycotoxins, since control over their presence has both technical and economic obstacles to overcome. MRLs will certainly show a general downward trend, due to increased knowledge of possible adverse effects and increased pressure from the public to produce foods with no inherent risks. The possible effect of economic counterforces is at present difficult to assess.

One should bear in mind, however, that the Western world still has plenty of food available. If for some reason the food supply were to become scarce, opinions on acceptability and risk might change rapidly.

12.8   Sources of further information and advice

Nowadays, the Internet is the place to find the most up-to-date information. For that reason, a number of relevant sites are mentioned below.

The Codex Alimentarius, an international body of FAO/WHO, has formulated a standard for non-microbial contaminants and toxins in food (ftp://ftp.fao.org/codex/standard/en/CXS_193e.pdf). This standard does not cover pesticides or veterinary drugs. The Codex also has a short code of practice for source-directed measures to reduce contamination of food with chemicals (CAC/RCP 49-2201), which can be found at the same website. Lists with MRLs can also be found there.

The toxicological evaluations for the Codex documents are carried out by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and its evaluations can be found at the website http://www.fao.org/WAICENT/faoinfo/economic/esn/jecfa/index_en.stm#.

Information on EU policy, legislation and the residue control program can be found at the EU website http://europa.eu.int/comm/food/fs/sfp/fcr/fcr_index_en.html. Separate links for veterinary drug residues, pesticide residues, feed additives and contaminants are present on that website.

Information concerning residues in the USA can be found at the FSIS website Residue Information Center http://www.fsis.usda.gov/OPPDE/ric/. US publications on, for example, residue policy and testing procedures, can be found at http://www.fsis.usda.gov/OPPDE/ric/Publications.htm.

12.9   References

ANTIGNAC, J. P., LE BIZEC, B., MONTEAU, F. and ANDRE, F. (2003), 'Validation of analytical methods based on mass spectrometric detection according to the ''2002/657/EC'' European decision: Guideline and application', *Analytica Chimica Acta* 483, 325–334.

COVACI, A., RYAN, J. J. and SCHEPENS, P. (2002), 'Patterns of pcbs and pcdd/pcdfs in chicken and pork fat following a Belgian food contamination incident', *Chemosphere* 47, 207–217.

DÄNICKE, S. (2002), 'Prevention and control of mycotoxins in the poultry production chain: A European perspective', *World's Poultry Science Journal* 58, 451–474.

DE VOS, S., MAERVOET, J., SCHEPENS, P. and DE SCHRIJVER, R. (2003), 'Polychlorinated biphenyls in broiler diets: Their digestibility and incorporation in body tissues', *Chemosphere* 51, 7–11.

DI CORCIA, A. and NAZZARI, M. (2002), 'Liquid chromatographic-mass spectrometric methods for analyzing antibiotic and antibacterial agents in animal food products', *Journal of Chromatography A* 974, 53–89.

FRIES, G. F., PAUSTENBACH, D. J. and LUKSEMBURG, W. J. (2002), 'Complete mass balance of

dietary polychlorinated dibenzo-*p*-dioxins and dibenzofurans in dairy cattle and characterization of the apparent synthesis of hepta- and octachlorodioxins', *Journal of Agricultural and Food Chemistry* 50, 4226–4231.

GROB, K., VASS, M., BIEDERMANN, M. and NEUKOM, H. P. (2001), 'Contamination of animal feed and food from animal origin with mineral oil hydrocarbons', *Food Additives and Contaminants* 18, 1–10.

HAASNOOT, W., HAMERS, A. R. M., SCHILT, R. and KAN, C. A. (1991), 'Immuno-affinity chromatography in combination with an enzyme immunoassay for the determination of clenbuterol in poultry tissue', in *Food Safety and Quality Assurance: Application of Immunoassay Systems*, pp. 185–188, Bowness-on-Windermere, Cumbria, UK.

HANSEN, L. G., GREEN, D., COCHRAN, J., VERMETTE, S. and BUSH, B. (1997), 'Chlorobiphenyl (pcb) composition of extracts of subsurface soil, superficial dust and air from a contaminated landfill', *Fresenius Journal of Analytical Chemistry* 357, 442–228.

HANSEN, L. G., SULLIVAN, J. M., NEFF, C. C., SANDERS, P. E., LAMBERT, R. J., BEASLEY, V. R. and STORR-HANSEN, E. (1989), 'Polychlorinated biphenyl contamination of domestic turkeys from building materials', *Journal of Agricultural and Food Chemistry* 37, 135–139.

HANSEN, L. G., TUINSTRA, L. G. M. T., KAN, C. A., STRIK, J. J. T. W. A. and KOEMAN, J. H. (1983), 'Accumulation of chlorobiphenyls in chicken fat and liver after feeding aroclor 1254 directly or fat from swine fed aroclor 1254', *Journal of Agricultural and Food Chemistry* 31, 254–260.

HOFFMANN, M. K., YOFFE, A., DEYRUP, C. L., EPSTEIN, R. L., SHISHANI, E. and AZNAR, G. (2002), 'An odessey – meeting European Union analytical criteria for residues from afar: Experiences from North America', *Analytica Chimica Acta* 473, 49–52.

HUWE, J. K. (2002), 'Dioxins in food: A modern agricultural perspective', *Journal of Agricultural and Food Chemistry* 50, 1739–1750.

IBEN, C., BÖHM, J., TAUSCH, H., LEIBETSEDER, J. and LUF, W. (2003), 'Dioxin residues in the edible tissue of broiler chicken', *Journal Animal Physiology and Animal Nutrition* 87, 142–128.

KAN, C. A. (1978), 'Accumulation of organochlorine pesticides in poultry: A review', *Journal of Agricultural and Food Chemistry* 26, 1051–1055.

KAN, C. A. (1991), 'Residues in poultry (products); a European perspective', in *10th Symposium on the Quality of Poultry Meat*, Vol. III, Mulder, R. W. A. W. and de Vries, A. W. eds, pp. 69–77. Spelderholt Centre for Poultry Research and Information Services, Doorwerth, Netherlands.

KAN, C. A. (1994), 'Factors affecting absorption of harmful substances from the digestive tract of poultry and their level in poultry products', *World's Poultry Science Journal* 50, 39–53.

KAN, C. A. (1996), 'Residues in poultry products from Western Europe; detection, occurrence and control', *Proceedings XX World's Poultry Science Association Congress New Delhi* 3, 85–96.

KAN, C. A. (2002), 'Prevention and control of contaminants of industrial processes and pesticides in the poultry production chain', *World's Poultry Science Journal* 58, 159–167.

KAN, C. A., JAGER, L. P. and GROMMERS, F. J. (1998), 'Feed additives: Do they add to animal welfare? An evaluation', *Animal Welfare* 7, 397–414.

KAN, C. A., KEUKENS, H. J. and BOERS, E. (1995), 'Nicarbazin residues in broiler muscle, liver and litter/faeces: Early exposure or recirculation', in *12th European Symposium on the Quality of Poultry Meat*, Vol. 1, Briz, R. C. ed, pp. 481–485.

WPSA Spanish Branch, Zaragoza.

MA, H. W. (2002), 'Using stochastic risk assessment in setting information priorities for managing dioxin impact from a municipal waste incinerator', *Chemosphere* 48, 1035–1040.

NASREDDDINE, L. and PARENT-MASSIN, D. (2002), 'Food contamination by metals and pesticides in the European Union. Should we worry?', *Toxicology Letters* 127, 29–41.

PARZEFALL, W. (2002), 'Risk assessment of dioxin contamination in human food', *Food and Chemical Toxicology* 40, 1185–1189.

ROPKINS, K. and BECK, A. J. (2002), 'Controlling organic chemical hazards in food manufacturing: A hazard analysis critical control points (HACCP) approach', *Nahrung* 46, 258–269.

SCAN, SCIENTIFIC COMMITTEE ON ANIMAL NUTRITION (2000), 'Dioxin contamination of feedingstuffs and their contribution to the contamination of food of animal origin', Opinion, November 6, 105 pp.

SCAN, SCIENTIFIC COMMITTEE ON ANIMAL NUTRITION (2003), http://europa.eu.int/comm/food/fs/sc/scan/out126_bis_en.pdf

SCHMID, P., GUJER, E., DEGEN, S., ZENNEGG, M., KUCHEN, A. and WÜTHRICH, C. (2002), 'Levels of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in food of animal origin. The Swiss dioxin monitoring program', *Journal of Agricultural and Food Chemistry* 50, 7482–7487.

STEPHENS, R. D., PETREAS, M. X. and HAYWARD, D. G. (1995), 'Biotransfer and bioaccumulation of dioxins and furans from soil: Chickens as a model for foraging animals', *Science of the Total Environment* 175, 253–273.

TRAUTMAN, T. D. (2001), 'Risk communication – the perceptions and realities', *Food Additives and Contaminants* 18, 1130–1134.

UEBERSCHÄR, K. H. and VOGT, H. (1986), 'Geflügelversuche zur Bestimmung der Anreicherungsfaktoren für PCB-einzelkomponenten in Geweben und Eiern', *VDLUFA Schriftenreihe* 20 Kongreßband, 641–655.

UEBERSCHÄR, K. H., SCHWIND, K. J. and HECHT, H. (2001), 'Carry over experiments with poultry using Toxaphen to establish maximum residue levels for feedstuffs', *Proceedings of the Society of Nutrition and Physiology* 10, 180.

VAN LAREBEKE, N., HENS, L., SCHEPENS, P., COVACI, A., BAEYENS, J., EVERAERT, K., BERNHEIM, J. L., VLIETINCK, R. and DE POORTER, G. (2001), 'The Belgian pcb and dioxin incident of January–June 1999: Exposure data and potential impact on health', *Environmental Health Perspectives* 109, 265–273.

VOS, G., LAMMERS, H. and KAN, C. A. (1990), 'Cadmium and lead in muscle tissue and organs of broilers, turkeys and spent hens and in mechanically deboned poultry meat', *Food Additives and Contaminants* 7, 83–91.

WILLETT, L. B., LIU, T. T. W., DURST, H. I., CARDWELL, B. D. and RENKIE, E. D. (1985), 'Quantification and distribution of polychlorinated biphenyls in farm silos', *Bulletin of Environmental Contamination and Toxicology* 35, 51–60.

WITTSIEPE, J., SCHREY, P., HACK, A., SELENKA, F. and WILHELM, M. (2001), 'Comparison of different digestive tract models for estimating bioaccessibility of polychlorinated dibenzo-p-dioxins and dibenzofurans from red slag "kieselrot"', *International Journal of Hygiene and Environmental Health* 203, 263–273.

ZABIK, M. J., POLIN, D., UNDERWOOD, M., WIGGERS, P. and ZABIK, M. E. (1998), 'Tissue residues in male chickens fed a 50 ng/kg dietary concentration of 2,3,7,8-tetrachlorodibezo-p-dioxin', *Bulletin of Environmental Contamination and Toxicology* 61, 664–668.

13

Shelf-life and spoilage of poultry meat

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13.1 Introduction: shelf-life and spoilage

The conditions under which poultry are offered for sale differ widely around the world, but only in more developed regions is there extensive use of refrigeration for the raw meat. Elsewhere, marketing may involve the sale of live birds, on-the-spot slaughter or same-day slaughter and sale. In all cases, however, it is recognised that poultry meat is a highly perishable commodity, the main reason being that it provides an excellent medium for microbial growth. While freezing and frozen storage can be expected to prevent the multiplication of microbes on the meat, holding the product under chill conditions merely serves to delay the growth of cold-tolerant organisms. Nevertheless, the establishment of an appropriate cold chain, from production to the point of sale, ensures that the meat has a shelf-life that is sufficiently long to satisfy consumer needs. The extent of shelf-life depends upon storage temperature and various other extrinsic and intrinsic factors that will be discussed in this chapter. Also considered are the nature of spoilage, the associated microflora and ways in which shelf-life can be extended by manipulating the storage environment to control growth of the usual spoilage organisms.

What is meant by the term 'spoilage'? Clearly, there is an inference that spoiled meat has become unfit for human consumption, due largely to the growth and metabolic activities of particular microorganisms. Thus, there may be changes in the odour, flavour or appearance of the meat that would render it unacceptable, although the exact point at which such changes are considered objectionable is a matter of personal judgement. The initial indicator of spoilage is 'off' odour and, for poultry carcasses, this first becomes evident in the neck flap, the portion of skin that remains on the carcass after the neck itself has been

removed (Patterson and McMeekin, 1981). In the case of chill-stored chicken portions, Ayres *et al.* (1950) reported a characteristic ester-like odour, described as resembling a 'dirty dishrag'. Shortly afterwards, numerous, small, translucent colonies were observed on the skin and cut-muscle surfaces, developing eventually into a layer of slime. At this stage, the odour had become ammoniacal and microbial populations exceeded 1.0×10^8 cfu/cm^2. Thornley *et al.* (1960) also reported a putrid, ammoniacal odour from chicken carcasses, when counts exceeded 1.0×10^7 cfu/cm^2 on the skin. Elliott and Michener (1961) found that 'off' odours were associated with aerobic plate counts between 1.6×10^5 and 1.0×10^8 cfu/cm^2, whereas slime appeared only when counts reached 3.2×10^7 to 1.0×10^9 cfu/cm^2. Cox *et al.* (1975) studied the 'off' odours produced by different strains of *Pseudomonas* spp., when inoculated into various sterile chicken media. They noted that the more intense odours were produced by the non-pigmented *Ps. fragi* and did not reflect different rates of multiplication among the test organisms. Using chicken carcasses inoculated with known spoilage organisms and stored at 4ºC, Viehweg *et al.* (1989) showed that virtually all the odorous substances formed could be attributed to microbial metabolism. It was concluded that autolytic changes in the meat *per se* played no direct part in the spoilage process and the metabolic activities of the microflora were mainly responsible for the 'off' odours produced.

13.2   Types of bacteria and the chemical basis of poultry meat spoilage

13.2.1   Microbial associations and meat spoilage

Aerobic storage of poultry meat under chill conditions leads to the development of a characteristic microflora. The organisms concerned are generally termed 'psychrotrophs', because they can multiply at chill temperatures, but have temperature optima above 20ºC (Eddy, 1960). On a suitable nutrient-agar medium, they form visible colonies at 1ºC within 14 days. Some of these organisms are capable of growth at −3ºC but, generally, not above 32–34ºC, and a few fail to grow at 30ºC (Barnes and Impey, 1968). At spoilage, the predominant organisms are invariably *Pseudomonas* spp., accompanied by lower numbers of *Acinetobacter, Moraxella* and *Psychrobacter* spp., including *Ac. johnsoni* and *Psychr. immobilis.* These bacteria show the fastest growth rates under the prevailing conditions and include strains with the greatest spoilage potential. The pseudomonads have been difficult to identify with known species. A numerical taxonomy study (Arnaut-Rollier *et al.*, 1999) revealed four major clusters among strains isolated from freshly processed and stored poultry meat: *Ps fragi*, *Ps lundensis*, *Ps fluorescens* biovars and an unidentified group with a high degree of similarity to *Ps fluorescens*. Other Gram-negative bacteria that can be isolated sometimes from spoiled poultry include *Shewanella putrefaciens* and various cold-tolerant strains of Enterobacteriaceae, such as *Enterobacter* and *Serratia* spp. All the above organisms are likely to originate in the

environment of the live bird, and most are common in soil and water (Mossel *et al*., 1995). Because of their inability to grow above 34ºC, the organisms would not be expected to occur in the avian alimentary tract. In addition to cold-tolerant bacteria, yeasts are now thought to play a more prominent role in the spoilage of poultry meat than was recognised previously (Ismail *et al*., 2000). During storage at 5ºC, yeast populations were found to increase significantly on whole chicken, liver, heart and gizzard, with numbers reaching a maximum of 10^5 cfu/g. The majority of isolates were *Yarrowia lipolytica* or *Candida zeylanoides,* which appeared capable of psychrotrophic growth. Most *Y. lipolytica* strains showed strong proteolytic and lipolytic activities, although their exact role in spoilage is presently unknown.

While *Pseudomonas* spp. predominate at spoilage on chilled poultry meat stored in air, any marked temperature abuse of the product can lead to the development of a different microbial association. Data shown in Table 13.1 indicate that, as the storage temperature was raised, the proportion of pseudomonads declined and, at 20–22ºC, these organisms comprised only one fifth or less of the overall flora. In parallel, there was an increase in organisms of other genera, including strains of Enterobacteriaceae. At 20ºC, Pooni and Mead (1984) isolated a variety of bacteria that included *Aeromonas* spp. and the mesophile, *Escherichia coli*. With storage at 22ºC, Ahmed (1979) found that *Proteus* spp. comprised 70% of the total flora and, in a similar study, Regez *et al*. (1988) reported that pseudomonads comprised less than 2% of the flora at this temperature. In a laboratory medium, Pooni and Mead (1984) found that some of the organisms they isolated from temperature-abused poultry grew as rapidly as the pseudomonads at ambient temperatures. The changes in microflora that result from storage of poultry at temperatures above the chill range will affect the pattern of microbial metabolites associated with spoilage, as discussed by Pooni and Mead (1984).

The composition of the spoilage microflora also changes when raw-meat products are treated in a manner that seeks to extend shelf-life by reducing populations of pseudomonads and other Gram-negative psychrotrophs or inhibit their growth by modifying the environmental conditions (see below). In the

Table 13.1   Relationship between storage temperature and spoilage microflora for chicken carcasses (adapted from Pooni and Mead, 1984)

Storage temp (ºC)	Proportional incidence at spoilage (%)					
	Pseudomonas spp.		Enterobacteriaceae		Other bacteria	
	study A	study B	study A	study B	study A	study B
0–7	100	70	0	3	0	26
7–10	80	33	0	15	20	52
15	50	11	40	27	10	61
20–22	20	13	70	26	10	61

Study A; Ahmed (1979); study B: Barnes and Thornley (1966) and Pooni and Mead (unpublished)

latter case, the organisms that predominate at spoilage are usually lactic acid bacteria, including those referred to previously as 'atypical lactobacilli' (Thornley and Sharpe, 1959). Some are *Lactobacillus* spp. or are now placed in the genus *Carnobacterium* (for example, *Carn. maltaromicus*) (Holzapfel, 1998). Other organisms that can occur in large numbers include *Brochothrix thermosphacta*, *Aeromonas* spp., strains of Enterobacteriaceae and *Shew. putrefaciens*.

13.2.2   The chemical basis of spoilage

The chemistry of meat spoilage has been studied extensively and, although much of the available information relates to red meat, there are no indications that poultry differs significantly in the basic processes involved (Dainty, 1982). Like other meats, poultry has a high water content and a variety of nutrients capable of providing sources of carbon and energy for microbial growth. The starting point is the condition of muscle following the physical and chemical changes associated with the development of *rigor mortis*. The most relevant changes occur in the concentrations of certain water-soluble, low-molecular-weight compounds (Gill, 1982). These include depletion of the high-energy phosphate substances, adenosine triphosphate (ATP) and creatine phosphate, while the storage carbohydrate, glycogen, is degraded to lactic acid and, in consequence, there is a fall in muscle pH, the extent of which depends upon the amount of glycogen present initially. The decline in pH results in some protein denaturation and a degree of proteolysis by muscle enzymes that leads to the release of peptides and amino acids. Other low-molecular-weight compounds present include ammonia, creatine and inosine monophosphate from the breakdown of ATP.

Despite the array of potential growth substrates in muscle, the main spoilage organisms of chilled meat stored aerobically (*Pseudomonas* spp.) preferentially utilise glucose and glucose-6-phosphate. Thus, a diffusion gradient develops, allowing glucose from within the muscle to continue reaching the meat surface on which the organisms multiply. Following uptake, glucose may be converted by pseudomonads to 2-oxo-gluconate or gluconate. These compounds are not readily assimilated by other organisms and therefore provide an energy reserve that may confer a competitive advantage (Nychas *et al.*, 1988). During the logarithmic phase of growth, glucose metabolism results in the formation of a complex mixture of short-chain fatty acids, ketones and alcohols, none of which are malodorous (Dainty, 1996). Once the glucose supply becomes depleted, however, at microbial populations $>10^7/cm^2$, lactate and amino acids begin to be utilised and malodorous compounds are formed, especially from the sulphur-containing amino acids, cysteine, cystine and methionine. These can include hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide that contribute to the putrid, sulphury 'off' odours associated with spoilage (McMeekin and Thomas, 1980; Dainty, 1996). In total, Nychas *et al.* (1998) list more than 40 volatile metabolites, including ammonia, that have been

detected in spoiled meats and appear to result largely from amino acid utilisation. Once the pool of amino acids has been depleted and cells enter the stationary growth phase, having reached maximum numbers, there may be microbial proteolysis and lipolytic activity as well.

Under conditions in which the oxygen concentration in a meat pack is greatly diminished and carbon dioxide increased, growth of *Pseudomonas* spp. is markedly reduced, due mainly to the inhibitory effect of the high level of carbon dioxide. The slower-growing lactic acid bacteria that often spoil the meat eventually are tolerant to carbon dioxide and ferment glucose to products that include lactic, *iso*-butanoic, *iso*-pentanoic and acetic acids, which give the meat a characteristic sour/cheesy odour. This does not preclude the possible presence of appreciable numbers of pseudomonads under some conditions, but the organisms no longer determine the nature of spoilage, when bacterial populations are ultimately dominated by lactic acid bacteria.

A detailed understanding of meat spoilage is of obvious scientific interest and has possible practical implications for extending shelf-life, such as addition of glucose to meat as a means of delaying microbial utilisation of amino acids (Shelef, 1977; Barua and Shelef, 1980). There is, however, a further reason why spoilage processes and their biochemical control require elucidation. This is because of the need for chemical or physical indicators that could be used to predict the onset of spoilage in chill-stored meat. Progress in the field is hampered by the subjective nature of spoilage and lack of agreement on suitable indicators. Part of the problem, discussed by Nychas *et al*. (1998), is that there is no information on the relationship between the presence of candidate metabolites or physical criteria and the organoleptic characteristics of the meat. Also, the exact sequence in which particular substrates are utilised by spoilage organisms appears to be less rigid than was previously supposed (Molin, 1985), while even microbial proteolysis, which is usually considered a late event, may be occurring prior to complete utilisation of glucose and lactate (Nychas and Tassou, 1997).

13.3   Spoilage of uneviscerated poultry

In the UK, the more traditional kind of turkey is valued for its particular flavour and eating quality, and is popular with many consumers at Christmas time. The quality characteristics of the product are partly related to the slower-growing type of bird that is used, but they also reflect the manner in which the carcass is processed and then stored for a period in the uneviscerated state. Processing should aim to keep the carcass dry and the skin intact, because the dryness of the surface is effective in retarding microbial growth, and spoilage bacteria will grow more readily on cut surfaces of skin and muscle, due to release of moisture and nutrients. The intact carcass is hung for two to three weeks at no more than 4ºC, before being 'cold' eviscerated in the processing plant. Production is restricted to the pre-Christmas period, when ambient temperatures tend to be low.

Like the hung game bird, spoilage of an uneviscerated turkey carcass is normally different from that of its eviscerated counterpart, and is due to microbial activity in the intestinal tract. The intestines contain large numbers of hydrogen sulphide-producing bacteria and, during storage, the gas will gradually diffuse through the musculature. At the surface of the carcass, it will react with the pigments of blood and muscle to produce a green discoloration that appears to be due to the formation of sulphaemoglobin (Barnes and Shrimpton, 1957). Greening often starts around the vent and on the abdomen, later occurring over the ribs and along the back and neck of the carcass. At 20ºC, greening will be evident within about a day, but the process takes 5–7 days at 10ºC, and considerably longer at lower temperatures. The muscles themselves appear to remain free from bacteria at all storage temperatures.

In practice, there are also other ways in which spoilage of this type of product can occur. Any retention of moisture at the carcass surface, such as that arising from poor storage conditions, will favour growth of the normal aerobic spoilage bacteria, especially pseudomonads, and 'off' odours may then develop. Another form of spoilage relates to flavour development during the period of hanging in the uneviscerated state. If the storage period is prolonged, the resultant meat flavour may be too strong to suit some consumers. It is possible to hang an uneviscerated carcass to encourage flavour development, because of its unusually long shelf-life. Barnes and Impey (1975) compared the shelf-life of eviscerated and uneviscerated chickens taken from the same processing plant and stored at 4ºC, both wrapped and unwrapped. The unwrapped, eviscerated carcasses had a mean shelf-life of 7.9 days before 'off' odours became evident, whereas holding them in polythene bags reduced the mean shelf-life to 5.6 days, due to enhanced moisture retention. By contrast, unwrapped, uneviscerated carcasses showed no sign of spoilage until day 28.

Effects of storage on meat texture and flavour in uneviscerated turkeys were studied by Griffiths et al. (1984). Although hanging at 4ºC had little or no effect on meat texture, the flavour of the cooked meat increased in intensity from about eight days onwards, according to assessments by a trained taste panel. By day 24, however, some members of the panel showed an adverse reaction to the flavour. Meat flavour development under these conditions is similar to that in hung game birds, such as the pheasant. It is usually attributed to autolytic changes occurring in the musculature, but bacterial metabolism in the gut may also play a part. In the study of Griffiths et al. (1984), large populations of microorganisms were present in the intestines and many remained viable throughout the hanging period; it is reasonable to assume, therefore, that some, at least, would be actively metabolising.

13.4   Factors affecting the shelf-life of poultry meat

13.4.1   Storage temperature
The principal factor affecting the shelf-life of raw, flesh foods is storage temperature and, because the spoilage of such foods appears to be due mainly to

microbial activity, the effect closely parallels that of microbial growth. Within the European Union (EU), there is a requirement for chilled poultry meat to be stored at a temperature not exceeding 4ºC (Directive 71/118/EEC). This limit relates more to product safety, however, and significantly lower temperatures are needed to safeguard shelf-life during cold storage and distribution. In commercial conditions, the processor usually aims to achieve an end-product temperature of 0–2ºC prior to distribution. The value of keeping processed carcasses as cold as possible is illustrated by the study of Barnes *et al*. (1978), in which eviscerated turkey carcasses wrapped in an oxygen-permeable film were stored at temperatures between +5 and −2ºC. Keeping the carcass at 0ºC rather than +2ºC extended shelf-life by more than seven days. At −2ºC, just above the freezing point, 'off' odours were not detected until about 38 days, although no attempt was made to assess any changes in meat flavour that might have occurred over such a long period. Studies of this kind, carried out under laboratory conditions, involve relatively constant storage conditions while, in commercial practice, the temperature will inevitably vary to some extent at the different stages of the cold chain. Thus, shelf-life will reflect the cumulative effects of fluctuating temperature throughout the storage history of the product. Predictive mathematical models relating temperature and spoilage-rate for poultry products were studied by Daud *et al*. (1978) and Pooni and Mead (1984), and data for these parameters were shown to fit the Arrhenius equation, as proposed by Olley and Ratkowsky (1973). Even more appropriate was the square root equation of Ratkowsky *et al*. (1982), according to tests on 28 sets of spoilage data from 14 published studies (Pooni and Mead, 1984). The data fitted well up to about 15ºC, but at higher temperatures the spoilage characteristics of the products were clearly different. Nevertheless, this approach supports the contention that spoilage over a wide range of temperatures is principally due to microbial growth and metabolism.

13.4.2   Microbiological condition

Another major determinant of shelf-life is the microbiological condition of the freshly processed product, especially in relation to levels of *Pseudomonas* contamination. Barnes *et al*. (1979a) showed a linear relationship between shelf-life and initial numbers of pseudomonads on the carcass. With counts of 10^2 / cm^2, a shelf-life at 1ºC of *c*. 19 days could be obtained, but this was reduced to *c*. 13 days, when the level reached $10^4/cm^2$. Because contamination of carcasses with pseudomonads is virtually eliminated during scalding (see Chapter 11), most of the contamination with these organisms must occur at later stages of the process. Table 13.2 shows that pseudomonads can be isolated in relatively high numbers from various items of processing equipment during the working period. The rubber gloves worn by operatives are often highly contaminated, as reported by Holder *et al*. (1997). Therefore, reducing product handling to a minimum or, at least, ensuring that rubber gloves are cleaned regularly will benefit product shelf-life. As part of a study of five UK processing plants, Mead *et al*. (1993)

Table 13.2 Contamination of processing equipment with *Pseudomonas* spp. (Abd el Hady and Mead, unpublished)

Item	Visit 1	Visit 2
Head puller (roll bar)	4.0*	2.7
Evisceration machine	3.7	5.1
Lung remover	4.4	4.3
Conveyor to chiller	2.6	2.2
Gloves of operatives		
loading chiller A	4.4	4.0
B	3.7	4.6
Automatic grader	4.3	5.3
Gloves of operatives		
loading trays A	5.6	5.4
B	5.2	4.5

* Log_{10} cfu/cm^2 or swab; samples taken 4 h after start of process.

found that levels of *Pseudomonas* on carcasses tended to increase either during or after chilling, whether by air blast or water immersion. With water chilling, the seeding of carcasses with pseudomonads from the chill-water can be prevented by use of super-chlorination, although this is not permitted in the EU and water chilling is used only for carcasses that will be sold frozen. The occurrence and possible growth of spoilage organisms on processing equipment underlines the need for effective, post-processing cleaning and disinfection programmes.

When poultry carcasses and cut portions are presented for sale in a butcher's shop, they are usually displayed unwrapped and the surface tends to dry out. In theory, this should help to increase shelf-life by lowering the water activity (a_w) of the skin and cut muscle, but whole carcasses do not dry out evenly and pockets of moisture may remain, especially within the abdominal cavity (Mead and Hudson, 1987). Studer *et al*. (1988) reported that storage of unwrapped chicken carcasses at 4ºC reduced the surface a_w to 0.97, but had no effect on spoilage rate. With packaged carcasses, conditions are usually such that microbial growth is unaffected by a_w. A study carried out in the EU (Report, 1978) showed that the surface a_w of water-chilled chicken carcasses was 0.996 immediately after chilling, whereas that of air-chilled carcasses was only 0.970 and could have affected the growth of spoilage bacteria. After packaging, however, the latter value increased to 0.990 during storage at 2ºC for 6 h, due to migration of moisture from deeper tissues. Ultimately, there was no significant difference in shelf-life between water-chilled carcasses and those chilled in air. Barnes and Impey (1975) found that the shelf-life of unwrapped, air-chilled carcasses stored at 4ºC varied considerably, due probably to unequal drying. Transferring a parallel batch of carcasses to polythene bags reduced the variability, but also the mean shelf-life. Storing eviscerated turkey carcasses at -2ºC, which would also reduce the surface a_w, led to an increase in growth of yeasts (Barnes *et al*., 1978). These organisms are more tolerant than bacteria to

low a_w and, at spoilage, the predominant species were *Cryptococcus laurentii* and *Candida zeylanoides*.

Poultry have both red and white muscle, which differ in chemical composition and pH value. However, pigmented and non-pigmented strains of *Pseudomonas* spp. were found by Barnes and Impey (1968) to grow equally well in breast (pH 5.7–5.9) and leg muscle (pH 6.4–6.7). In contrast, strains of *Acinetobacter* and *Moraxella (Psychrobacter)* spp. grew in leg, but not in breast muscle, while a strain of *Shew. putrefaciens* grew faster in leg than in breast. At spoilage, 80% of psychrotrophic isolates from breast were capable of producing 'off' odours, whereas only 21% did so from leg (McMeekin, 1975, 1977). Such differences in behaviour may be significant in relation to the spoilage of particular cuts of poultry meat.

Among the Gram-negative spoilage bacteria, those that usually predominate on aerobically stored poultry are obligate aerobes, but pseudomonads, in particular, have a very high affinity for oxygen and are capable of growth in relatively low oxygen tensions (Molin, 1985; Drosinos and Board, 1994). On red meat, Shaw and Nicol (1969) showed that growth was unaffected until the oxygen concentration was reduced below 0.8%. Of greater significance for meat storage is the sensitivity of these organisms to carbon dioxide. It was shown by Coyne (1933) and Haines (1933) that 10–20% carbon dioxide reduced the growth rates of pseudomonads and certain other spoilage bacteria, as long as the incubation temperature remained below 4ºC and ideally close to 0ºC. Even approximately 3% carbon dioxide was found by Gardner and Carson (1967) to inhibit growth of *Pseudomonas* on pork held at 2ºC. The effectiveness of carbon dioxide at low storage temperatures is likely to be influenced by the high solubility of the gas in these conditions. However, solubility increases by about 19 ml/kg of meat for each 1ºC rise in temperature between -1ºC and 10ºC and by about 360 ml/kg for each pH unit rise (Gill, 1988). Despite a long history of usage by the meat industry as a means of extending shelf-life, the exact mechanism of carbon dioxide inhibition is still uncertain. Possible factors, reviewed by Stanbridge and Davies (1998), include changes in cellular membrane function that affect nutrient uptake in sensitive bacteria, direct inhibition of key enzymes, alteration of intracellular pH, among others. For practical purposes, it needs to be recognised that carbon dioxide has a bacteriostatic effect, which extends the lag phase of susceptible organisms and/or increases their generation time. Therefore, it is most effective when applied before any significant growth of spoilage organisms has occurred on the meat.

13.4.3   Film permeability

When meat is vacuum-packed in an oxygen-impermeable film, any remaining oxygen is soon consumed by residual tissue respiration and by the metabolic activities of microbial contaminants. Depending on film permeability, oxygen is largely prevented from entering the pack, while the internal carbon dioxide concentration steadily increases. Although vacuum-packaging is widely used in

Table 13.3   Effect of storage conditions on microbiological changes and spoilage rate of turkey breast and leg portions (Jones *et al.*, 1982)

Type of portion	Storage conditions	Total count,* 1°C	Pseudo-monads** (%)	Atypical lactobacilli (%)	Days to 'off' odour
Breast	Aerobic	9.3	66	0	16
	Vacuum	8.4	0	100	25
Leg	Aerobic	8.9	89	0	14
	Vacuum	8.3	0	100	20

* Geometric mean of 3 samples ($\log_{10}$ cfu/g).
** Proportion of isolates from plate count agar incubated at 1°C for 14 d.

the red-meat sector for meat storage and wholesale distribution, it has few applications for chilled poultry. Nevertheless, Shrimpton and Barnes (1960) showed that storing chicken carcasses at 1°C in vacuum packs, using an oxygen-impermeable film, increased shelf-life by about four days. While the oxygen concentration fell rapidly below 7%, carbon dioxide within the packs increased to more than 9%. Vacuum packaging of duck carcasses in a heat-shrunk, oxygen-impermeable film extended shelf-life at +2°C and −1°C by more than 50% in each case (Barnes *et al.*, 1979b). Subsequently, vacuum-packed ducks were marketed in the UK for several years. Extending product shelf-life with vacuum packaging has shown different effects on turkey breast and leg portions (Jones *et al.*, 1982). During storage at 1°C (Table 13.3), vacuum-packaging in a barrier film delayed 'off'-odour development from 16 to 25 days for breast fillets (pH 5.9–6.0) and from 14 to 20 days in the case of drumsticks (pH 6.1–6.3). Pseudomonads predominated at spoilage on portions packed in oxygen-permeable film, but, in vacuum packs, the principal organisms were two groups of 'atypical lactobacilli', one of which was more common on breast portions, the other on leg meat. It was observed that deleterious flavour changes tended to precede the development of 'off' odours in the vacuum packs, and this may be a particular problem with turkey meat.

13.4.4   Modified atmosphere packaging
A more useful approach for retail display purposes is the use of modified atmosphere packaging (MAP), in which the composition of the gaseous environment can be tailored to particular needs. The technology is considered further in Chapter 7. Its application to poultry has expanded in recent years, with the development of more cost-effective packaging materials, and the system is also used for bulk packs. When mixed with air or oxygen, the optimum concentration of carbon dioxide is 20–30%, which avoids any discoloration or loss of bloom (Stanbridge and Davies, 1998), but, in the absence of oxygen, inhibition of aerobic spoilage bacteria increases with increasing concentration of carbon dioxide. With 100% of this gas, packs would tend to collapse because of

the high solubility of carbon dioxide in the meat, but this is unimportant with bulk packs that are not used for direct retailing. Timmons (1976) described a system in which *c.* 30 kg of product was packaged, evacuated and then back-flushed with carbon dioxide prior to heat-sealing. The method was said to give an 18–21 day shelf-life at −2ºC to +1ºC. Transferring meat stored in 100% carbon dioxide to normal atmosphere under chill conditions gives an extended shelf-life, which is intermediate between that in air alone and the shelf-life in carbon dioxide. The value of such an effect in a retail store is that individual items can be removed from bulk storage as required, provided that the original atmosphere can be restored by re-gassing. The residual 'preservative' effect may be due to slow release of carbon dioxide from the tissues or merely transferring the product from one set of conditions to another, thereby inducing a lag phase in the growth of aerobic spoilage bacteria.

With red meat, an advantage in using MAP for retail display is that the attractive red colour of the meat is enhanced and maintained by including 80% oxygen in the pack to sustain the oxymyoglobin content. The high concentration is also inhibitory to aerobic spoilage bacteria. The same approach can be used for poultry meat, although the colour of the product is less critical, especially when the skin is present. Moreover, with turkey breast fillets, inclusion of 10% or 20% oxygen in gas packs containing 20–30% carbon dioxide led to the appearance of unpleasant flavours after storage at 1ºC (Mead *et al.*, 1983). At the higher level of oxygen, meat colour was enhanced, but varied in intensity from one fillet to another. Also, patches of pink colour tended to persist after cooking, giving those parts of the meat a raw appearance. By contrast, Hotchkiss *et al.* (1985) found that chicken breast and leg portions stored at 2ºC in atmospheres containing up to 80% carbon dioxide in air had higher sensory-panel ratings for raw-meat odour and overall acceptability, with little effect on eating quality up to 35 days of storage. Gas mixtures containing carbon dioxide and air were also found to be suitable for duck portions stored at 1ºC (Mead *et al.*, 1986). However, when the air was replaced by nitrogen, the skin developed an unsightly waxen or milky appearance.

In a further study of chicken portions, Patterson *et al.* (1984) compared the effects of vacuum-packaging and MAP, using 10% or 20% carbon dioxide in nitrogen. Both methods gave useful extensions of shelf-life, which were more marked at 1ºC than at 4–5ºC, and for breast portions than leg or thigh. Because the potent spoilage organism, *Shew. putrefaciens*, grew in some gas-packed samples, tests were carried out on portions dipped for 30 s in either 5% potassium sorbate or 3% lactic acid, prior to packaging. Both treatments appeared capable of controlling *Shew. putrefaciens* and avoiding any problem from the early production of sulphide-like odours, but, in the absence of a detailed sensory evaluation, a storage period of only 14 days was recommended initially. A chemical pre-treatment was also studied by Jiménez *et al.* (1999), who treated chicken breast portions with 1% acetic acid and then packaged them in an atmosphere containing 70% carbon dioxide in nitrogen. The acid treatment reduced counts of all microbial genera studied and extended shelf-life beyond

that obtained with gas-packaging alone, but no account was taken of possible changes in meat flavour during storage.

13.5   The effects of freezing and frozen storage

Most work on this topic that relates to the behaviour of microbial cells was carried out more than 50 years ago and is reviewed by Ingram and Mackey (1976). It is generally accepted that microbes are unable to grow below −10ºC to −12ºC and that they can be adversely affected by conditions of freezing, frozen storage and thawing. Indeed, such conditions are likely to be just as important in relation to cell viability as differences in survival capability between individual organisms (Ingram and Mackey, 1976).

Freezing itself causes some inactivation, with slow freezing being more damaging, because of the increased period of exposure to concentrated solutes that cause osmotic water loss from microbial cells. Death during subsequent frozen storage is a function of time and temperature, and is often more rapid at −2 to −5ºC than at −20ºC. After freezing, cell death sometimes follows an exponential course at a particular temperature, but the rate of die off is usually more rapid initially, and then becomes slower until the number of cells remaining viable reaches an almost constant level. Gram-positive bacteria are usually more resistant to freezing and frozen storage than Gram-negative spp., with Gram-positive cocci, such as *Enterococcus* and *Staphylococcus* spp., being among the most resistant. However, even Gram-negative psychrotrophs survive relatively well, and poultry that is frozen and then thawed shows little or no difference in shelf-life under chill conditions, when compared with non-frozen controls (Spencer *et al.*, 1955, 1961; Elliott and Straka, 1964).

13.6   Food safety implications of chill storage and the isolation of spoilage organisms

13.6.1   Chill storage

Microbial spoilage of chill-stored poultry meat is normally due to organisms that are non-pathogenic to humans. After extensive multiplication of these organisms, the meat becomes unwholesome and clearly unfit for human consumption. However, measures to extend shelf-life, as in MAP, not only provide a longer period during which slower-growing organisms, such as cold-tolerant pathogens, could multiply, but the point at which spoilage from 'off' odours occurs will tend to be less clearly defined. Thus, pathogens could reach dangerous levels, especially on high-pH meat, without spoilage being evident as a 'hazard indicator'. The organisms of possible concern in this context include *Aeromonas* spp., *Listeria monocytogenes, Yersinia enterocolitica* and psychrotrophic strains of *Clostridium botulinum.* The first three are not uncommon on poultry meat, although strains of *Y. enterocolitica*

associated with poultry do not usually belong to serotypes involved in human illness (Waldroup, 1996). Also, while yersinias can grow readily in vacuum packs and in packs containing 20% carbon dioxide, their growth on chill-stored pork was inhibited at higher concentrations (Enfors *et al.*, 1979), provided that the meat was kept below 10ºC (Karitu and Mead, unpublished). Strains of *Aeromonas* spp., especially *A. sobria*, with characteristics identical to those associated with human diarrhoea, were frequently isolated from raw poultry by Kirov *et al.* (1990). Enterotoxigenic strains had T min values of about 4.5ºC, but no enterotoxin was produced below 15ºC, and it was concluded that the organisms were unlikely to present a significant public health risk, provided that poultry was properly stored and cooked. Also, there is evidence that growth of aeromonads on meats is inhibited by carbon dioxide-enriched atmospheres (García de Fernando *et al.*, 1995). The likelihood of *List. monocytogenes* multiplying on meats appears to be highly dependent on temperature, meat pH and type of tissue, and on the nature of the background microflora, with lactobacilli exerting a marked antimicrobial effect (Farber and Peterkin, 1991). While poultry meat seems to support better growth of *List. monocytogenes* than other meats, the organism grew more slowly on vacuum-packed chicken breast (Carpenter and Harrison, 1989), and growth was greater on thigh portions with skin than on skinless breast portions (Bolder *et al.*, 1991). In both cases, however, the organism was markedly inhibited in MAP containing 100% carbon dioxide. With skinless breast meat (pH 5.8), Hart *et al*. (1991) found that *List. monocytogenes* failed to multiply at 1ºC, even without MAP. Some growth occurred at 6ºC under aerobic conditions, before the onset of spoilage, but not in 100% carbon dioxide.

The spore-forming anaerobe, *Clostridium botulinum*, includes psychro-trophic, non-proteolytic strains that can produce toxin at temperatures down to 3.3ºC (Schmidt *et al.*, 1961). In addition, the build-up of carbon dioxide in vacuum packs may even stimulate spore germination. At chill temperatures, however, 100% carbon dioxide delays growth of the organism (Doyle, 1983). Because of the risk that the anaerobe will multiply sufficiently to be hazardous in packs containing only carbon dioxide and nitrogen, one option is to incorporate oxygen in the gas mixture. This gas would need to be at a concentration in excess of that utilised by the respiring meat and associated microbes, but would not necessarily prevent toxin-formation, should other conditions be favourable. In practice, *Cl. botulinum* is very rarely found on raw poultry meat and any preformed toxin would be readily destroyed by cooking. MAP has an excellent safety record with respect to this and other psychrotrophic pathogens. Growth of all these organisms is inhibited to some degree by enrichment of the storage atmosphere with carbon dioxide and, generally, the higher the carbon dioxide concentration and the lower the temperature and meat pH, the greater is the inhibition of growth (García de Fernando *et al.,* 1995). The risk of growth occurring is more significant when meat pH is 6.0 or higher, as in poultry leg muscle, and/or temperature abuse of the product occurs. Otherwise,

the use of carbon dioxide-enriched atmospheres appears to be no more hazardous than conventional chill storage under aerobic conditions, and an additional safeguard is the setting of appropriate 'use by' dates for particular products.

13.6.2   Isolation of spoilage organisms

All of the psychrotrophic spoilage bacteria can be recovered on relatively simple, non-selective isolation media, such as plate count agar or nutrient agar, following surface inoculation with appropriate sample dilutions and incubation of plates at 1ºC for 14 days. Alternatively, shorter periods at higher temperatures may be used, (for example, 7ºC for 10 days) (Gilliland *et al.*, 1984). Complex supplements such as whole blood are generally unnecessary, although they usefully improve the growth of some organisms. When a flora analysis is required, it is important to choose plates with a suitable number of colonies that will include all the principal colony types, and to divide each plate into sectors. All colonies in one particular sector should be picked for analysis to avoid any inadvertent bias. On non-selective media, meat strains of *Shew. putrefaciens* usually show a salmon-pink coloration, but require use of confirmatory tests. For *Pseudomonas* spp., several selective media are available and are discussed by García-López *et al.* (1998). The cephaloridine-fucidin-cetrimide (CFC) agar of Mead and Adams (1977) allows isolation of both pigmented and non-pigmented strains, following incubation at 25ºC for 48 h. However, the medium does not include a differential test to distinguish pseudomonads from background organisms and, for this reason, it is advisable to flood the incubated plates with oxidase reagent, since, unlike *Pseudomonas* spp., none of the interfering organisms should be oxidase-positive. As an alternative, Stanbridge and Board (1994) added 1% arginine and phenol red to the medium to detect ammonia production from arginine, but the reaction was obscured by growth of other organisms and this modification is rarely used now.

Selective isolation of psychrotrophic Enterobacteriaceae may be achieved with overlaid pour-plates of violet red-bile-glucose agar, incubated at 4ºC for 10 days. There are no selective media for organisms of the *Acinetobacter/ Moraxella/Psychrobacter* group, although detection of low numbers can be facilitated by the use of a medium containing bile salts and crystal violet (García-López *et al.*, 1998). For lactic acid bacteria that may become predominant under conditions in which pseudomonads are inhibited, there is a range of elective and selective media, including the MRS Medium of de Man, Rogosa and Sharpe (1960) at pH 6.4, acetate agar (pH 5.6) and Rogosa agar (pH 5.5), as discussed by Holzapfel (1998). The best selective medium for *Br. thermosphacta* is still the streptomycin-thallous acetate-actidione agar of Gardner (1966), with incubation at 22ºC for up to five days. Other Gram-positive organisms are largely inhibited on this medium. Selective isolation of yeasts and moulds makes different demands, as discussed by Pitt (1986). The ideal enumeration medium should have the following attributes:

- bacterial growth should be completely suppressed
- there should be no inhibition of the organisms being sought
- the nutritional status of the medium should support the growth of relatively fastidious organisms
- radial growth of fungal colonies should be constrained, without preventing spore germination.

Not surprisingly, no one medium is adequate for all yeasts and moulds in foods, but several antibiotic-containing media are suitable for most analytical purposes (for example, oxytetracycline-glucose-yeast extract agar, rose bengal-chlortetracycline agar and dichloran-rose bengal-chloramphenicol agar (Beuchat, 1995)).

13.7   Future trends

The development of affordable, effective materials and systems for gas-packaging of poultry has opened up considerable opportunities for the marketing of products with an extended shelf-life in the chilled state. However, any further extension of product shelf-life will not be possible without parallel improvements in the control of psychrotrophic foodborne pathogens. Also, further research is still needed to provide a better understanding of the relationship between growth of psychrotrophic pathogens and the development of spoilage floras on meat held in different gaseous environments. Such research will need to take account of the effects of product abuse in the hands of consumers, and the data are required for risk assessment purposes. In the case of pathogens that would *not* be expected to multiply in gas packs, there may be an opportunity to use the gaseous environment of the pack to enhance die off. At present, conditions that are known to be most inhibitory to spoilage organisms are correspondingly favourable for survival of *Campylobacter* (high carbon dioxide concentration, high humidity), as discussed by van Laack *et al*. (1996). Anecdotal evidence suggests that gas packs containing high oxygen concentrations may cause a more rapid decline in levels of *Campylobacter*, and this needs further investigation. Also, a better understanding of the mechanism of carbon dioxide inhibition in microorganisms could facilitate further exploitation of this phenomenon. Thus, in the future, gas mixtures used in MAP could be more closely tailored to particular products for control purposes.

In relation to improvements in shelf-life, better control of primary processing would reduce contamination of carcasses with spoilage organisms and minimise carcass-to-carcass variation. Recent introduction of Hazard Analysis Critical Control Point (HACCP) principles in poultry processing is aimed mainly at foodborne pathogens, especially *Salmonella* and *Campylobacter*, and is particularly important in the context of the EU, where no chemical decontamination of carcasses or use of super-chlorinated process water is presently permitted. While the application of HACCP principles will not overcome the basic hygiene problems in processing (Chapter 11), it does have relevance to the

control of spoilage organisms and, for this purpose, can be used to target the post-scalding stages of the process, which include the most likely sources of product contamination. Improving control of spoilage organisms may also involve more attention to cleaning and disinfection procedures.

13.8   Sources of further information

Two publications of the Institute of Food Science and Technology, London, are relevant: one is *Shelf Life of Foods – Guidelines for its Determination and Prediction* (1993, ISBN 0 905367 11 1), which deals with spoilage processes and factors affecting shelf-life throughout the food chain, and gives information on possible approaches to shelf-life forecasting. This publication is supplemented by *Food and Drink – Good Manufacturing Practice: A Guide to its Responsible Management*, 4th Edition (1998, ISBN 0 905367 15 4). Further discussion of strategies for extending the shelf-life of poultry meat products can be found in Woods and Church (1999). The general influence of packaging and other relevant factors on meat quality of fresh and frozen products is considered by Taylor (1996). For details of the properties of spoilage organisms and their identification, the book edited by Davies and Board (1998) should be consulted. Finally, details of many appropriate isolation media for spoilage organisms are given in Corry *et al.* (1995).

13.9   References

AHMED M A (1979), *Aspects of the Microbiology of the Spoilage of Meat with Special Reference to Gram-negative Facultatively Anaerobic Rods of the Family Enterobacteriaceae*, PhD thesis, The Queen's University, Belfast, N Ireland, UK.

ARNAUT-ROLLIER I, VAUTERIN L, DE VOS P, MASSART D L, DEVRIESE L A, DE ZUTTER L and VAN HOOF J (1999), 'A numerical taxonomic study of the *Pseudomonas* flora isolated from poultry meat', *Journal of Applied Microbiology* 87, 15–28.

AYRES J C, OGILVY W S and STEWART G F (1950), 'Post mortem changes in stored meats. I. Microorganisms associated with development of slime on eviscerated cut-up poultry', *Food Technology* 4, 199–205.

BARNES E M and IMPEY C S (1968), 'Psychrophilic spoilage bacteria of poultry', *Journal of Applied Bacteriology* 31, 97–107.

BARNES E M and IMPEY C S (1975), 'The shelf-life of uneviscerated and eviscerated chicken carcasses stored at 10ºC and 4ºC', *British Poultry Science* 16, 319–326.

BARNES E M and SHRIMPTON D H (1957), 'Causes of greening of uneviscerated poultry carcasses during storage', *Journal of Applied Bacteriology* 20, 273–285.

BARNES E M and THORNLEY M J (1966), 'The spoilage flora of eviscerated chickens stored at different temperatures', *Journal of Food Technology* 1, 113–119.

BARNES E M, IMPEY C S, GEESON J D and BUHAGIAR R W M (1978), 'The effect of storage temperature on the shelf-life of eviscerated air-chilled turkeys', *British Poultry Science* 19, 77–84.

BARNES E M, MEAD G C, IMPEY C S and ADAMS B W (1979a), 'Spoilage organisms of refrigerated poultry meat', in *Cold Tolerant Microbes in Spoilage and the Environment*, eds Russell A D and Fuller R, Society for Applied Bacteriology Technical Series no 13, London, Academic Press, 101–116.

BARNES E M, IMPEY C S and GRIFFITHS N M (1979b), 'The spoilage flora and shelf-life of duck carcasses stored at 2ºC or −1ºC in oxygen-permeable or oxygen-impermeable film', *British Poultry Science* 20, 491–500.

BARUA M and SHELEF L A (1980), 'Growth suppression of pseudomonads by glucose utilization', *Journal of Food Science* 45, 349–351.

BEUCHAT L R (1995), 'Media for detecting and enumerating yeasts and moulds', in *Culture Media for Food Microbiology*, eds Corry J E L, Curtis G D W and Baird R M, Progress in Industrial Microbiology, vol 34, Amsterdam, Elsevier, 229–242.

BOLDER N M, VAN LITH L A J T, PUTIRULAN F F and MAST M (1991), 'Influence of modified atmosphere packaging (MAP) of air and water chilled broiler parts on the survival and growth of *Listeria monocytogenes* and competitive pseudomonads', in *Quality of Poultry Products III. Safety and Marketing Aspects,* eds Mulder R W A W and de Vries A W, Beekbergen, Netherlands, Spelderholt Centre for Poultry Research and Information Services, 145–153.

CARPENTER S L and HARRISON M A (1989), 'Survival of *Listeria monocytogenes* on processed poultry', *Journal of Food Science* 54, 556–557.

CORRY J E L, CURTIS G D W and BAIRD R M (1995) *Culture Media for Food Microbiology*, Progress in Industrial Microbiology, vol 34, Amsterdam, Elsevier.

COX N A, JUVEN B J, THOMSON J E, MERCURI A J and CHEW V (1975), 'Spoilage odors in poultry meat produced by pigmented and nonpigmented *Pseudomonas*', *Poultry Science* 54, 2001–2006.

COYNE F P (1933), 'The effect of carbon dioxide on bacterial growth', *Proceedings of the Royal Society, Series B* 113, 196–216.

DAINTY R H (1982), 'Biochemistry of undesirable effects attributed to microbial growth on proteinaceous foods stored at chill temperatures', *Food Chemistry* 9, 103–113.

DAINTY R H (1996), 'Chemical/biochemical detection of spoilage', *International Journal of Food Microbiology* 33, 19–34.

DAUD H B, McMEEKIN T A and OLLEY J (1978), 'Temperature function integration and the development and metabolism of poultry spoilage bacteria', *Applied and Environmental Microbiology* 36, 650–654.

DAVIES A and BOARD R (eds) (1998), *The Microbiology of Meat and Poultry*, London, Blackie Academic & Professional.

DE MAN J C, ROGOSA M and SHARPE M E (1960), 'A medium for the cultivation of lactobacilli', *Journal of Applied Bacteriology* 23, 130–135.

DOYLE M P (1983), 'Effect of carbon dioxide on toxin production by *Clostridium botulinum*', *European Journal of Applied Microbiology and Biotechnology* 17, 53–56.

DROSINOS E H and BOARD R G (1994), 'Metabolic activities of pseudomonads in batch cultures in extract of minced lamb', *Journal of Applied Bacteriology* 77, 613–620.

EDDY B P (1960), 'The use and meaning of the term psychrophilic', *Journal of Applied Bacteriology* 23, 189–190.

ELLIOTT R P and MICHENER H D (1961), 'Microbiological standards and handling codes for chilled and frozen foods. A review', *Applied Microbiology* 9, 452–468.

ELLIOTT R P and STRAKA R P (1964), 'Rate of microbial deterioration of chicken meat at 2ºC after freezing and thawing', *Poultry Science* 43, 81–86.

ENFORS S-O, MOLIN G and TERNSTRÖM A (1979), 'Effect of packaging in carbon dioxide, nitrogen or air on the microbial flora of pork stored at 4ºC', *Journal of Applied Bacteriology* 47, 197–208.

FARBER J M and PETERKIN P I (1991), '*Listeria monocytogenes*, a food-borne pathogen', *Microbiological Reviews* 55, 476–511.

GARCÍA DE FERNANDO G D, NYCHAS G J E, PECK M W and ORDÓÑEZ J A (1995), 'Growth/survival of psychrotrophic pathogens on meat packaged under modified atmospheres', *International Journal of Food Microbiology* 28, 221–231.

GARCÍA-LÓPEZ M L, PRIETO M and OTERO A (1998), 'The physiological attributes of Gram-negative bacteria associated with spoilage of meat and meat products', in *The Microbiology of Meat and Poultry,* eds Davies A and Board R, London, Blackie Academic & Professional, 1–34.

GARDNER G A (1966), 'A selective medium for the enumeration of *Microbacterium thermosphactum* in meat and meat products', *Journal of Applied Bacteriology* 29, 455–460.

GARDNER G A and CARSON A W (1967), 'Relationship between carbon dioxide production and growth of pure strains of bacteria on porcine muscle', *Journal of Applied Bacteriology* 30, 500–510.

GILL C O (1982), 'Microbial interaction with meats', in *Meat Microbiology*, ed. Brown M H, London, Applied Science, 225–264.

GILL C O (1988) 'The solubility of carbon dioxide in meat', *Meat Science* 22, 65–71.

GILLILAND S E, MICHENER H D and KRAFT A A (1984), 'Psychrotrophic microorganisms', in *Compendium of Methods for the Microbiological Examination of Foods*, Washington DC, American Public Health Association, 136.

GRIFFITHS N M, MEAD G C, JONES J M and GREY T C (1984), 'Effect of storage on meat quality in uneviscerated turkeys held at 4ºC', *British Poultry Science* 25, 259–266.

HAINES R B (1933), 'The influence of carbon dioxide on the rate of multiplication of certain bacteria as judged by viable counts', *Journal of the Society of Chemical Industry* 52, 13T–17T.

HART C D, MEAD G C and NORRIS A P (1991), 'Effects of gaseous environment and temperature on the storage behaviour of *Listeria monocytogenes* on chicken breast meat', *Journal of Applied Bacteriology* 70, 40–46.

HOLDER J S, CORRY J E L and HINTON M H (1997), 'Microbial status of chicken portions and portioning equipment', *British Poultry Science* 38, 505–511.

HOLZAPFEL W H (1998), 'The Gram-positive bacteria associated with meat and meat products', in *The Microbiology of Meat and Poultry*, eds Davies A and Board R, London, Blackie Academic & Professional, 35–84.

HOTCHKISS J H, BAKER R C and QURESHI R A (1985), 'Elevated carbon dioxide atmospheres for packaging poultry. II. Effects of chicken quarters and bulk packages', *Poultry Science* 64, 333–340.

INGRAM M and MACKEY B M (1976), 'Inactivation by cold', in *Inhibition and Inactivation of Vegetative Microbes*, eds Skinner F A and Hugo W B, Society for Applied Bacteriology Symposium Series no 5, London, Academic Press, 111–151.

ISMAIL S A S, DEAK T, ABD EL-RAHMAN H A, YASSIEN M A M and BEUCHAT L R (2000), 'Presence and changes in populations of yeasts on raw and processed poultry products stored at refrigeration temperature', *International Journal of Food Microbiology* 62, 113–121.

JIMÉNEZ S M, SALSI M S, TIBURZI M C, RAFAGHELLI R C and PIROVANI M E (1999), 'Combined use of acetic acid treatment and modified atmosphere packaging for extending the

shelf-life of chilled chicken breast portions', *Journal of Applied Microbiology* 87, 339–344.

JONES J M, MEAD G C, GRIFFITHS N M and ADAMS B W (1982), 'Influence of packaging on microbial, chemical and sensory changes in chill-stored turkey portions', *British Poultry Science* 23, 25–40.

KIROV S M, ANDERSON M J and McMEEKIN T A (1990), 'A note on *Aeromonas* spp. from chicken as possible foodborne pathogens', *Journal of Applied Bacteriology* 68, 327–334.

McMEEKIN T A (1975), 'Spoilage association of chicken breast muscle', *Applied Microbiology* 29, 44–47.

McMEEKIN T A (1977), 'Spoilage association of chicken leg muscle', *Applied and Environmental Microbiology* 33, 1244–1246.

McMEEKIN T A and THOMAS C J (1980), 'Microbiological problems associated with refrigerated poultry', *CSIRO Food Research Quarterly* 40 (3/4), 141–149.

MEAD G C and ADAMS B W (1977), 'A selective medium for the rapid isolation of pseudomonads associated with poultry meat spoilage', *British Poultry Science* 18, 661–670.

MEAD G C and HUDSON W R (1987), 'Survival of campylobacters on air-chilled broiler carcasses held under different conditions', *British Poultry Science* 28, 776.

MEAD G C, GRIFFITHS N M, JONES J M, GREY T C and ADAMS B W (1983), 'Effect of gas-packaging on the keeping quality of turkey breast fillets stored at 1°C', *Lebensmittel-Wissenschaft und -Technologie* 16, 142–146.

MEAD G C, GRIFFITHS N M, GREY T C and ADAMS B W (1986), 'The keeping quality of chilled duck portions in modified atmosphere packs', *Lebensmittel-Wissenschaft und -Technologie* 19, 117–121.

MEAD G C, HUDSON W R and HINTON M H (1993), 'Microbiological survey of five poultry processing plants in the UK', *British Poultry Science* 34, 497–503.

MOLIN G (1985), 'Mixed carbon source utilization of meat-spoiling *Pseudomonas fragi* 72 in relation to oxygen limitation and carbon dioxide inhibition', *Applied and Environmental Microbiology* 49, 1442–1447.

MOSSEL D A A, CORRY J E L, STRUIJK C B and BAIRD R M (1995), *Essentials of the Microbiology of Foods. A Textbook for Advanced Studies,* Chichester, Wiley.

NYCHAS G J E and TASSOU C C (1997), 'Spoilage processes and proteolysis in chicken as detected by HPLC', *Journal of the Science of Food and Agriculture* 74, 199–208.

NYCHAS G J E, DILLON V M and BOARD R G (1988), 'Glucose the key substrate in the microbiological changes occurring in meat and certain meat products', *Biotechnology and Applied Biochemistry* 10, 203–231.

NYCHAS G J E, DROSINOS E H and BOARD R G (1998), 'Chemical changes in stored meat', in *The Microbiology of Meat and Poultry,* eds Davies A and Board R, London, Blackie Academic & Professional, 288–326.

OLLEY J and RATKOWSKY D A (1973), 'Temperature function integration and its importance in the storage and distribution of flesh foods above the frozen point', *Food Technology Australia* 25, 66–73.

PATTERSON J T and McMEEKIN T A (1981), 'Biodeterioration of air chilled poultry carcasses at chill temperatures', in *Quality of Poultry Meat*, eds Mulder R W A W, Scheele C W and Veerkamp C H, Beekbergen, Netherlands, Spelderholt Institute for Poultry Research, 454–458.

PATTERSON J T, GILLESPIE C W and HOUGH B (1984), 'Aspects of the microbiology of vacuum and gas-packaged chicken, including pre-treatments with lactic acid and

potassium sorbate', *British Poultry Science* 25, 457–465.

PITT J I (1986), 'Properties of the ideal enumeration medium', in *Methods for the Mycological Examination of Food*, eds King A D, Pitt J I, Beuchat L R and Corry J E L, NATO ASI Series A: Life Sciences, vol 122, New York, Plenum Publishing Company, 132–142.

POONI G S and MEAD G C (1984), 'Prospective use of temperature function integration for predicting the shelf-life of non-frozen poultry-meat products', *Food Microbiology* 1, 67–78.

RATKOWSKY D A, OLLEY J, McMEEKIN T A and BALL A (1982), 'Relationship between temperature and growth rate of bacterial cultures', *Journal of Bacteriology* 149, 1–5.

REGEZ P, GALLO L, SCHMITT R E and SCHMIDT-LORENZ W (1988), 'Microbial spoilage of refrigerated fresh broilers. III. Effect of storage temperature on the microbial association of poultry carcasses', *Lebensmittel-Wissenschaft und -Technologie* 21, 229–233.

REPORT (1978), *Microbiology and Shelf-life of Chilled Poultry Carcasses*, Information on Agriculture No 61, Brussels, Commission of the European Communities.

SCHMIDT C F, LECHOWICH R V and FOLINAZZO J F (1961), 'Growth and toxin production by type E *Clostridium botulinum* below 40ºF', *Journal of Food Science* 26, 626–630.

SHAW M K and NICOL D J (1969), 'Effect of the gaseous environment on the growth on meat of some food poisoning and food spoilage organisms', *Proceedings of the 15th European Meeting of Meat Research Workers*, Helsinki, 226–232.

SHELEF L A (1977), 'Effect of glucose on the bacterial spoilage of beef', *Journal of Food Science* 42, 1172–1175.

SHRIMPTON D H and BARNES E M (1960), 'A comparison of oxygen-permeable and impermeable wrapping materials for the storage of chilled, eviscerated poultry', *Chemistry and Industry*, 1492–1493.

SPENCER J V, SAUTER E A and STADELMAN W J (1955), 'Shelf life of frozen poultry meat after thawing', *Poultry Science* 34, 1222–1223.

SPENCER J V, SAUTER E A and STADELMAN W J (1961), 'Effect of freezing, thawing and storing broilers on spoilage, flavor, and bone darkening', *Poultry Science* 40, 918–920.

STANBRIDGE L H and BOARD R G (1994), 'A modification of the *Pseudomonas* selective medium, CFC, that allows differentiation between meat pseudomonads and Enterobacteriaceae, *Letters in Applied Microbiology* 18, 327–328.

STANBRIDGE L H and DAVIES A R (1998), 'The microbiology of chill-stored meat', in *The Microbiology of Meat and Poultry,* eds Davies A and Board R, London, Blackie Academic & Professional, 174–219.

STUDER P, SCHMITT R E, GALLO L and SCHMIDT-LORENZ W (1988), 'Microbial spoilage of refrigerated fresh broilers. II. Effect of packaging on microbial association of poultry carcasses', *Lebensmittel-Wissenschaft und -Technolgie* 21, 224–228.

TAYLOR S A (1996), 'Basic considerations in meat packaging', in *Meat Quality and Meat Packaging*, eds Taylor S A, Raimundo A, Severini M and Smulders F J M, Utrecht, Netherlands, ECCEAMST, 259–271.

THORNLEY M J and SHARPE M E (1959), 'Micro-organisms from chicken meat related to both lactobacilli and aerobic spore formers', *Journal of Applied Bacteriology* 22, 368–376.

THORNLEY M J, INGRAM M and BARNES E M (1960), 'The effects of antibiotics and irradiation on the *Pseudomonas – Achromobacter* flora of chilled poultry', *Journal of Applied Bacteriology* 23, 487–498.

TIMMONS D (1976), 'Dryer fryers – is CVP the ultimate bulk pack?' *Broiler Business,* December, 10–17.

VAN LAACK R L J M, JOHNSON J L and SMULDERS F J M (1996), 'Health aspects of packaging meat and meat products: the prevalence and survival of human pathogens', in *Meat Quality and Meat Packaging,* eds Taylor S A, Raimundo A, Severini M and Smulders F J M, Utrecht, Netherlands, ECCEAMST, 369–383.

VIEHWEG S H, SCHMITT R E and SCHMIDT-LORENZ W (1989), 'Microbial spoilage of refrigerated fresh broilers. VII. Production of off odours from poultry skin by bacterial isolates', *Lebensmittel-Wissenschaft und -Technologie* 22, 356–367.

WALDROUP A L (1996), 'Contamination of raw poultry with pathogens', *World's Poultry Science Journal* 52, 7–25.

WOODS L F J and CHURCH P N (1999), 'Strategies for extending the shelf-life of poultry meat and products', in *Poultry Meat Science*, eds Richardson R I and Mead G C, Poultry Science Symposium Series, vol 25,Wallingford, UK, CABI Publishing, 297–311.

14

Measuring quality parameters

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14.1 Introduction: defining quality

Quality is a complicated concept, defined by AFNOR (French Association for Normalisation) as 'the overall properties of a product (or a service) which confer on it the capacity to satisfy expressed or implicit needs'. This general definition can be used for meat products and developed in five directions: hygienic, psycho-social, nutritional, technological and sensory aspects. Only the last three will be considered in this chapter.

Poultry meat can be sold as whole carcasses or as cut portions. In 1997, the latter represented more than 50% of total poultry production in France (source: Institut Technique de l'Aviculture), and increased 2.7–fold between 1987 and 1997: turkey (90%), duck (60%), chicken (35%) and guinea fowl (10%). Carcass appearance is important to the consumer, and slaughterhouses assess the relevant aspects and pay the farmer accordingly. Generally, carcasses with defects (Table 14.1) are downgraded, trimmed or rejected. With the development of the market for cut portions, carcass composition and particularly meat yield are important issues to be taken into account by the whole production system (poultry breeders, farmers, feed manufacturers, slaughterers). In this chapter, the different methods of evaluating carcass appearance and estimating composition are described.

The last stage in the diversification of poultry production occurred with the development of further processing (Mandava and Hoogenkamp, 1999). A prospective study in France showed that the percentage of further processed products (breaded, smoked and marinaded products, delicatessen items, etc.) was 15% of overall poultry meat production in 1999 and should reach 25% by 2005 (Magdelaine and Philippot, 2000). There is, therefore, an increasing need

Table 14.1   Carcass defects leading to downgrading or trimming

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Defects related to the animal and production factors
Claw-marks or injuries to the skin
Regrowth of feathers
Bone deformations (breast, legs)
Blisters, abscesses, ematomas, pustules

Defects related to slaughter technology
Red wingtips, pygostyles and/or feather tracts
Engorged or haemorragic wing veins
Quality of plucking
Burned, grazed or torn skin
Dislocated or broken bones

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for reliable methods to determine the technological quality and functional properties of poultry meat.

Physico-chemical methods are mostly used to measure or estimate nutritional, technological and sensory aspects of meat quality. Repeatability, objectivity, accuracy, speed, on-line application and cost are essential criteria in selecting the most appropriate test methods. It is, of course, more difficult to meet all these demands in the case of sensory methods. Reference to standardised methods will be indicated where possible.

14.2   Quality parameters: carcass appearance and composition

Visual and subjective methods are used mainly by a single trained person to assess carcass appearance and any defects that may be present (Table 14.1). The criteria and scales used are, in fact, different from one slaughterhouse to another and may vary between experimental studies reported in the literature. Carcass presentation has been assessed very often in studies concerning the effects of stunning conditions or the influence of stocking density. Wilkins *et al.* (1999) and Santé *et al.* (2000) used a three-point, subjective scoring scale for red pygostyles, red wing tips, wing haemorrhaging, engorged wing veins and shoulder haemorrhaging, with higher scores corresponding to worsening of the condition (0 = absence of defect, 0.5 or 1 = mild defect and 1 or 2 = substantial defect). Martrenchar *et al.* (1999) used the same type of scoring scale to assess breast lesions (blisters, pustules and haematoma). In general, this scoring system reflects the processor's wish to achieve higher quality for oven-ready carcasses and fresh portions (Göksoy *et al.*, 1999). A score of 0 indicates that carcasses are fully acceptable, a score of 1 indicates that the bird will be downgraded because of defects and either sold at a lower price or used for further processing, and a score of 2 indicates a blemish of sufficient severity to require the affected part to be removed. To evaluate deeper defects such as broken pectoral bones

(furculum, coracoid and scapula), it is necessary to dissect carcasses and remove the appropriate muscles. It is then possible to measure the incidence of associated haemorrhaging in, for example, the breast muscles (0 = absent, 1 = present and the fillet downgraded, 2 = present and the fillet requires trimming or rejection, Raj *et al.*, 2001). In other studies, Raj *et al.* (1998) and Berthelot *et al.* (2001) scored defects as either absent or present. The percentage incidence of particular defects was noted. Abdalla and Jensen (1997) evaluated the effects of different scalding temperatures on plucking rate and skin condition of broilers, using a visual system in which a score of 1 corresponded to a few residual feathers on the back, wings and tail, with the skin cuticle partially removed and a score of 2 corresponded to clean carcasses with the skin cuticle completely removed.

It is now possible, on a processing line, to use an integrated system which consists of a visible near-infrared spectroscopic device in combination with an intensified multispectral imaging system that allows separation of abnormal from normal poultry carcasses (Park *et al.*, 1996). More recently, Chen *et al.* (1998a, 1998b) reported that a visible near-infrared spectrophotometer system was a highly accurate, reliable tool for on-line classification of carcasses. The reflectance spectrum was measured with a stationary fibre-optic probe set 2– 5 cm from carcasses moving at 60 or 90 birds/min, either in artificial light or in a dark environment. Using a neural-network classification model with 190 input nodes, the average accuracy for both normal and abnormal carcasses was above 94%. For a line speed of 140 birds/min, the data-acquisition and computation time would need to be reduced. By reducing the number of input nodes to the neural network, the training time and number of training samples could also be reduced. The use of principal component analysis reduced the number of input nodes and improved classification accuracy. A real-time, colour, machine-vision system was also designed to estimate turkey-carcass quality, and algorithms using colour-image segmentation were developed. The results showed the effectiveness of image processing in detecting carcass defects on processing lines in real-time (Marty-Mahé *et al.*, 1999).

An important feature to consumers is the colour of the carcass skin (white or yellow). This characteristic depends mainly on bird genotype and composition of the diet, particularly the level of lipid-soluble pigments such as carotenoids (Fletcher, 1999). For example, Salichon and Blum (1995) and Margas and Nys (1997) evaluated the influence of different pigment sources on the skin colour of chicken carcasses by means of a subjective test, and compared these results with the objective measurement of skin colour for the breast and back, using a spectrocolorimeter in the CIE L*, a*, b* system. In the subjective test, a panel of 30 people compared the skin colour of four carcasses per treatment with the Roche colour fan and gave the corresponding score. The authors reported a good correlation between skin-colour evaluation and colorimetric measurements.

The first option for determining carcass yield, composition, fat content and meat yield is dissection of the carcass. This method is old but is still used. A precise description of the dissection method and definitions of the different cuts

were first published by Ricard and Rouvier (1967). The method allowed comparison of different genotypes, species and birds differing in sex and age. It also permitted an analysis of the influence of different production factors. Working Group no. 5, 'Quality of poultry meat', of the European Federation of Branches of the World's Poultry Science Association (WPSA), standardised the dissection method and defined the individual parts of the carcass used in different countries (WPSA, 1983). It was then possible to compare the various findings presented subsequently in the literature. Later, Marché (1995) published a detailed description of chicken, duck and turkey dissection, illustrated with photographs and a video and complemented in 2000 with a CDRom (Marché, 2000). Hahn and Spindler (2002) also published a detailed description of a method for dissecting turkey carcasses, illustrated with photographs. The main parameters measured are the weight of the 'oven-ready' carcass, the amount of meat on the thigh, drumstick and breast to determine meat yield and the weight of abdominal fat to estimate carcass fat content. For waterfowl, the weight of breast skin is also determined to estimate subcutaneous fat deposition. Findings are usually expressed as a percentage of the live weight at slaughter. However, the dissection method is time-consuming and the birds have to be reared to slaughter age. Therefore, various attempts have been made to estimate body composition by other means.

The first approach was to predict slaughter yield from conformation traits such as breast angle, breast width, keel and shank length, leg circumference and shank diameter. In practice, the correlation values were quite different between studies and not high enough to predict slaughter yields precisely (Ricard, 1980). Regression equations were investigated for *in vivo* estimation of breast weight, and meat and fat content of carcasses (Michalik and Bochno, 1986; Bochno *et al.*, 2000; Rymkiewicz *et al.*, 2001). However, the validity of these equations depended on bird species and the level of prediction was not sufficiently accurate. Since carcasses are mechanically eviscerated during processing, it is not possible to weigh the abdominal fat of each bird. Therefore, other criteria had to be used to estimate whole-carcass fat content. For broiler chickens and turkeys respectively, Ehinger (1977), and Castaing *et al.* (1997), measured fat content or directly the weight of a triangular section of back skin in the lumbo-sacral area. High correlations were found between these parameters and whole-carcass fat content ($r = 0.88$–0.91). With ducks, on the other hand, Ziolecki and Konieczny (1983) found lower correlations between the fat content of skin sections and that of the total skin plus adipose tissue ($r = 0.66$) or between the fat content of skin sections and that of the breast and thigh ($r = 0.28$).

Non-invasive, physical methods such as ultrasound scanning, nuclear magnetic resonance-imaging (MRI) and tomography were also evaluated to determine breast yield, meat yield and carcass fat content. Scollan *et al.* (1998) and Davenel *et al.* (1999) used three-dimensional reconstruction of transverse images from MRI to estimate breast volume, weight and yield in chickens. Regression analysis resulted in r^2 values (coefficient of determination) greater than 0.90 for the relationship between breast weight and yield, and breast

volume. Rémignon *et al.* (1997) evaluated computerised-tomography X-ray images obtained from broiler breast muscle and subjected to computerised image analysis. The r^2 values showed that the combination of body-weight value and values for two breast-muscle cross-sectional areas successfully predicted breast muscle weight and yield (0.83 and 0.56, respectively). Breast muscle thickness was first determined in ducks using a needle catheter (Pingel, 1990). The main advantage of this method was its simplicity, enabling measurements to be performed in any conditions. The disadvantages were the need to pierce the skin and muscle (inflicting pain on the bird and allowing the possibility of infection) and the constraint of making a single measurement at only one place.

Another method that is practical and comparatively low in cost, is ultrasound scanning, which has been widely tested to determine the thickness of breast muscle and breast skin plus subcutaneous fat in broilers (König *et al.*, 1997, 1998; Seigneurin *et al.*, 1999), ducks (Grashorn, 1986; Sorensen and Jensen, 1992) and geese (Cywa-Benko *et al.*, 1997, 1999). A selection experiment was performed successfully on Peking ducks with increasing thickness of breast muscle, as measured by ultrasound scanning (Lavallee *et al.*, 1998; Farhat and Chavez, 2000, 2001). Seigneurin *et al.* (1999) obtained the best prediction of breast weight and yield in broilers with three parameters: live weight and measurement of two transverse areas. The r^2 values were 0.82 to 0.84 for breast weight and 0.60 to 0.63 for breast yield. König *et al.* (1998) demonstrated that breast-meat yield based on live weight and cross-sectional areas of breast muscle was predicted with a correlation of 0.71 to 0.73, depending on the sex of the birds. Only one person was needed to perform the measurements at an average rate of 76 birds per hour. With ducks, the accuracy in predicting breast yield was 0.7 (Sorensen and Jensen, 1992). In contrast, prediction of fat thickness on the breast was unsatisfactory. These physical methods are relatively expensive, require qualified personnel to analyse the images obtained and are time-consuming. In the near future, ultrasound technology will certainly be applied in bird selection programmes, instead of dissection. However, this type of technology does not match the line speeds in large slaughterhouses. With turkeys, carcass composition was determined on-line by video-image analysis (Hahn *et al.*, 1997). This study recommended the use of sex-specific formulae for the analysis of different cuts. It was possible to estimate total carcass meat-yield and, to some extent, bone weight, but impossible, with the method described, to determine precisely total fat weight.

14.3   Assessing the sensory quality of poultry meat: colour, texture and flavour

There are two main categories of test to evaluate the sensory quality of meat: hedonic or consumer tests and analytical tests with trained panels. The hedonic process studies the acceptability or the preference for a particular product among a group of clearly-identified consumers, through the pleasure induced by its taste

or consumption. The analytical process comprises a group of techniques allowing specific measurements to be made on the sensory properties of a product, following them over a period of time, and comparing and controlling them. The first step is to define clearly the aims of the study before choosing the appropriate tests. The main tests used in the hedonic process are: a preference test with comparisons in pairs, a preference test by classification and an hedonic test (ASTM, 1986; AFNOR, 1995; ACTIA, 1999). The minimum size of the consumer group is 60 people. Participating consumers are chosen according to the aim of the study and require a balance between sex, age, socio-economic origin and, of course, knowledge of the product. The test items must be clearly identified and homogeneous, and the samples unrecognisable to the assessors. The preparation of samples, their size, order of presentation and number must be well defined (ASTM, 1986; AFNOR, 1995; ACTIA, 1999). The questionnaire, scale of scoring and statistical analysis of scores (AFNOR, 1996) should be appropriate to the aims. In relation to 'Label Rouge' poultry, hedonic tests are always used for the evaluation of poultry meat quality and the results presented with the documents examined by the French National Commission on Labelling and Certification for any new proposal, where the sensory quality must be higher than that of standard poultry from the same species.

The sensory properties of poultry meat are usually evaluated by an analytical process. Working group no. 5, 'Quality of poultry meat', of the European Federation of Branches of the WPSA published recommendations for a standardised method of sensory analysis for broilers (Mead, 1987), and the AMSA (1995) published research guidelines for cooking, sensory evaluation and instrumental tenderness measurements for fresh meat. The WPSA method covers the preparation of samples (thawing, cooking of whole carcasses and excised meat, serving), the test conditions (training of panel members, number of sessions, number of samples per person in one session, size of sample, time) and the test designs (type of test, criteria judged, scales, scoring, statistical test). Whole carcasses are usually roasted and excised meat is grilled. The main tests used in the analytical process are: discrimination (triangular, duo-trio, two-on-five), position (comparisons in pairs, classification, score) or description.

Many studies in the literature have evaluated the sensory quality of poultry meat according to the intensity of perceived sensory characteristics. In this case, the required number of trained panel members is 12 and the number of samples tested per session and per person is 6, while the recommended statistical test is Student's *t*-test (ACTIA, 1999). The main criteria for raw meat are appearance and odour, whereas for cooked meat, they are flavour, juiciness, tenderness, colour, fattiness. Each criterion is well defined and can be further specified with appropriate terms. For example, in the study of Sheldon *et al.* (1997), the panel members developed a range of cooked aroma and taste descriptors including typical, fresh turkey-meat aroma and taste, oxidised aroma and taste, cooked and oxidised after-taste. These were used in evaluating the influence of dietary vitamin E on the flavour of cooked turkey breast meat. The scales are presented graphically or numerically, generally from 0 to 10. See ASTM (1986), AFNOR

(1995), ACTIA (1999) and Nute (1999) for further information. The results of sensory tests depend strongly on the experience of consumers or other panel members and their eating habits. It is, therefore, quite difficult to compare results obtained in different countries. In many studies, the sensory approach is complemented by physico-chemical measurements to evaluate meat colour, stability, tenderness and flavour. Although these characteristics are important in both whole tissues and further-processed meats, the following methods are restricted to whole-tissue products, recognising the multitude of differences that can exist with further-processed products.

14.3.1   Colour

Meat colour can be measured objectively with a spectro-colorimeter (Hunterlab or Minolta). Guidelines for evaluation of meat colour have been published (Anon, 1991). Carcasses should be sampled at least 24 h *post mortem*. The muscle and the location within the muscle must be clearly specified. The best location for breast muscle (in the *Pectoralis major*) is the part located above the *Pectoralis minor* muscle, where the connective tissue does not interfere with the measurement. The sample should be at least 1.5 cm thick to avoid the influence of background. If the muscle is too thin it may be folded. The recommended parameters are a light source of D65, a standard observer at 10 and colour scale as L* a* b* (Honikel, 1997). Barbut (1996) and Owens *et al.* (2000) suggested using the L* value as an indicator of paleness to detect pale, soft, exudative (PSE) turkey meat, which results in lower water-holding capacity and technological yield after curing and cooking (Fernandez *et al.*, 2002). Simple, rapid measurement systems for on-line assessment of meat quality would provide the processor with a method of segregating meat according to its attributes and channelling it into appropriate processing areas. Sebastian *et al.* (2002) studied this possibility by measuring turkey breast colour on images acquired with a video camera. Breast samples giving the lowest cooking yield had L* values above 55.

The major pigments responsible for colour in meat are myoglobin, haemoglobin and cytochrome c. The concentration of haem pigments in poultry muscles (Table 14.2) can be determined indirectly but rapidly by extracting and measuring the iron concentration in meat, as described by Hornsey (1956). The colour of meat can change during storage, according to the status of the myoglobin, which may change from the purplish red of deoxygenated myoglobin to the bright red of oxymyoglobin or brown/grey of metmyoglobin (Fletcher, 1999). It is possible to follow the amount of metmyoglobin present on the meat surface, particularly for red muscle (leg meat, waterfowl meat), by using one of two methods. One involves calculating the difference between meat-reflectance values at two separate wave lengths, 580 and 630 nm (% R630–% R580) as described by Van Den Oord and Wesdorp (1971), when measured with a spectrophotometer equipped with an integration sphere. The second method requires the determination of the ratio between the absorption

Table 14.2   Heme pigment concentration in poultry muscle (Froning, 1995)

Species	Myoglobin mg/g		Total heme pigments[1] mg/g		Cytochrome C μg/g	
	Breast	Thigh	Breast	Thigh	Breast	Thigh
Chicken broiler	0.15[3]	0.21[3]	0.49[5]	1.66[5]	13.71[3]	37.38[3]
Chicken fowl	0.41[4]	1.78[4]	0.64[4]	3.06[4]	6.30[4]	13.50[4]
Turkey	0.50[2]	2.00[2]	0.58[5]	2.15[5]	13.10[5]	47.40[5]
Goose	–	–	6.53[5]	3.90[5]	141.00[5]	107.80[5]
Duckling	–	–	4.31[5]	3.54[5]	111.20[5]	149.90[5]

[1] Myoglobin + haemoglobin
Sources: [2] Froning *et al.* (1978); [3] Fleming *et al.* (1991); [4] Narasubhai and Kallapur (1977); [5] Pikul *et al.* (1986).

(K) and diffusion (S) of light coefficients at two separate wave lengths, 525 and 572 nm (K/S 525 and K/S 572) according to Stewart *et al.* (1965). These measurements have often been used in studies concerning the effects of dietary vitamin E on colour stability and pigment oxidation in poultry meat (Mercier *et al.*, 1998). Liu and Chen (2001) studied variations in meat colour under conditions of cold storage and following different cooking processes by observing changes in R1 = $A_{485\,nm}/A_{560\,nm}$ and R2 = $A_{635\,nm}/A_{560\,nm}$ ratios, which are related to absorbancy of the bands at 485 (metmyoglobin), 560 (oxymyoglobin) and 635 nm (sulfmyoglobin).

14.3.2   Texture

Meat texture can be evaluated with shear (Warner-Bratzler) and tensile tests (Instron Universal Testing Machine). The reference methods have been described by AMSA (1995) and Honikel (1997). Meat samples should be vacuum-packed individually and frozen rapidly in absolute alcohol at −20ºC, 24 h *post mortem*. The storage period should not exceed three months. Thawing must be carried out at 4ºC over 12 h. These tests can be performed with raw or cooked meat. Samples are cooked in their plastic bag in a waterbath (time and temperature are chosen in relation to the nature and size of the sample; e.g. 15 min at 85ºC for half a broiler breast), then cooled for 30 min in ice and held at 4ºC until tested. For both tests, the measurements on one sample should be repeated at least three times and, where possible, ten times, depending on the size of the meat sample. Strips of meat should be cut so that the cross-section measures 10 × 10 mm and the muscle fibres run parallel to the length of the sample for at least 30 mm. The sample should be sheared at a right angle to the fibre axis. The Warner-Bratzler shear method uses a single blade. The parameters to be measured are the maximum force (N or kg/g) recorded and the energy (J) required at the same point. The parameters for the tensile test are

force (N) recorded at 20% (K20) and 80% (K80) of strip height, specifically expressing the mechanical resistance of muscle fibre and of muscle fibre plus collagen (Culioli *et al.*, 1990). Dual compression of the sample simulates mastication (Lyon and Buhr, 1999) and, in this case, the results include values for the attributes of hardness, springiness, cohesiveness, gumminess and chewiness (Meullenet *et al.*, 1997). It is possible to combine shear and tensile tests using a ten-blade Allo-Kramer shear compression cell (Heath and Owens, 1997; Smith and Fletcher, 1998; Sams, 1990). Lyon and Lyon (1990) established relationships between two objective shear procedures and sensory responses to tenderness for broiler *Pectoralis major* muscles. Their findings indicated that Warner-Bratzler values in the range of 6.5–3.5 kg and Allo-Kramer values in the range of 8.8–6.0 kg per g would correspond to the 'slightly tender' to 'moderately tender' part of the sensory scale.

Another possible way of evaluating contractile muscle status is to measure sarcomere length. This measurement is used to study the effects of electrical stimulation on breast-meat tenderness (Thompson *et al.*, 1987; Gault *et al.*, 2000). The values for sarcomere length in breast muscle reported in these studies were between 1.53 and 1.84 μm. After a step of fibre separation and fixation, sarcomere length was measured by diffraction methods, using a helium-neon laser (Koolmees *et al.*, 1986; Cross *et al.*, 1980; Gif *et al.*, 1995) or by phase-contrast microscopy (Silva *et al.*, 1999). Kuber *et al.* (2003) and Kojczak *et al.* (2003) described another technique. Muscle samples were fixed in two steps (glutaraldehyde and osmium tetroxide), dehydrated, polymerised with a resin, sliced into blocks and thin longitudinal sections obtained using an ultramicrotome. The sections were stained with lead citrate and uranyl acetate before viewing with a transmission electron microscope.

Collagen content and solubility is also involved in meat tenderness. Heat-solubility of collagen is generally determined according to the method of Hill (1966) and collagen content is estimated by measuring total hydroxyproline content according to Bergman and Loxley (1963) or the procedure of Woessner (1961), using a standard curve. A factor of 7.14 (Listrat *et al.*, 1999), 7.25 (Smith *et al.*, 1993; Liu *et al.*, 1996; Silva *et al.*, 1999) or 7.52 (Silva *et al.*, 1999) is used to convert hydroxyproline content to collagen content. The amount of heat-soluble collagen is expressed as a percentage of the total amount of collagen, and collagen content is expressed as mg of collagen per g of skeletal muscle (Table 14.3). Standardised procedures to determine hydroxyproline and L-hydroxyproline content in meat were published by AFNOR (St Denis la Plaine, France) in September 1994 and October 2002: ISO 3496:1994 and NF V04-415.

Currently, spectrofluorometry is used to evaluate meat tenderness. This technique was first used for bovine meat (Swatland *et al.*, 1996; Frencia *et al.*, 2002) and also for turkey meat (Swatland, 1999). Frencia *et al.* (2002) compared the spectra obtained from meat with compression testing and sensory analysis of meat tenderness, and calculated coefficients of correlation of 0.91 and 0.95. In their system, the beam of light from a xenon-mercury source crossed an optical

Table 14.3   Total collagen content in *Pectoralis major* muscle

Species	Total collagen content (mg/g)	Sources
Chicken broiler	1.27	Smith *et al.* (1993)
Chicken broiler	9.4 to 10.4	Touraille *et al.* (1981)
Chicken broiler	3.12	Ruantrakool and Chen (1986)
Chicken fowl	3.5 to 4.7	Sekoguchi *et al.* (1978)
Pheasant	3.6	Mounier (1990)
Muscovy duck	7.3 to 16.3	Baéza *et al.* (2002)
Peking duck	1.75	Smith *et al.* (1993)
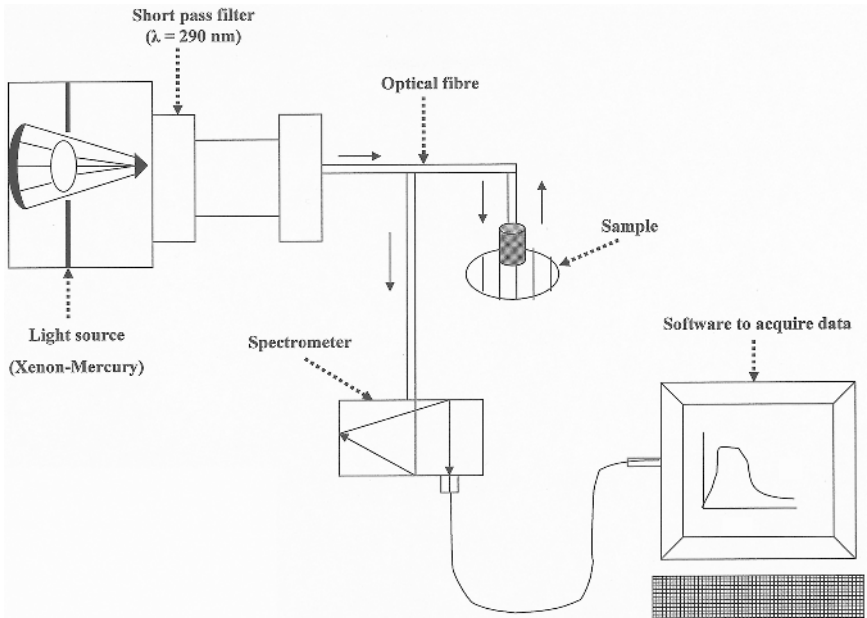
Fig. 14.1   Evaluation of raw meat tenderness with spectrofluorometry (Frencia *et al.*, 2002).

fibre with a mean wavelength of 209 nm. On contact with the raw meat sample, it excited fluorophores (mainly protein tryptophanes) which, again, emitted a signal. This signal went through the optical fibre in the opposite direction and was analysed with a spectrophotometer linked to data acquisition software (Fig. 14.1).

14.3.3   Flavour
Flavour is a combination of the sensations perceived by two senses, taste and smell. The sense of smell detects certain chemicals which, because of their chemical structure, stimulate the olfactory receptors at the top of the nasal

cavity. These odorous substances can be detected in the air above the food, before we eat it. It is possible, therefore, to identify, quantify and describe these compounds, using gas chromatography combined with mass spectrometry and olfactometry methods (Stephen *et al.*, 2001; Brunton *et al.*, 2002; Du *et al.*, 2002; Kim *et al.*, 2002). Farmer (1999) reviewed the components important for aroma in cooked chicken meat. The list includes a range of sulphur compounds (both heterocyclic and aliphatic), other heterocyclic compounds containing oxygen or nitrogen, aldehydes and ketones. First, the meat-headspace volatiles are collected on a solid-phase micro-extraction (SPME) fibre. The fibre is then desorbed in the injection port of a gas chromatograph, using helium as a carrier gas. The compounds are identified by comparing their mass spectra with authentic standards, published values or those of the National Institute of Standards and Technology (NIST), US Environmental Protection Agency (EPA), National Institute of Health (NIH) and the Mass Spectral Database (Wiley Library). More information is available in Rouseff and Cadwalleder (2001), Schieberle and Engel (2000) and Hopp and Mori (1993).

The fatty-acid composition of meat lipids is a major determinant of the flavour and shelf-life stability of fresh and cooked meats. In stored, fresh meats, lipid peroxidation leads to the development of rancid odours and flavours. In cooked meats, this same process is more rapid, as a result of tissue disruption, and is exacerbated by reheating to give 'warmed-over flavour' (Enser, 1999). The susceptibility of meat to oxidation depends on the degree of unsaturation of the fatty acids and the concentrations of pro-oxidants such as iron compounds and antioxidants such as vitamins A, C and E and selenium-containing enzymes. The most common method of estimating the susceptibility of meat to oxidation is to measure substances which react with thiobarbituric acid (TBA) to give an absorption peak at 532–535 nm (TBARS test). The major reactant is malonic dialdehyde and results are expressed as mg malonic dialdehyde per kg of meat. Pikul *et al.* (1989) evaluated three modified TBA methods for measuring lipid oxidation in chicken meat. Their results indicated that aqueous extraction was an acceptable and convenient method. Many studies have used the method described by Lynch and Frei (1993). Samples (0.5 ml: one g of muscle minced in ten ml of KCl 0.15 M + butyl-hydroxytoluene 0.1 mM) are held in boiling water for 10 min with 1% (w/v) 2-thiobarbituric acid in 50 nM NaOH (0.25 ml) and 2.8% (w/v) trichloroacetic acid (0.25 ml). After cooling to room temperature, the pink chromogen is extracted into n-butanol (2.0 ml) and its absorbance is measured at 535 nm. TBARS concentrations are calculated using 1,1,3,3-tetramethoxypropane. It is also possible to measure TBARS after oxidation with $FeSO_4$ (Kornbrust and Mavis, 1980; Santé and Lacourt, 1994). Fluorometric TBARS methods, which have much greater sensitivity than spectrophotometric methods, have also been developed for samples with low lipid-oxidation products such as fresh, raw chicken and turkey meat (Draper *et al.*, 1993; Jo and Ahn, 1998).

14.4   Methods of analysing the functional properties of poultry meat and final product quality

When an animal dies from blood loss and the resulting anoxia, muscle tissue continues to produce ATP from its glycogen store using the glycolytic pathway. Lactate accumulates and pH decreases until glycogen is completely consumed or it reaches a minimal value (around 5.4) that inhibits further glycolysis. Many studies have shown that the rate and extent of *post-mortem* decrease in pH could explain some meat defects such as dark, firm, dry (DFD) or PSE meat. Muscle pH is also critical in relation to binding properties and moisture retention in cooked meat (Lyon and Buhr, 1999; Berri, 2000). Therefore, pH is frequently measured in studies concerning poultry meat quality. To estimate the rate of *post-mortem* decrease in pH, it is necessary to measure pH values at one or more intervals during the initial phase of decline, such as at 5, 15, 30, 60, 120 min or more. To estimate the full extent of the change, pH is measured 24 h after slaughter and this is called ultimate pH (pHu). Meat samples (2 g) are homogenised with a Turrax blender in 18 ml of 5 nM sodium iodoacetate in 150 nM KCl solution and the pH is measured with a pH-meter. At 24 h *post-mortem*, pHu can be determined by inserting the electrode directly into the muscle, as moisture spreads into the extra-cellular spaces. Measurement of pH in slaughterhouses is not appropriate to the high rate of poultry processing. Santé and Fernandez (2000) have shown that freezing muscle samples in liquid nitrogen before homogenisation in sodium iodoacetate solution can be substituted for the reference method in determining pH at 3 and/or 20 min *post mortem* but not for pHu. Standardised procedures to determine meat pH were published by AFNOR (St Denis la Plaine, France) in January 1974 and December 1999: NF V04-408 and ISO 2917:1999.

Proteins are the main structural and functional components in many food systems. Functional properties determine the value of a protein and its impact on final product quality. For processed poultry products, water-binding, fat-binding and meat-solubility, viscosity and emulsification are the principal properties of interest in the initial, raw product. Heat-induced gelation, water-binding and fat-binding are some of the more important functional properties in cooked products (Smyth *et al.*, 1999). The following provides information on methods of measuring these attributes.

Water makes up 73–76% of raw poultry meat (Culioli *et al.*, 2003), and is an important component that largely accounts for the juiciness of cooked meat and technological yield for processed products. Standardised procedures to determine the water content of meat (drying at 105ºC for 12 h) were published by AFNOR (St Denis la Plaine, France) in February 1997 and April 2001: ISO 1442:1997 and NF V04–401 and AOAC (1996).

The water-holding capacity of meat is very often estimated by measuring drip-loss in raw, fresh meat after cold storage at 4ºC, and juice-loss after freezing-thawing and cooking treatments (Honikel, 1997). Meat samples are cut from the carcass and weighed immediately. They are then placed in plastic bags,

hung from a hook and stored at 4ºC for 24 h or more, if necessary. After hanging, the samples are wiped with absorbent paper and weighed again. The difference in weight corresponds to the drip-loss. This is generally expressed as a percentage of the initial weight. It is possible to measure juice-loss by placing the samples in polystyrene containers covered with a plastic film. In this case, the samples are stored horizontally. To measure juice-loss after freezing and thawing, meat samples are held under vacuum in sealed plastic bags. Following storage at −20ºC and thawing gently at 4ºC for 12 h, the samples are wiped with absorbent paper and weighed. Juice-loss after freezing and thawing is calculated by the difference in weight before and after treatment. The third step consists of measuring juice-loss after cooking. Meat samples are held under vacuum in sealed plastic bags and cooked in a water bath (10 min at 85ºC for a chicken breast). They are then removed, cooled for 30 min on ice and wiped with absorbent paper. The juice-loss after cooking is calculated from the difference in weight before and after treatment. It is generally expressed as a percentage of the initial weight.

Another method of determining water-holding capacity is to measure expressible moisture, which corresponds to the amount of liquid that can be squeezed from a protein system by the application of force. The modified procedures of Jauregui *et al.* (1981) and Earl *et al.* (1996) can be used to measure expressible moisture. A sample of ground muscle (1.5 g) is weighed in a tube and centrifuged under refrigeration (15 min, 20 000–23 000 g). The supernatant is then removed and the meat 'cake' in the tube is dried by turning it out onto absorbent paper and leaving it for a few minutes before weighing. The difference in weight corresponds to expressible moisture. The other way to determine this attribute is to weigh accurately a meat sample of 200–400 mg and to press it onto a filter paper mounted between plexi-glass plates at 35 kg/cm^2 for 1 min. The expressible juice is estimated by determining the difference in area between the juice and the sample, using planimetry (Qiao *et al.*, 2001) or video-image analysis (Irie *et al.*, 1996).

Cremonini *et al.* (2001) have proposed using low-resolution nuclear magnetic resonance (LR-NMR) to investigate water-holding capacity in turkey breast meat. Their data showed that this tool is reliable, confirming previous studies on pork (Bertram *et al.*, 2001). The basis of all the methods now in use to measure the emulsion capacity of muscle proteins is the system first reported by Swift *et al.* (1961). A fixed amount of meat homogenate, or of a protein solution of known concentration, is stirred vigorously with a high-speed mixer together with a fixed amount of vegetable oil. More oil is added at a specific rate from a separation funnel during mixing. The oil-water emulsion formed becomes increasingly more viscous with increasing amounts of fat and then suddenly changes so that the viscosity decreases. The addition of fat ceases when the emulsion changes in character, and the amount of oil that has been added is equated with the emulsifying capacity of the material, being expressed per unit of protein (Gillet *et al.*, 1977; MacCready and Cuningham, 1971; Kijowski and Niewiarowicz, 1978; Bogh-Sorensen, 1985; Hamm, 1986; Qiao *et al.*, 2001). An

important improvement in the procedure was the detection of the endpoint (emulsion collapse) by measurement of electrical resistance (Webb *et al.*, 1970; Hamm, 1986). The myofibrillar proteins (myosin, actomyosin) within muscle proteins are the major emulsifiers. Water-soluble (sarcoplasmic) proteins exhibit very low emulsifying properties (Kijowski, 2001).

An important measure of the stability of an emulsion is the time required to break it. Kijowski and Niewiarowicz (1978), Bøgh-Sorensen (1985) and Hamm (1986) describe several methods. The principle used is to weigh a suitable amount of emulsion in a centrifuge tube, heat it in a water bath and then centrifuge gently. The weight of the remaining emulsion is determined and emulsion stability is expressed as a percentage. The majority of studies have concentrated on the gelation properties of myofibrillar and myosin proteins and subunits of myosin molecules. Sarcoplasmic proteins exhibit very low gelation capability and, as stromal proteins, coagulate on heating (Kijowski, 2001). The first stage in the study of gelation properties is to extract myofibrillar or myosin proteins. The myofibrillar type is generally termed salt-soluble (Foegeding, 1987; Smyth *et al.*, 1999). Different methods for protein extraction were described by Foegeding (1987; 1990) and included various stages of solubilisation with salt solutions and centrifugation. It was then possible to determine protein solubility by measuring the protein concentration in the soluble fraction (supernananat) as a percentage of the total protein in the muscle sample (Foegeding, 1987; 1990; Xiong and Brekke, 1989; Gil *et al.*, 1998). The denaturation of muscle proteins during heat-induced gelation is monitored by differential scanning calorimetry (DSC), in which thermal transition temperatures represent points where conformational changes occur in protein structure (Stabursvik and Martens, 1980; Stabursvik *et al.*, 1984; Xiong *et al.*, 1987; Kijowski and Mast, 1988a, 1988b; Xiong and Brekke, 1990; Popiel *et al.*, 1998; Kijowski, 2001; Woloszyn, 2002). Poultry meat undergoes three to five major thermal transitions at about 54–60ºC, 65–73ºC and 78–83ºC, depending on the species and test conditions (Kijowski, 2001). However, DSC requires a high concentration of muscle protein. Li-Chan *et al.* (1985) and Xiong and Brekke (1990) succeeded in determining thermally-induced protein-unfolding by measuring changes in protein hydrophobicity with a fluorescence probe, 8-anilino-1-naphthalene sulfonate (ANS). ANS-fluorescence intensity increases when a more non-polar (hydrophobic) region of a protein becomes available as a result of protein unfolding. Two stages can be distinguished in the thermal gelation of myofibrillar proteins: denaturation of native protein molecules, followed by aggregation of the partially unfolded molecules. Ziegler and Acton (1984), Acton and Dick (1986) and Xiong and Brekke (1990) studied thermally-induced protein-protein interactions by continuously monitoring changes in the optical density of heated actomyosin or salt-soluble protein solutions. They showed that aggregation of proteins during denaturation resulted in an increased turbidity of the solution. Different methods were used to analyse the gel texture. Foegeding (1987) determined stresses and strains at the point of structural failure and obtained an Instron profile by a two-cycle, uniaxial compression of a

cylindrical gel to 20% of the original height. Xiong and Brekke (1989) and Barbut (1997) estimated gel strength by measuring the penetration force, the force and the total energy required to rupture the gel with a Universal Testing Instrument. Foegeding (1990) and Daum-Thunberg *et al.* (1992) determined 'true stress' (strength of the gel) and 'true shear' (deformability of the gel) at failure using a torsion test and a viscometer.

The methods used to analyse the functional properties of poultry meat are often time-consuming and hardly suitable for the large numbers of samples that product manufacturers have to deal with; therefore, more rapid techniques are needed. In order to simulate the behaviour of turkey breast meat during curing/cooking, Fernandez *et al.* (2001) determined the Napole yield. One hundred grams of trimmed breast muscle were cut into 1 cm cubes and placed in a beaker. Twenty grams of 136 g/l nitrite-treated salt were added, according to Naveau *et al.* (1985). The cured meat was covered with a 200 g steel weight, kept at 4ºC for 24 h and cooked for 10 min in boiling water. After being allowed to drip for 2.5 h, the sample yield was calculated as the weight of cooked cured meat, expressed as a percentage.

14.5   Assessing the nutritional quality of poultry meat

The major components of raw poultry meat are proteins, lipids and minerals at proportions between 18.4 and 23.4%, 1.3 and 6.0%, 0.8 and 1.2%, respectively (Culioli *et al.*, 2003). The total protein content of meat is generally determined using the Kjeldhal (1883) procedure ($N \times 6.25$) which comprises three steps: mineralisation in the presence of concentrated sulfuric acid and a mineral catalyst, distillation with soda, and finally titration (Adrian *et al.*, 1998). Determination of the total lipid content usually involves cold extraction with chloroform/methanol followed by the gravimetric procedure of Folch *et al.* (1957). The total mineral content is generally determined by dry mineralisation in a furnace at 550ºC for 12 h (Adrian *et al.*, 1998). Standardised procedures to determine total protein, lipid and mineral contents of meat have been published by AFNOR (St Denis la Plaine, France): NF V04-407 (September 2002) and ISO 937:1978 (December 1978) for proteins, NF V04-402 (January 1968) and ISO 1443:1973 (April 1973) for lipids, NF V04-404 (April 2001) and ISO 936:1998 (August 1998) for minerals and AOAC (1996).

It is now possible to predict with great accuracy the fat content of meat by near-infrared reflectance spectroscopy (NIRS) (Cozzolino *et al.*, 1996; Abeni and Bergoglio, 2001). Calibration is a very important step for this technique and requires a wide range of values for the parameter being measured. This technique is rapid and can be used for commercial on-line analysis (Togersen *et al.*, 1999). However, predictability is lower for protein and mineral contents. For more information see the review of Bertrand and Dufour (2000). Amino acid composition (Table 14.4) is determined after acid hydrolysis of the meat sample. The analysis involves ion exchange chromatography, with selective elution of

Table 14.4 Amino acid composition (g/100 g edible portion) of poultry meat

Amino acids	Ostrich[1]	Chicken[1]	Raw breast of guinea fowl[2]	Raw thigh of guinea fowl[2]
Threonine	0.76	0.90	0.89	0.82
Isoleucine	0.92	1.13	1.08	0.91
Leucine	1.70	1.61	1.82	1.51
Lysine	1.65	1.82	1.81	1.60
Methionine	0.55	0.59	0.61	0.48
Phenylalanine	0.94	0.85	0.95	0.80
Tyrosine	0.61	0.72	0.81	0.65
Valine	0.97	1.06	1.08	0.96
Arginine	1.36	1.29	1.46	1.35
Histidine	0.39	0.66	1.18	0.66
Alanine	1.06	1.17	1.33	1.42
Aspartic acid	1.90	1.91	1.97	1.86
Glutamic acid	2.51	3.20	3.31	3.19
Glycine	0.82	1.05	1.03	1.74
Serine	0.59	0.74	–	–
Tryptophane	–	–	0.18	0.17
Proline	–	–	0.81	1.17
Cystine	–	–	1.22	0.18

[1] Sales (1999); [2] Cerioli et al. (1992)

amino acids according to their isoelectric point, physico-chemical properties and ability to react with ninhydrin, which allows quantification by spectro-photometry (AOAC, 1996; Adrian et al., 1998).

Fatty-acid composition is determined after methylation of dried lipids with a boron trifluoride-methanol complex in a methanol solution (Morrison and Smith, 1964; Adrian et al., 1998; Kim et al., 2002). The top hexane layer containing methylated fatty acids is analysed using gas chromatography, with programmed temperature conditions and a capillary column, a flame ionisation detector and helium as carrier gas (Adrian et al., 1998; Lopez-Ferrer et al., 2001; Kim et al., 2002). The amounts of fatty acids are integrated and calculated as a percentage using specific software. Each fatty acid is identified in the form of a methyl ester by comparing the retention time with known standards. Standardised procedures for the preparation and analysis of methylated fatty acids have been published by AFNOR (St Denis la Plaine, France): ISO 5509:2000 (April 2000) and ISO 5508:1990 (September 1990) and AOAC (1996).

The usual technique used to determine the different minerals and metallic ions in food is flame atomic absorption spectrometry, following a mineralisation step (AOAC, 1996; Adrian et al., 1998; Ruperez, 2002). The apparatus is equipped with a single, hollow cathode lamp (source of radiation) for each element and an air-acetylene burner (source of atoms). The major minerals in poultry meat are presented in Table 14.5. Lipo-soluble vitamins (A, D, E, K) are generally determined by high performance liquid chromatography (HPLC) equipped with UV, or by fluorometry after saponification and solvent extraction

Table 14.5   Major mineral elements (mg/100 g) and vitamins in raw poultry meat (Favier *et al.*, 1995)

Elements	Duck	Turkey	Chicken
Sodium	90	72	76
Magnesium	19	24	25
Phosphorus	202	210	191
Potassium	262	300	300
Calcium	11	14	11
Vitamin A (μg/100 g)	24	traces	12
Vitamin D (μg/100 g)	traces	traces	0.1
Vitamin E (mg/100 g)	0	0.2	0.22
Vitamin C (mg/100 g))	traces	0	traces
Vitamin B1 (mg/100 g)	0.33	0.09	0.08
Vitamin B2 (mg/100 g)	0.43	0.17	0.16
Vitamin B3 (mg/100 g)	5.4	6.8	7.7
Vitamin B5 (mg/100 g)	1.6	0.91	1.1
Vitamin B6 (mg/100 g)	0.34	0.46	0.45
Vitamin B9 (μg/100 g)	30	11	10
Vitamin B12 (μg/100 g)	1.3	1.5	0.4

(Adrian *et al.*, 1998). Over the last ten years, the vitamin E content of meat has usually been measured in studies concerning the role of this substance in preventing lipid oxidation. Hydro-soluble vitamins, B1, B2, B3, and B6 are generally determined by HPLC equipped with UV or by fluorometry after acid hydrolysis and protein precipitation (Adrian *et al.*, 1998). Vitamins B5 and B9 require enzymatic hydrolysis and are determined by gas chromatography and HPLC respectively. Vitamin B8 is determined by spectrophotometry after acid hydrolysis. Vitamin C is also determined by HPLC (Adrian *et al.*, 1998). Vitamin B12 is determined by radio-immunoassay (Adrian *et al.*, 1998). The main vitamins in poultry meat are presented in Table 14.5. Standardised procedures for the analysis of certain vitamins have been published by AFNOR (St Denis la Plaine, France): ISO 12821:2001 (January 2001) for vitamins D2 (cholecalciferol) and D3 (ergocalciferol), ISO 12822:2001 (January 2001) for vitamin E (α, β, γ, δ tocopherols), ISO 12823–1 and -2:2001 (January 2001) for vitamin A (trans-retinol, 13–cis-retinol, β-carotene), ISO 14164:2002 (September 2002) for vitamin B6, and AOAC (1996).

14.6   Conclusions and future trends

Considerable efforts have been made to standardise methods of determining carcass composition, the sensory quality of meat by means of hedonic and analytical tests, and nutritional quality (chemical composition). However, there is still a need to standardise methods for determining the functional properties of meat, meat colour, texture and flavour and lipid oxidation to facilitate

comparisons between studies and to provide reference values. With the increasing development of further processing, there is a demand from the industry for rapid methods of determining the technological quality of meat. The key to success for any such technique in the meat industry lies in demonstrating the existence of a real need and an assured benefit, a direct relationship with the desired quality traits in the end-product, reasonable accuracy of prediction, realistic cost, rapidity, potential for full automation and non-invasiveness (Monin, 1998). While instrumentation has made considerable progress at the laboratory level, in providing a better understanding of the mechanisms underlying meat quality, application of this knowledge to quality evaluation in the meat industry has remained very limited. With increasing international trade in poultry meat and the growing segmentation of the poultry meat market, there is greater consumer interest in the authenticity and sensory characteristics of products marketed under quality labels (geographical origin, breed within a species, production system), and demand from the processing industry concerning the status of meat (ageing, previous freezing, irradiation, undesirable residues, trace elements). Therefore, it is now necessary to develop new techniques so that the origin of meat and its freshness can be guaranteed.

Among techniques recently described, the most promising for large-scale meat quality evaluation are:

- Visible near-infrared spectrophotometry to assess carcass appearance and detect defects.
- Ultrasound scanning to estimate the body composition of live birds for selection programmes and video image analysis to determine carcass composition on processing lines.
- Spectrofluorometry to determine meat texture on-line.
- On-line determination of PSE meat to facilitate selection of meat for further processing.
- Near-infrared spectrophotometry for rapid determination of the chemical composition of meat.

There is still a largely unsatisfied demand for the rapid determination of functional properties.

14.7   Sources of further information and advice

Further information and advice concerning topics covered in this chapter can be obtained from the following institutes and research units:

- Poultry Meat Quality Unit, Station de Recherches Avicoles, INRA Tours, 37380 Nouzilly, France.
- Department of Zootechnology and Quality of Animal Products, ENSAT, BP 107, Avenue de l'Agrobiopôle, Auzeville-Tolosane, 31326 Castanet-Tolosan Cedex, France.

- Station de Recherches sur la Viande, INRA Theix, 63122 Saint-Genès Champanelle, France.
- Federal Centre for Meat Research, Institute for Meat Production and Market Research, E.C. Baumann Strasse 20, D-95326 Kulmbach, Germany.
- Department of Farm Animal Ethology and Poultry Science, University of Hohenheim, 70593 Stuttgart, Germany.
- Universidad Complutense, Facultad de Veterinaria, Departamento de Produccion Animal, Ciudad Universitaria, 28040 Madrid, Spain.
- Universidad Autonoma de Barcelona, Facultad de Veterinaria, Departamento de Nutricion y Alimentacion Animale, 08193 Bellaterra, Spain.
- IRTA, Department of Animal Nutrition, Centro de Mas Bove, Apartat 415, 43280 Reus, Spain.
- IRTA, Food Chemistry Unit, Meat Technology Centre, 17121 Monells, Girona, Spain.
- Facultad Veterinaria, Departamento de Produccion Animal y Ciencia de los Alimentos, Zaragoza, Spain.
- Department of Food Science, Alma Mater Studiorum, University of Bologna, College of Agriculture, Via S. Giacomo, 9, 40126 Bologna, Italy.
- Universita di Camerino, Facolta di Medicina Veterinaria, Macerata, Italy.
- Laboratory of Poulty Products Technology, Department of Food Technology, A. Cieszkowski Agricultural University, 60–624 Poznan, Poland.
- Division of Farm Animal Science, School of Veterinary Science, University of Bristol, Langford, Bristol BS40 5DU, UK.
- Food Science Division, Department of Agriculture and Rural Development for Northern Ireland and the Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX, UK.
- Department of Food Science and Technology, University College, Cork, Ireland.
- Poultry Processing and Meat Quality Research Unit, Department of Agriculture, Agricultural Research Service, Russell Research Centre, Athens, GA 30604, USA.
- Department of Poultry Science, University of Georgia, Athens, GA 30602, USA.
- Department of Poultry Science, Texas A&M University, College Station, TX 77843–2472, USA.
- Department of Animal and Poultry Science, University of Guelph, Ontario, N1G 2W1, Canada.

14.8   References

ABDALLA S A A, JENSEN J F (1997), 'Effect of different scalding temperatures on carcasses and meat quality in broilers', *Archiv für Geflügelkunde*, 61 (6), 249–253.
ABENI F, BERGOGLIO G (2001), 'Characterization of different strains of broiler chicken by carcass measurements, chemical and physical parameters and NIRS on breast muscle', *Meat Science,* 57, 133–137.

ACTIA (1999), *Evaluation sensorielle, guide des bonnes pratiques*, Association de Coordination Technique pour l'Industrie Agro-alimentaire, Paris, 128 pp.

ACTON J C, DICK R L (1986), 'Thermal transitions of natural actomyosin from poultry breast and thigh tissues', *Poultry Science,* 65, 2051–2055.

ADRIAN J, POTUS J, POIFFAIT A, DAUVILLIER P (eds) (1998), *Introduction à l'analyse nutritionnelle des denrées alimentaires,* Tec & Doc, Lavoisier, Paris, 254 pp.

AFNOR (1995), *Contrôle de la qualité des produits alimentaires – Analyse sensorielle*, Association Française de Normalisation, St Denis la Plaine, 420 pp.

AFNOR (1996), *Méthodes statistiques*, Association Française de Normalisation, St Denis la Plaine, 5 vols.

AMSA (1995), *Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat*, American Meat Science Association, Chicago, 50 pp.

ANON (1991), *Guidelines for meat colour evaluation*, American Meat Science Association and National Live Stock and Meat Board, Chicago, 15 pp.

AOAC (1996), 'Meat and meat products', in Cunniff P (ed.), *Official methods of analysis*, 16th edn, Gaithersburg MD, AOAC International, 39.1–39.6

ASTM (1986), *Manual on consumer sensory evaluation*, 2nd edn, American Standard for Testing and Material, special technical publication 682.

BAÉZA E, DESSAY C, WACRENIER N, MARCHÉ G, LISTRAT A (2002), 'Effect of selection for improved body weight and composition on muscle and meat characteristics in Muscovy duck', *British Poultry Science,* 43, 560–568.

BARBUT S (1996), 'Estimates and detection of the PSE problem in young turkey breast meat', *Canadian Journal of Animal Science,* 76, 455–457.

BARBUT S (1997), 'Microstructure of white and dark turkey meat batters as affected by pH', *British Poultry Science,* 38, 175–182.

BERGMAN I, LOXLEY R (1963), 'Two improved and simplified methods for the spectrophotometric determination of hydroxyproline', *Analytical Chemistry,* 35 (12), 1961–1965.

BERRI C (2000), 'Variability of sensory and processing qualities of poultry meat', *World's Poultry Science Journal*, 56, 209–224.

BERTHELOT A, BARON F, BOUVAREL I, MIRABITO L, AUBERT C, DALIBARD F, BOCQUIER C, LOIZEAU J M, SANTE V, LE POTTIER G (2001), 'Impact d'une baisse de densité et d'un allongement de la durée d'élevage chez la dinde sur des paramètres technico-économiques et à forte valeur sociale : intégrité physique, comportement, environnement', *Sciences et Techniques Avicoles*, 37, 19–28.

BERTRAM H C, ANDERSEN H J, KARLSSON A H (2001), 'Comparative study of low-field relaxation measurements and two traditional methods in the determination of water holding capacity of pork', *Meat Science,* 57, 125–132.

BERTRAND D, DUFOUR E (eds) (2000), *La spectroscopie infrarouge et ses applications analytiques*, Tec & Doc, Lavoisier, Paris, 566 pp.

BOCHNO R, RYMKIEWICZ J, SZEREMETA J (2000), 'Regression equations for *in vivo* estimation of the meat content of Peking duck carcasses', *British Poultry Science,* 41, 313–317.

BØGH-SORENSEN L (1985), 'Objective methods for measuring functional properties of poultry meat', *7th WPSA European Symposium on the Quality of Poultry Meat*, Vejle (Denmark), 6–10 May, 112–125.

BRUNTON N P, CRONIN D A, MONAHAN F J (2002), 'Volatile components associated with freshly cooked and oxidized off-flavours in turkey breast meat', *Flavour and*

Fragrance Journal, 17, 327–334.

CASTAING J, MOLINIER V, LARROUDÉ P, BOUVAREL I, RÉMIGNON H, ZWICK J L (1997), 'Mise au point d'une méthode d'estimation de l'état d'engraissement des carcasses de dindes', *Viandes et Produits Carnés*, 18 (3), 150–152.

CERIOLI C, FIORENTINI L, PIVA G (1992), 'Valore alimentare delle carni di gallina faraona', La *Rivista della Societa Italiana di Scienza dell'Alimentazione*, 21 (4), 373–382.

CHEN Y R, NGUYEN M, PARK B (1998a), 'Neural networks with principal component analysis for poultry carcass classification', *Journal of Food Process Engineering*, 21, 351–367.

CHEN Y R, PARK B, HUFFMAN R W, NGUYEN M (1998b), 'Classification of on-line poultry carcasses with back propagation neural networks', *Journal of Food Process Engineering*, 21, 33–48.

COZZOLINO D, MURRAY I, PATERSON R, SCAIFE J R (1996), 'Visible and near infrared reflectance spectroscopy for the determination of moisture, fat and protein in chicken breast and thigh muscle', *Journal of Near Infrared Spectroscopy*, 4, 213–223.

CREMONINI M A, BIANCHI M, CAVANI C, LAGHI L, PETRACCI M, CAPOZZI F (2001), 'Study on the water holding capacity of turkey breast meat by low-resolution NMR', *15th WPSA European Symposium on the Quality of Poultry Meat*, Kusadasi (Turkey), 9–12 September, 313–318.

CROSS H R, WEST R L, DUTSON T R (1980), 'Comparison of methods for measuring sarcomere length in beef semitendinosus muscle', *Meat Science,* 5, 261–266.

CULIOLI J, TOURAILLE C, BORDES P, GIRARD J P (1990), 'Caractéristiques des carcasses et de la viande du poulet label fermier', *Archiv für Geflügelkunde*, 53, 237–245.

CULIOLI J, BERRI C, MOUROT J (2003), 'Muscle foods: consumption, composition and quality', *Science des Aliments*, in press.

CYWA-BENKO K, ROSINSKI A, KNAPIK K, WEZYK S, KRAWCZYK J, BIELINSKA H (1997), 'In vivo evaluation of breeding geese musculature using ultrasonography', *13th WPSA European Symposium on the Quality of Poultry Meat*, Poznan (Poland), 21–26 September, 631–637.

CYWA-BENKO K, WEZYK S, KRAWCZYK J, ROSINSKI A, BIELINSKA H (1999), 'Measuring meat and fat in live geese with use ultrasonography', *1st WPSA World Waterfowl Conference*, Taichung (Taiwan ROC), 1–4 December, 590–596.

DAUM-THUNBERG D L, FOEGEDING E A, BALL H R (1992), 'Rheological and water holding properties of comminuted turkey breast and thigh: effects of initial pH', *Journal of Food Science*, 57 (2), 333–337.

DAVENEL A, SEIGNEURIN F, COLLEWET G, RÉMIGNON H (1999), 'Estimation *in vivo* du rendement en filet chez le poulet par imagerie de résonance magnétique', *3èmes Journées de la Recherche Avicole*, St Malo (France), 23–25 March, 367–370.

DRAPER H H, SQUIRES E J, MAHMOODI H, WU J, AGARWAL S, HADLEY M (1993), 'A comparative evaluation of thiobarbituric acid methods for the determination of malondialdehyde in biological materials', *Free Radical Biology and Medicine*, 15, 353–363.

DU M, AHN D U, MENDONCA A F, WESLEY I V (2002), 'Quality characteristics of irradiated ready-to-eat-breast rolls from turkeys fed conjugated linoleic acid', *Poultry Science*, 81, 1378–1384.

EARL L A, KING A J, FITZPATRICK D P, COOPER J E (1996), 'A modification of a method to determine expressible moisture in ground, dark poultry meat', *Poultry Science*, 75, 1433–1436.

EHINGER F (1977), 'Relations between skin fat, total body fat and plasma values in broilers of different origins', *Archiv für Geflügelkunde*, 41 (1), 35–37.

ENSER M (1999), 'Nutritional effects on meat flavour and stability', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 197–215.

FARHAT A, CHAVEZ E R (2000), 'Comparative performance, blood chemistry and carcass composition of two lines of Peking ducks reared mixed or separated by sex', *Poultry Science*, 79, 460–465.

FARHAT A, CHAVEZ E R (2001), 'Metabolic studies on lean and fat Peking ducks selected for breast muscle thickness measured by ultrasound scanning', *Poultry Science*, 80, 585–591.

FARMER L J (1999), 'Poultry meat flavour', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 159–175.

FAVIER J C, IRELAND-RIPERT J, TOQUE C, FEINBERG M (eds) (1995), *Répertoire général des aliments*, 2nd edn, Tec & Doc, Lavoisier, Paris, 897 pp.

FERNANDEZ X, SANTÉ V, BAÉZA E, LEBIHAN-DUVAL E, BERRI C, RÉMIGNON H, BABILÉ, LE POTTIER G, MILLET N, BERGE P, ASTRUC T (2001), 'Post-mortem muscle metabolism and meat quality in three genetic types of turkey', *British Poultry Science,* 42, 462–469.

FERNANDEZ X, SANTÉ V, BAÉZA E, LEBIHAN-DUVAL E, BERRI C, RÉMIGNON H, BABILÉ, LE POTTIER G, ASTRUC T (2002), 'Effects of the rate of muscle post-mortem pH fall on the technological quality of turkey meat', *British Poultry Science,* 43, 245–252.

FLEMING B K, FRONING G W, YANG T S (1991), 'Heme pigment levels in chicken broilers chilled in ice slush and air', *Poultry Science*, 70, 2197–2200.

FLETCHER D L (1999), 'Poultry meat colour', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 159–175.

FOEGEDING E A (1987), 'Functional properties of turkey salt-soluble proteins', *Journal of Food Science*, 52 (6), 1495–1498.

FOEGEDING E A (1990), 'Development of a test to predict gelation properties of raw turkey muscle proteins', *Journal of Food Science*, 55 (4), 932–941.

FOLCH J, LEES M, SLOANE G S H (1957), 'A simple method for the isolation and purification of total lipids from animal tissue', *Journal of Biological Chemistry*, 226, 497–509.

FRENCIA J P, THOMAS E, DUFOUR E (2002), 'Mesure de la tendreté de la viande par spectroscopie de fluorescence frontale', *9èmes Journées des Sciences du Muscle et de la Technologie de la Viande*, Clermont-Ferrand (France), 15–16 October, 251–252.

FRONING G W (1995), 'Colour of poultry meat', *Poultry and Avian Biology Reviews*, 6 (1), 83–93.

FRONING G W, DADDARIO J, HARTUNG T E (1978), 'Colour and myoglobin concentration in turkey meat as affected by age, sex and strain', *Poultry Science*, 48, 668–674.

GAULT N F S, BURNS C, TOLLAND E L C, KILPATRICK D J (2000), 'Effect of some electrical stimulation variables on wing flapping, post-mortem glycolysis and eating quality characteristics of broiler *Pectoralis major* muscle', *British Poultry Science,* 41, 293–299.

GIF P, TOURNAYRE P, CULIOLI J (1995), 'Automatisation d'un banc de mesure de la longueur des sarcomères de la viande par diffraction d'une lumière cohérente (laser)', *Viandes et Produits Carnés*, 16 (2), 39–45.

GIL M, HORTOS M, SARRAGA C (1998), 'Calpain and cathepsin activities and protein extractability during ageing of *longissimus porcine* muscle from normal and PSE meat', *Food Chemistry*, 63 (3), 385–390.

GILLET T A, MEIBURG D E, BROWN C L, SIMON S (1977), 'Parameters affecting meat protein extraction and interpretation of model system data for meat emulsion formation', *Journal of Food Science*, 42 (6), 1606–1610.

GÖKSOY E O, McKINSTRY L J, WILKINS L J, PARKMAN I, PHILLIPS A, RICHARDSON R I, ANIL M H (1999), 'Broiler stunning and meat quality', *Poultry Science*, 78, 1796–1800.

GRASHORN M (1986), 'The prediction of the breast yield in Muscovy ducks', *Archiv für Geflügelkunde*, 50 (3), 97–100.

HAHN G, SPINDLER M (2002), 'Method of dissection of turkey carcasses', *World's Poultry Science Journal*, 58 (2), 179–197.

HAHN G, DÜNKEL R, DOBROWOLSKI A, BRANSCHEID W (1997), 'On line determination of turkey carcasses value during slaughter by video image analysis', *13th WPSA European Symposium on the Quality of Poultry Meat*, Poznan (Poland), 21–26 September, 419–423.

HAMM R (1986), 'Functional properties of the myofibrillar system and their measurements', in Betchel P J (ed.), *Muscle as food*, Orlando, Academic Press Inc, 135–199.

HEATH J L, OWENS S L (1997), 'Measurement of broiler breast meat shear values', *Journal of Applied Poultry Research*, 6, 185–190.

HILL F (1966), 'The solubility of intramuscular collagen in meat animals of various ages', *Journal of Food Science*, 31, 161–166.

HONIKEL K O (1997), 'Reference methods supported by OECD and their use in Mediterranean meat products', *Food Chemistry*, 59 (4), 573–582.

HOPP R, MORI K (eds) (1993), *Recent Development in Flavor and Fragrance Chemistry*, VCH Weinheim, 222 pp.

HORNSEY (1956), 'The colour of cooked cured pork – Estimation of the nitric oxide-haem pigments', *Journal of Science of Food and Agriculture*, 7, 534–540.

IRIE M, IZUMO A, MOHRI S (1996), 'Rapid method for determining water-holding capacity in meat using video image analysis and simple formulae', *Meat Science,* 42 (1), 95–102.

JAUREGUI C A, REGENSTEIN J M, BAKER R C (1981), 'A simple centrifugal method for measuring expressible moisture, a water-binding property of muscle foods', *Journal of Food Science*, 46, 1271–1273.

JO C, AHN D U (1998), 'Fluorometric analysis of 2-thiobarbituric acid reactive substances in turkey', *Poultry Science*, 77, 475–480.

KIJOWSKI J (2001), 'Decisive role of myofibrillar proteins for texture and functional properties of poultry meat and meat products', *15th WPSA European Symposium on the Quality of Poultry Meat*, Kusadasi (Turkey), 9–12 September, 303–312.

KIJOWSKI J, NIEWIAROWICZ A (1978), 'Emulsifying properties of proteins and meat from broiler breast muscles as affected by their initial pH values', *Journal of Food Technology*, 13, 451–459.

KIJOWSKI J, MAST M G (1988a), 'Thermal properties of proteins in chicken broiler tissues', *Journal of Food Science*, 53 (2), 363–366.

KIJOWSKI J, MAST M G (1988b), 'Effect of sodium chloride and phosphates on the thermal properties of chicken meat proteins', *Journal of Food Science*, 53 (2), 367–370.

KIM Y H, NAM K C, AHN D U (2002), 'Volatile profiles, lipid oxidation and sensory characteristics of irradiated meat from different animal species', *Meat Science,* 61 (3), 257–265.

KJELDHAL J (1883), 'Neue Methode zur Bestimung des Stickstoffs in organischen Körpern', *Z Analytical Chemistry,* 22, 366–382.

KOJCZAK T, POSPIECH E, PALKA K, LACKI J (2003), 'Changes in structure of psosas major and minor and semitendinosus muscles of calves, heifers and cows during post-mortem ageing', *Meat Science,* 64 (1), 77–83.

KÖNIG T, GRASHORN M A, BESSEI W (1997), 'Estimation of breast meat yield in living broilers using B-scan sonography: defining sites of measurement', *Archiv für Geflügelkunde*, 61 (5) 227–231.

KÖNIG T, GRASHORN M A, BESSEI W (1998), 'Estimation of breast meat yield in living broilers using B-scan sonography: accuracy of the method', *Archiv für Geflügelkunde*, 62 (3), 121–125.

KOOLMEES P A, KORTEKNIE F, SMULDERS F J M (1986), 'Estimation of breast meat yield in living broilers using B-scan sonography: accuracy of the method', *Food Microstructure*, 5, 71–76.

KORNBRUST D J, MAVIS R D (1980), 'Relative susceptibility of microsomes from lung, heart, liver, kidney, brain and testis to lipid peroxidation: correlation with vitamin E content', *Lipids*, 15, 315–322.

KUBER P S, DUCKETT S K, BUSBOOM J R, SNOWDER G D, DODSON M V, VIERCK J L, BAILEY J F (2003), 'Measuring the effects of phenotype and mechanical restraint on proteolytic degradation and rigor shortening in calipyge lamb longissimus dorsi muscle during extended aging', *Meat Science,* 63 (3), 325–331.

LAVALLEE S, CHAVEZ E R, TOUCHBURN S P (1998), 'Ultrasound measurements for maximum breast muscle thickness of Peking breeder ducks at market age and progeny response', *10th WPSA European Poultry Conference*, Jerusalem (Israel), 21–26 June, 664–668.

LI-CHAN E, NAKAI S, WOOD D F (1985), 'Relationship between functional (fat binding, emulsifying) and physicochemical properties of muscle proteins. Effects of heating, freezing, pH and species', *Journal of Food Science*, 50, 1034–1040.

LISTRAT A, RAKADJIYSKI N, JURIE C, PICARD B, TOURAILLE C, GEAY Y (1999), 'Effect of the type of diet on muscle characteristics and meat palatability of growing Salers bulls', *Meat Science,* 53, 115–124.

LIU A, NISHIMURA T, TAKAHASHI K (1996), 'Relationship between structural properties of intramuscular connective tissue and toughness of various chicken skeletal muscles', *Meat Science,* 43 (1), 43–49.

LIU Y, CHEN Y R (2001), 'Analysis of visible reflectance spectra of stored, cooked and diseased chicken meats', *Meat Science,* 58, 395–401.

LOPEZ-FERRER S, BAUCELLS M D, BARROETA A C, GRASHORN M A (2001), 'N-3 enrichment of chicken meat – Use of very long chain fatty acids in chicken diets and their influence on meat quality: fish oil', *Poultry Science*, 80, 741–752.

LYNCH S M, FREI B (1993), 'Mechanisms of copper and iron dependent oxidative modification of human low density lipoprotein', *Journal of Lipid Research*, 34, 1745–1753.

LYON C E, BUHR R J (1999), 'Biochemical basis of meat texture', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 99–126.

LYON C E, LYON B G (1990), 'The relationship of objective shear values and sensory tests to changes in tenderness of broiler breast meat', *Poultry Science*, 69, 1420–1427.

MacCREADY S T, CUNNINGHAM F E (1971), ' Salt soluble proteins of poultry meat – Composition and emulsifying capacity', *Poultry Science*, 50, 243–248.

MAGDELAINE P, PHILIPPOT J B (2000), ' Segmentation du marché français du poulet: différenciation qualitative et développement des produits élaborés', *Viandes et Produits Carnés*, 21 (1), 31–37.

MANDAVA R, HOOGENKAMP H (1999), 'The role of processed products in the poultry meat industry', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 397–410.

MARCHÉ G (1995), *La découpe anatomique et la dissection des volailles*, Tours, SYSAAF-INRA (eds), 71 pp.

MARCHÉ G (2000), CDRom: *Dissection of poultry carcasses*, INRA Tours, Nys Y (ed.) http://www.tours.inra.fr/tours/sra/cdrom/decoupevolaille.htm

MARGAS C, NYS Y (1997), 'Comparaison de l'efficacité de trois sources végétales de pigment pour la coloration de la peau de poulet', *2èmes Journées de la Recherche Avicole*, Tours (France), 8–10 April, 203–206.

MARTRENCHAR A, HUONNIC D, COTTE J P, BOILLETOT E, MORISSE J P (1999), 'Influence of stocking density on behavioural, health and productivity traits of turkeys in large flocks', *British Poultry Science,* 40, 323–331.

MARTY-MAHÉ P, RAFFY G, MICHEL O, MARCHAL P (1999), 'Détection de défauts sur carcasses de dinde sur chaîne d'abattage par vision numérique couleur', *3èmes Journées de la Recherche Avicole*, St Malo (France), 23–25 March, 371–374.

MEAD G C (1987), 'Recommendation for a standardized method of sensory analysis for broilers', *World's Poultry Science Journal*, 43, 64–68.

MERCIER Y, GATELLIER P, VIAU M, RÉMIGNON H, RENERRE M (1998), 'Effect of dietary fat and vitamin E on colour stability and on lipid and protein oxidation in turkey meat during storage', *Meat Science,* 48 (3/4), 301–318.

MEULLENET J F C, CARPENTER J A , LYON B G, LYON C E (1997), 'Bi-cyclical instrument for assessing texture profile parameters and its relationship to sensory evaluation of texture', *Journal of Texture Studies*, 28, 101–118.

MICHALIK D, BOCHNO R (1986), 'Investigations on deriving multiple regression equations for supravital estimation of meatiness and fatness of ducks', *Roczniki Nauk Rolniczych B*, 102 (4), 131–139.

MONIN G (1998), 'Recent methods for predicting quality of whole meat', *Meat Science,* 49, suppl. 1, S231–S243.

MORRISSON W R, SMITH M L (1964), 'Preparation of fatty acid methyl esters and dimethylacetates from lipid with boron trifluoride methanol', *Journal of Lipid Research*, 5, 600–608.

MOUNIER F (1990), 'Estimation de la teneur en collagène par dosage de l'hydroxyproline de la viande de faisan', *Report IUT*, La Rochelle (France), pp. 55.

NARASUBHAI A V, KALLAPUR V L (1977), 'Correlation between cytochrome c and myoglobin contents of the different leg muscles and *Musculus pectoralis* with reference to sex of the domestic fowl', *Current Science*, 46, 269–270.

NAVEAU J, POMMERET P, LECHAUX P (1985), 'Proposition d'une méthode de mesure du rendement technologique, la méthode Napole', *Techni-Porc*, 8, 6–13.

NUTE G R (1999), 'Sensory assessment of poultry meat quality', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 159–175.

OWENS C M, HIRSCHLER E M, McKEE S R, MARTINEZ-DAWSON R, SAMS A R (2000), 'The characterization and incidence of pale, soft, exudative turkey meat in a commercial plant', *Poultry Science*, 79, 553–558.

PARK B, CHEN Y R, HUFFMAN R W (1996), 'Integration of visible NIR spectroscopy and multispectral imaging for poultry carcass inspection', *Journal of Food Process Engineering*, 30, 197–207.

PIKUL J, NIEWIAROWICZ A, KUPIJAJ H (1986), 'The cytochrome c content of various poultry meats', *Journal of Science of Food and Agriculture*, 37, 1236–1240.

PIKUL J, LESZCZYNSKI D E, KUMMEROW F A (1989), 'Evaluation of three modified TBA methods for measuring lipid oxidation in chicken meat', *Journal of Agriculture and Food Chemistry*, 37, 1309–1313.

PINGEL H (1990), 'Genetics of growth and meat production in waterfowl', in Crawford R D, *Poultry Breeding and Genetics*, Elsevier, Amsterdam, 691–704.

POPIEL A K, SMOLINSKA T, TRZISZKA T L (1998), 'An attempt to use an oscillating differential calorimetry for measuring the thermal properties of chicken meat', *10th WPSA European Poultry Conference*, Jerusalem (Israel), 21–26 June, 695–699.

QIAO M, FLETCHER D L, SMITH D P, NORTHCUTT J K (2001), 'The effect of broiler breast meat colour on pH, moisture, water-holding capacity and emulsification capacity', *Poultry Science*, 80, 676–680.

RAJ A B M, RICHARDSON R I, WILKINS L J, WOTTON S B (1998), 'Carcass and meat quality in ducks killed with either gas mixtures or an electric current under commercial processing conditions', *British Poultry Science,* 39, 404–407.

RAJ A B M, WILKINS L J, O'CALLAGHAN M, PHILLIPS A J (2001), 'Effect of electrical stun/kill method, interval between killing and neck cutting and blood vessels cut on blood loss and meat quality in broilers', *British Poultry Science,* 42, 51–56.

RÉMIGNON H, SEIGNEURIN F, DESROSIERS V (1997), 'Measurements of *in vivo* breast meat amount and yield in broilers by using computerised tomography', *13th WPSA European Symposium on the Quality of Poultry Meat*, Poznan (Poland), 21–26 September, 607–612.

RICARD F H (1980), 'Carcass conformation of poultry and game birds', in Mead G C and Freeman B M (eds), *Meat Quality in Poultry and Game Bird*, Brit Poultry Science Ltd, Edinburgh, 31–50.

RICARD F H, ROUVIER R (1967), 'Etude de la composition anatomique du poulet', *Annales de Zootechnie*, 16 (1), 23–39.

ROUSEFF R L, CADWALLEDER K R, eds (2001), *Headspace Analysis of Food and Flavours: Theory and Practice*, Kluwer Academic, New York, 304 pp.

RUANTRAKOOL B, CHEN T C (1986), 'Collagen contents of chicken gizzard and breast meat tissues as affected by cooking methods', *Journal of Food Science*, 51, 301–304.

RUPEREZ P (2002), 'Mineral content of edible marine seaweeds', *Food Chemistry*, 79, 23–26.

RYMKIEWICZ J, SCHYMCZYK J, BOCHNO R (2001), 'Comparison of regression equations for subgroups with a general model to estimate the breast muscle weight in geese', *Archiv für Geflügelkunde,* 65 (2) 92–96.

SALES J (1999), 'Slaughter and products', in Deemin D C (ed.), *The ostrich: biology, production and health*, CABI International, Oxon, 231–274.

SALICHON M R, BLUM J C (1995), 'Utilisation des protéines de luzerne (Px super) pour la croissance et la coloration du poulet de chair', *1ères Journées de la Recherche Avicole*, Angers (France), 28–30 March, 33–36.

SAMS A R (1990), 'Electrical stimulation and high temperature conditioning of broiler carcasses', *Poultry Science*, 69, 1781–1786.

SANTÉ V, FERNANDEZ X (2000), 'The measurement of pH in raw and frozen turkey *Pectoralis superficialis* muscle', *Meat Science,* 55, 503–506.

SANTÉ V, LACOURT A (1994), 'The effect of dietary α-tocopherol supplementation and antioxidant spraying on colour stability and lipid oxidation of turkey meat', *Journal of Science of Food and Agriculture*, 65, 503–507.

SANTÉ V, LE POTTIER G, ASTRUC T, MOUCHONIERE M, FERNANDEZ X (2000), 'Effect of

stunning current frequency on carcass downgrading and meat quality of turkey', *Poultry Science*, 79, 1208–1214.

SCHIEBERLE P, ENGEL K H (eds) (2000), *Frontiers of Flavour Science,* Deutsche Forschungsanstalt für Lebensmittelchemie, Garching, 602 pp.

SCOLLAN N D, CASTON L J, LIU Z, ZUBAIR A K, LEESON S, McBRIDE B W (1998), 'Nuclear magnetic resonance imaging as a tool to estimate the mass of the *Pectoralis* muscle of chickens *in vivo*', *British Poultry Science,* 39, 221–224.

SEBASTIAN I, SANTÉ V, LE POTTIER G, MARTY-MAHÉ P, LOISEL P, BROSSARD D, MONIN G (2002), 'Application de la vision numérique à l'analyse de la couleur des filets de dinde en vue de leur tri pour la transformation', *9èmes Journées des Sciences du Muscle et Technologies de la Viande*, Clermont-Ferrand (France), 15–16 October, 235–236.

SEIGNEURIN F, RÉMIGNON H, MOATI F (1999), 'Estimation in vivo du rendement en filet chez le poulet par échographie', *3èmes Journées de la Recherche Avicole*, St Malo (France), 23–25 March, 459–461.

SEKOGUCHI S R, NAKAMURA R, SATO Y (1978), 'The effect of thiosecarbazide administration on the tenderness of meat obtained from mature chickens and on some characteristics of its intramuscular collagen', *Poultry Science*, 57, 104–110.

SHELDON B W, CURTIS P A, DAWSON P L, FERKETT P R (1997), 'Effect of dietary vitamin E on the oxidative stability, flavour, color and volatile profiles of refrigerated and frozen turkey breast meat', *Poultry Science*, 76, 634–641.

SILVA J A, PATARATA L, MARTINS C (1999), 'Influence of ultimate pH on bovine meat tenderness during ageing', *Meat Science,* 52 (4), 453–459.

SMITH D P, FLETCHER D L (1998), 'Effects of broiler breast meat fiber direction, dicing and post-mortem deboning time on Allo-Kramer shear', *Journal of Applied Poultry Research*, 7, 281–286.

SMITH D P, FLETCHER D L, BUHR R J, BEYER R S (1993), 'Peking duckling and broiler chicken *pectoralis* muscle structure and composition', *Poultry Science*, 72, 202–208.

SMYTH A B, O'NEILL E, SMITH D M (1999), 'Functional properties of muscle proteins in processed poultry products', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 99–126.

SORENSEN P, JENSEN J A (1992), 'Use of ultrasonic techniques to detect breast muscle proportion in live ducks', *19th WPSA World Poultry Congress*, vol 3, Amsterdam (Netherlands) 20–24 September, 225–228.

STABURSVIK E, MARTENS H (1980), 'Thermal denaturation of proteins in post rigor muscle tissue as studied by differential scanning calorimetry', *Journal of Science of Food and Agriculture*, 31, 1034–1042.

STABURSVIK E, FRETHEIM K, FROYSTEIN T (1984), 'Myosin denaturation in pale, soft and exudative porcine muscle tissue as studied by differential scanning calorimetry', *Journal of Science of Food and Agriculture*, 35, 240–244.

STEPHEN J, ELMORE J S, DONALD S, MOTTRAM D S, HIERRO E (2001), 'Two-fibre solid-phase microextraction combined with gas chromatography-mass spectrometry for the analysis of volatile aroma compounds in cooked pork', *Journal of Chromatography A*, 905, 233–240.

STEWART M R, ZIPSER M N, WATTS B M (1965), 'The use of reflectance spectrophotometry for the assay of raw meat pigments', *Journal of Food Science*, 39, 988–992.

SWATLAND H J, NUTE G R (1999), 'On-line assessment of poultry meat quality', in Richardson R I and Mead G (eds), *Poultry Meat Science*, CAB International, Abingdon, 159–175.

SWATLAND H J, MADSEN N T, NIELSEN T (1996), 'Fluorometry of connective tissue in beef,

relative to direction of measurement', *Lebensm-Wiss u- Technologie*, 29, 536–541.

SWIFT C E, LOCKET C, FRYAR A J (1961), 'Comminuted meat emulsions – The capacity of meats for emulsifying fat', *Food Technology*, 15, 468–473.

THOMPSON L D, JANKY D M, WOODWARD S A (1987), 'Tenderness and physical characteristics of broiler breast fillets harvested at various times from post-mortem electrically stimulated carcasses', *Poultry Science*, 66, 1158–1167.

TOGERSEN G, ISAKSSON T, NILSEN B N, BAKKER E A, HILDRUM K I (1999), 'On-line NIR analysis of fat, water and protein in industrial scale ground meat batches', *Meat Science,* 51, 97–102.

TOURAILLE C, KOPP J, VALIN C, RICARD F H (1981), 'Qualité du poulet: Influence de l'âge et de la vitesse de croissance sur les caractéristiques physico-chimiques et organoleptiques de la viande', *Archiv für Geflügelkunde*, 45, 69–76.

VAN DEN OORD A H, WESDORP J J (1971), 'Analysis of pigments in intact beef samples', *Journal of Food Technology*, 6, 1–8.

WEBB N B, IVEY F J CRAIG H B, JONES V A, MONROE R J (1970), 'The measurement of emulsifying capacity by electrical resistance', *Journal of Food Science*, 35, 501–504.

WILKINS L J, WOTTON S B, PARKMAN I D, KETTLEWELL P J, GRIFFITHS P (1999), 'Constant current stunning effects on bird welfare and carcass quality', *Journal of Applied Poultry Research*, 8, 465–471.

WOESSNER J F (1961), 'The determination of collagen in tissue and protein samples containing small proportions of imino acid', *Archives of Biochemistry and Biophysics*, 93, 440–448.

WOLOSZYN J (2002), 'The functional properties of muscles from force fed mulard ducks – The thermal properties of muscle proteins', *Archiv für Geflügelkunde*, 66 (6), 274–279.

WPSA (1983), 'Method of dissection of broiler carcasses and description of parts. Terms used for parts of poultry in different languages', World's Poultry Science Association, European Federation, Working Group V, Jensen F (ed.), Denmark.

XIONG Y L, BREKKE C J (1989), 'Changes in protein solubility and gelation properties of chicken myofibrils during storage', *Journal of Food Science*, 54 (5), 1141–1146.

XIONG Y L, BREKKE C J (1990), 'Thermal transitions of salt-soluble proteins from pre- and post rigor chicken muscles', *Journal of Food Science*, 55 (6), 1540–1543.

XIONG Y L, BREKKE C J, LEUNG H K (1987), 'Thermal denaturation of muscle proteins from different species and muscle types as studied by differential scanning calorimetry', *Canadian Institute for Food Science and Technology Journal*, 20 (5), 357–362.

ZIEGLER G R, ACTON J C (1984), 'Heat induced transitions in the protein-protein interaction of bovine natural actomyosin', *Journal of Food Biochemistry*, 8, 25–30.

ZIOLECKI J, KONIECZNY P (1983), 'The relationship between back skin fat content and body fat content in the carcasses of Table duck', *6th WPSA European Symposium on the Quality of Poultry Meat*, Ploufragan (France), 17–20 May, 96–104.

15

Managing the safety and quality of poultry meat

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15.1 Introduction: an overview of poultry meat processing

Governments and industry worldwide have agreed on the need for foods of animal origin to be produced in a manner that ensures their safety for human consumption, especially in relation to poultry, eggs and egg products. Therefore, food safety has become an integral part of the relevant production processes to meet the strongly negative reactions of consumers and consumer organisations to recent crises in the food-animal industry. In addition to their demands regarding food safety and quality, consumers have many concerns about sustainability and aspects of production that impinge on the needs and values of society, including animal welfare and environmental protection. In our present exacting world, the production process has to meet many different requirements.

Truly safe products are free from microorganisms that are pathogenic to man (*Salmonella, Campylobacter* and, to a lesser extent, *Clostridium perfringens,* pathogenic *Escherichia coli, Staphylococcus aureus* and *Listeria monocytogenes*), and without any residues of substances used in primary production, including antibiotics, coccidiostats and other chemicals, or foreign bodies. Also, the presence of spoilage organisms (*Pseudomonas, Brochothrix* etc) should not be overlooked. Both pathogenic and spoilage microorganisms may result in considerable economic losses in society: food poisoning leading to high costs for medical treatment and absence from work, spoilage involving costly product recalls and food wastage. However, bacteria are not the only microbial hazards. Recent events during an epidemic of avian influenza in The Netherlands, where a veterinarian died from the illness, showed that some viruses of poultry origin are also potentially dangerous to man.

During the 1970s, Dutch producers were given a so-called 'licence to produce'; in 1980–1990 this changed to a 'licence to operate' and today there is a 'licence to sell', from which all aspects of product safety, as demanded and expected by consumers, are integrated with sustainable methods of production. Integrated control programmes incorporate food safety requirements and guarantee the quality of foods of animal origin, particularly poultry products. The Hazard Analysis Critical Control Point (HACCP) concept is included in these programmes. The concept and its many applications were described by the International Commission on Microbiological Specifications for Foods (ICMSF, 1988). Whatever system is used, however, all have in common the managing of potential health risks associated with foods.

In the European Union (EU), there are several directives that relate to food safety and quality. These directives are concerned with labelling, product liability and general hygiene principles. The present Food Law (93/43/EEC, Anon 1993), which will be replaced in January 2005, incorporates the basic principles of the HACCP concept. The new law will add a balanced system for product identification and registration, and a tracing and tracking mechanism (see section 15.3.2) will also become mandatory. In 2000, the United States Department of Agriculture (USDA) introduced a HACCP-based Inspection Model Project (HIMP), in which the carcass inspection process (identification and removal from the processing line of carcasses or parts that are diseased, unwholesome or otherwise unacceptable) becomes the responsibility of processing-plant personnel. Under the HIMP project, there are also performance standards for both food-safety and non-food-safety aspects of product quality (USDA, 2000).

15.1.1   Poultry-meat processing

Artisan slaughtering may have existed for many thousands of years. In the early years of commercial poultry processing, carcasses varied in the extent to which they were plucked and eviscerated, and they were marketed under names such as 'New York Dressed' (plucked, but not eviscerated), 'effilée' (plucked, with intestines removed) and 'eviscerée (plucked and completely eviscerated). These artisan types of product are still available today in some local markets. With these carcasses, the upper layer of the skin remains intact after scalding and plucking, due to the low scalding temperature used (< 54ºC). The presence of the upper epidermal layer is important with respect to shelf-life. Carcasses that were only plucked and not opened had a longer shelf-life. Another reason for the prolonged shelf-life was the minimal use of water during production, leading to the use of 'dry' slaughter to describe such a process, as opposed to 'wet' slaughter for carcasses involving ice-water chilling.

The more industrialised forms of poultry processing began with the introduction of mechanical lines bearing shackles and continued through the development of scald tanks, plucking equipment and machinery for mechanical evisceration of carcasses. These developments made it possible to improve the hygienic quality and shelf-life of the carcasses. At the same

time, more water and energy were needed. Water was required to scald the carcasses, remove the feathers during plucking and to chill them after evisceration. Energy was necessary for transport chains, scald tanks and plucking equipment, and later for continuous evisceration procedures. Continued development of the process resulted in the use of higher temperatures for scalding to facilitate feather removal. At temperatures around 58ºC, the upper layer of the skin is removed during plucking. However, the absence of this layer causes discoloration and drying out of the skin and therefore carcasses treated in this way could not be marketed fresh, but were sold deep-frozen instead, because, in this condition, carcass appearance is less critical. In the years 1970–1999, European processors changed from deep-frozen products to those that were sold chilled. This change was accelerated by an increasing consumer demand for fresh products, and resulted in several important consequences for the processing industry.

Because chilled products need a lower scald temperature than those that are frozen, the arrangement of the plucking machines had to be changed and it became necessary in Europe to move away from water-immersion chilling. Although all the usual processes can be applied to fresh, chilled products, the use of immersion chilling (highly economical, but sometimes associated with a large water uptake), was replaced by air chilling and/or evaporative chilling. The resultant products also demanded a new packaging technology. From these changes, it is evident that aspects of water and energy usage have gained in importance. Also, product shelf-life is a key issue to processors and retailers alike, and governments have put an extra burden on the industry in relation to controlling human pathogens on poultry products. Human foodborne disease, and therefore product safety, have become major considerations. In the EU, this has resulted in the mandatory use of cleaning and disinfection procedures in processing plants, both during and after the processing period.

15.2   The influence of technology, inspection and carcass grading on product safety and quality

15.2.1   Technology

Modern poultry processing implies a high rate of throughput. Slaughter capacities of more than 6000 birds per hour are common, and can only be realised with highly mechanised and automated processing lines. Depending on the degrees of automation, the individual processing steps may or may not involve human labour. During processing, several stages are critical in controlling microbial contamination of products and equipment. These include catching, transporting and holding the birds before slaughter, and the conditions that obtain have a considerable influence on faecal contamination of the feathers and skin of the birds. Cleaning and disinfection of transport crates or containers after each journey is therefore necessary, and should be optimised in terms of the use of water, detergents, energy and labour.

The two most important quality attributes of poultry meat are appearance (colour) and texture. These are influenced by various technological procedures during processing. Colour is important for skin and meat, but colour of the bones is also significant in relation to quality. There are several pre-slaughter factors that can influence colour but, in the processing plant, the major factors are mainly in stunning, chilling and freezing. Bruising and haemorrhages, which can lead to condemnation of carcasses, are mainly caused by poor pre-slaughter handling and can be intensified by some processing procedures.

Meat tenderness has more to do with the maturity of the connective tissue and the completion of changes associated with *rigor mortis*. Both are influenced by live-bird handling procedures, while stunning (electrical or gas) and slaughter also play an important role. Electrical stunning delays *rigor* development and therefore techniques to accelerate *rigor* changes and improve meat quality, as with electrical stimulation, could overcome this effect. However, results obtained with electrical stimulation systems have not been consistent.

15.2.2   Purposes of poultry-meat inspection
Inspection comprises all the measures necessary to establish that live broilers and poultry products show no sign that the meat will be unsuitable for human consumption. All birds supplied to the plant are inspected, including those that are dead on arrival or have died before slaughter. The primary objective of the inspection protocol, as it relates to this chapter, is to facilitate interpretation of the findings and ensure uniformity of application for any action that is needed. More information can be found in EC Directive 71/118 (Anon, 1971).

15.2.3   Grading of carcasses
Process control in poultry-meat production needs objective criteria and methods for measuring both the growth performance of the birds and product quality. This is especially true for the visible defects that are so important for the overall quality and acceptability of a broiler flock. Some criteria relating to yield, functional properties of the meat and general carcass characteristics are relatively simple to measure, while, for others, no methods are yet available. The aspects involved in measurement are:

- how to measure, including technical details, sample size and technique of sampling
- what type of equipment is needed to carry out the measurement
- the environmental conditions needed to obtain optimum results
- how the data collected should be processed
- how the information should be used to improve the means of production and product quality.

It will be clear that the schedule cannot be followed completely in all cases. This is due partly to a lack of standard methods for quality assessment and partly to

continuing technological developments in the process that may change accepted criteria. Currently, special attention is being directed towards the development of on-line methods to control production capacity and product quality. It is expected that, for some quality criteria, on-line methods will be available in the near future.

Important measurements are: the number of birds received and their age; live weight and uniformity; those found dead on arrival; bird fasting status, condition of feathers and fatness; carcass and meat yield. The assessment of visible defects on the carcass skin should include any ammonia burns, litter spots, scabby hips and bruises on breast, legs and wings (Daniels *et al.*, 1992).

15.3   Managing the hygiene and quality of poultry meat

All systems used for the production of food from animals, including every aspect of live-bird production, collection and handling of eggs, and carcass processing, can be covered by the HACCP concept. Critical Control Points (CCPs) can be recognised at various stages of the production cycle. In this case, the HACCP approach involves a combination of factors in Good Hygienic Practices (GHP) and Good Manufacturing Practices (GMP). It includes the following steps:

- Conduct a hazard analysis to identify realistic hazards, which can be biological, chemical or physical. These are described in Chapter 1 of this book. It will be necessary to determine the severity of each hazard and the likely frequency of its occurrence.
- Determine the CCPs at which the hazard can be prevented or eliminated (CCP1), or minimised (CCP2). In practice, the two categories are not always distinguished from each other.
- Establish a system of control at each CCP, which involves identifying suitable criteria and setting critical limits for those criteria.
- Develop monitoring procedures to ensure that the CCP is functioning effectively. These must be easy to apply, rapid and reliable.
- Establish the corrective action to be taken when monitoring indicates that a particular CCP is no longer under control.
- Determine procedures for verifying that the HACCP system is working properly overall.
- Arrange documentation on all necessary procedures and keep records appropriate to the above principles and their application.

The implementation of quality assurance systems, including HACCP, can only be done effectively, when production is already carried out under codes for GHP or GMP.

Governments and industry in almost all developed countries have agreed to reduce foodborne human pathogens in products of animal origin and especially in poultry meat, eggs and egg products. These pathogen-reduction programmes include implementation of specific HACCP plans, standard operating

procedures for plant cleaning and disinfection and testing protocols for the major pathogens.

The feasibility of applying the HACCP concept in live-bird production is questionable. Recently, however, some examples have been published regarding HACCP plans for chicken and turkey meat production and plans are available for implementation on layer farms as well (Bord Bia, 1999). An example relating to broiler production and processing is given in Table 15.1. For poultry processing, the application of HACCP principles is more obviously feasible.

15.3.1   Implementation of HACCP systems on broiler farms and in processing plants

Live birds being sent off for slaughter carry large numbers of microorganisms on their feet, feathers and skin, and in their intestines. During the slaughter process, the birds are killed, bled, scalded and plucked, before the viscera are removed and the carcasses spray-washed and chilled. Then, the carcasses are either sent to the portioning department, used for further processing or they leave the processing plant as packaged, whole carcasses. Several stages are critical in controlling microbial contamination of products and/or equipment. Stress incurred by transportation and live-bird handling causes an increased shedding of pathogenic microorganisms, if present. The increased shedding may cause additional contamination of processed products and equipment. Effective cleaning and disinfection of the transport crates and containers is therefore necessary after each journey.

As mentioned earlier, modern poultry processing involves slaughter capacities of 6000 or more birds per hour and, depending on the degree of mechanisation and automation, several stages are critical to microbiological control. As well as conditions during catching, transport and holding of birds at the slaughterhouse, scalding, plucking, evisceration and chilling are considered critical processes in terms of the HACCP concept. However, technological improvements in the process may help to facilitate control of microbial contamination. There are already new developments in multi-stage scalding, plucking, evisceration technology and the automatic cleaning and disinfection of equipment, by which microbial contamination can be reduced. These developments pose the question of what limits should be accepted for the microbiological quality of carcasses at different CCPs? Some proposed limit values are shown in Table 15.2. Although the critical limits given here are just examples and others could be suggested for further parts of the supply chain, they highlight the difficulties inherent in monitoring and controlling the HACCP system. First, there is a need for suitable microbiological methods that are rapid and accurate enough to determine the organisms present within a short period of time. Then, there is the question of the availability of corrective measures that can be taken in the processing plant to adjust levels of product contamination. Third, it is not clear what can be done with products that harbour higher numbers of microorganisms than those within the set limits. Because of these limitations,

Table 15.1 Example of a HACCP plan for broiler farms and processing plants

Step	CCP	Hazard (source)	Preventive measure	Limits	Monitoring	Corrective action	Doc. ref
Chicks history, pre-lay	CCP 1	Disease carriers	Poultry from certified sources	EU Directive (Anon 1992)	Flock sourcing	Notify authority	Hatchery certificate
Feed and storage	CCP 2	Product contamination due to pathogens and medication misuse	Feed from certified sources and produced under certified conditions	EU Directive	Feed sampling	Reject source, alternative supply	Delivery document, storage record
Water and storage	CCP 2	Pathogens in potable water	Clean supply and protected storage	Local regulation	Water sampling	Upgrade water source, inform supplier	Test report
Catching and transport	CCP 2	Shedding of pathogens through stress	Application of feed and water withdrawal Cleaning and disinfection of transport vehicles	Criteria, see example Table 15.2	Testing for cleaning and disinfection, visible inspection	Cleaning and disinfection of equipment, instruction of farmers	Production chart
Scalding and plucking	CCP 2	Cross contamination during the process	Sufficient water supply, cleaning and disinfection	Criteria see example Table 15.2	Water and product sampling, testing for cleaning and disinfection	Instruction of management, cleaning and disinfection	Processing chart

Evisceration	CCP 2	Cross contamination through equipment and gut breakage	Cleaning and disinfection during processing	Criteria see example Table 15.2	Product sampling, testing for cleaning and disinfection	Instruction of management, cleaning and disinfection	Processing chart
Chilling	CCP 2	Cross contamination, (water and air-borne)	Sufficient water supply, cleaning and disinfection of evaporators	Criteria see example Table 15.2, EU Directive	Water and product sampling, testing for cleaning and disinfection	Instruction of management, cleaning and disinfection	Processing chart, records of water temperature and water usage
Cutting	CCP 2	Cross contamination, through equipment	Cleaning and disinfection of cutting equipment	Criteria, see example Table 15.2	Product sampling, testing for cleaning and disinfection	Instruction of management, cleaning and disinfection	Processing chart
Packaging	CCP 1	Contaminated packaging materials	Visual check, proper storage	EU Directive		Reject product, alternative supply	Processing chart.

Table 15.2   Examples of suggested critical limits for the microbiological quality of broiler skin

Stage	Enterobacteriaceae (cfu/cm^2)	*Salmonella* (%)	*Campylobacter* (%)
Live broilers	100–10 000	4–12	30–43
Carcasses after plucking	1–100	6–9	24–34
Oven-ready carcasses	100–1 000	7–9	37–41

use of the HACCP system should be supplemented by a quantitative risk analysis, which, again, involves a stepwise analysis of hazards, but gives an estimation of the probability of occurrence of adverse effects on human health from consuming the product. Such an analysis can also provide an indication of the benefits that are likely to arise from specific hygiene intervention measures, such as carcass decontamination treatments, where permitted.

15.3.2   HACCP systems in practice

The new HIMP, introduced by the USDA in 2000, includes performance standards for food-safety and non-food-safety aspects, as shown in Table 15.3. These cover certain disease conditions and the presence of faecal material, for which the tolerance levels are zero. Thus, while visible faecal contamination is unacceptable, the presence of non-faecal ingesta is permitted for 18.6% of carcasses. Integrated quality control systems (IQCS) and hygiene codes for broiler meat and egg production were introduced in The Netherlands in the early 1990s (Daniels, 1989). Goals of both type of project were to develop an integrated system for the whole poultry supply chain. Controlling the entire production chain (starting at the level of the grower and continuing through the processing operation), aims to guarantee the quality of the final product. By doing this, the whole process can be effectively managed and optimised. Data collection and registration accompany upstream and downstream communication to satisfy consumer demands regarding product safety and quality. The relevant processes have been certified and standards are now set for production of both poultry meat (including turkeys) and eggs. IQCS include hygiene standards of which HACCP plans and *Salmonella* and *Campylobacter* control programmes are an important part. Although participation in the system is on a voluntary basis, the programme has attracted almost all existing companies as participants. These all agree on the application of the strict rules set by the system, which is also based on European legislation regarding prevention of foodborne zoonoses in animal production as a whole.

An overview of international standards to be applied in the management and control of food safety and quality in the poultry supply-chain is presented in Table 15.4. Included here are requirements for tracing and tracking products in the chain. Traceability is the potential to determine the location or origin of a

Table 15.3 HIMP performance standards for young chickens (USDA, 2000)

Category		Types	Example Performance Standards (%)
FS*-1	Condition (infectious)	Septicaemia, toxaemia	Zero
FS-2	Contamination (digestive content)	Faecal material	Zero
OCP*-1	Condition (animal diseases)	Airsacculitis, arthritis, ascites, avian leucosis complex, avian tuberculosis, cadaver, enteritis, erysipelas, inflammatory process, nephritis, osteomyelitis, pericarditis, pneumonia, salpingitis, tenosynovitis	1.7
OCP-2	Condition (miscellaneous)	Breast blisters, bruises, fractures, localised inflammatory processes, mutilation, over-scalding, scabs, sores	52.5
OCP-3	Contamination (digestive content)	Ingesta	18.6
OCP-4	Dressing defects (other)	Extraneous material: bile, feathers, lungs, oil gland, trachea	80.0
OCP-5	Dressing defects (digestive tract)	Bursa of fabricius, cloaca, crop, intestines, oesophagus	20.8

* FS: Food Safety Standard; OCP: Other Consumer Protection Standard

Table 15.4 International standards for the management of food quality (Verdenius and Beumer, 2003)

Terminology	Agro-Food International Standards
ISO 8402	HACCP
S88/S95	EurepGap
	Global Food Safety Initiative
Quality Management	International Food Standard
ISO 9000	Safe Quality Food
ISO 14000	British Retail Consortium
Specific Standards for Traceability (in preparation)	
Codex Alimentarius	
ISO (TC 34)	

product at any point in the production, processing or distribution stages. On the basis of data provided by regular control systems, products can be traced both upstream and downstream. Tracking, on the other hand, is the 'real-time' assessment of a product, whether it has been processed, will be processed, or is undergoing processing. It also has two directions, one from consumer to producer, for example, to discover the source of a problem, or from producer to consumer, for example to enable recall of a product with a certain defect. Several Dutch companies have installed food safety and quality control systems that include aspects of traceability in their day-to-day production activities. Some examples are:

- *Nutreco-'NU Trace'.* Monitoring is carried out from the start of production through to the final, consumer-ready product. Risk management, the potential to act rapidly and adequately in acute crises on the basis of well-described, transparent protocols, is the key to this approach. An advanced tracing and tracking system, which makes it possible to determine the origins of both animals and feed, is the most important tool available. Quality criteria in this system include all aspects of food safety and quality based on the demands of European retail organisations and, therefore, consumers.
- *Plukon Poultry-De Kuikenaer.* De Kuikenaer is a poultry suppply-chain organisation, to which the information system Poultrace is connected. Quality control is achieved through a well-described Safe Quality Food Poultrace system, from breeding farms to retail level. The use of a product code is the most important tool, in this case.
- *NIVE Egg Products* apply an 'EGG TraceBase' approach in which traceability throughout the whole egg production and processing chain is guaranteed.

15.4   Future trends

15.4.1   Production

As a result of recent crises in the European food animal industry, which started to become a real problem after the dioxin incident was followed by Bovine Spongiform Encephalopathy, Foot and Mouth Disease and Avian Influenza, consumers show increasing concern about the production methods used for food animals. Now, 'high-yield farming' seems to be unacceptable to the general public, which has almost complete antipathy to modern farming practices. This is despite the fact that, within limits, the present system guarantees a range of nutritious, safe food products at an acceptable price. Inevitably, public opinion today will lead to a more 'organic' approach to farming, with fewer animals per unit, a ban on the use of any growth-promoting antibiotics, wider use of organic acids, pre- and probiotics, improvements in feed quality, etc. The present controversy over organic versus high-yield farming has already led to an EU Directive in which minimum production standards for organic farming are described.

A positive outcome from this new trend could be the restoration of consumer confidence in foods of animal origin. However, the more negative aspects of high-yield systems tend to obscure the positive benefits that already exist from intensive animal production. These include the limited use of land, low mortality among the animals and relatively low prices, especially for poultry products. It is to be expected that a more organic approach or merely free-range farming, will lead to higher product prices. This will occur because more land is needed for rearing purposes and, under present circumstances, about 25% more feed. Some studies suggest that organic farming will lead to a 50% rise in the use of veterinary medicines, 33% more eggs contaminated with salmonellas and several times the current usage of anti-worm preparations. Since few proper trials have been carried out to compare high-yield and organic farming practices, there is little data on the presence of pathogenic microorganisms, the incidence of different diseases, the need for antibiotic therapy, the concentrations of drug residues in the end-product, etc. Nevertheless, quality control systems and pathogen reduction plans, including the use of HACCP principles and risk assessment strategies, which are already implemented in high-yield farming, may contribute in the future to making organic products as safe as possible.

15.4.2   Processing

It is expected that the process will be increasingly automated. Automatic systems for hanging birds on the processing line will become available and equipment will be developed to optimise removal of intestines from the carcasses and avoid breakage. To facilitate monitoring and control of food safety and quality parameters during processing, several tools are available or will be developed. Increasingly, process optimisation and quality management are taking advantage of modern information technology. At the processing level,

so-called integrated logistic solutions are available, which, in practice, provide optimal control of the processes involved, the vertical and horizontal integration of processing equipment and other control and information systems. The non-destructive assessment of meat quality, which currently focuses on the prediction of tenderness, is one of the new tools to be applied in quality management. Quality grading systems will be camera-based and logistic control will be implemented throughout the process. This approach will guarantee adequate management of all aspects of food hygiene, safety and shelf-life, as well as ensuring animal welfare and control of product characteristics, such as tenderness.

15.5   Sources of further information

ANON (1997), *Microbial Control in the Meat Industry,* EU Concerted Action CT 94-1456, Series Editors: Hinton M H, Mead G C and Rowlings C, Bristol, University of Bristol Press.

BROWN M, ed (2000), *HACCP in the Meat Industry*, Cambridge, Woodhead Publishing.

PEARSON A M and DUTSON T R eds (1995), *HACCP in Meat, Poultry and Fish Processing,* Advances in Meat Research, Vol 10, London, Blackie Academic & Professional.

15.6   References

ANON (1971), 'Council Directive 71/118/EEC of 15 February 1971 on health problems affecting the trade in fresh poultry meat', *Official Journal*, L55, 08/03/1971, pp 23–39.

ANON (1992), 'Council Directive 92/117/EEC of 17 December 1992 concerning measures for protection against specified zoonoses and specified zoonotic agents in animals and products of animal origin in order to prevent outbreaks of food-borne disease infections and intoxications', *Official Journal,* L62, 15/03/1993, pp 38–48.

ANON (1993), 'Council Directive 93/43/EEC of 14 June 1993 on the hygiene of foodstuffs' *Official Journal*, L175, 19/07/1993, pp 1–11.

BORD BIA (1999), *Egg Quality Assurance Scheme*, Technical manual, Dublin, Ireland, Bord Bia.

DANIELS H P (1989), *Integrale Kwaliteitsbeheersing Slachtpluimvee*, Zeist, The Netherlands, Commodity Board of Poultry and Eggs.

DANIELS H P, FRIS C, OOSTENBACH P J G, VEERKAMP C H, DE VRIES A W AND WIJNKER P (1992), *Standard Methods for Classification of Broiler Carcasses*, Zeist, The Netherlands, Commodity Board of Poultry and Eggs.

ICSMF (1988), *Microorganisms in Foods 4. Application of the Hazard Analysis Critical Control Point (HACCP) System to Ensure Microbiological Safety and Quality*, London, Blackwell Scientific, pp 66–116.

USDA (2000), 'Performance standards of HACCP-based inspection models project', Washington DC, *FSIS News Release,* November 3.

VERDENIUS F AND BEUMER H (2003), 'Traceerbaarheid: eisen en standaarden', *Voedingsmiddelentechnologie,* 6 June, 19–22.

16

Treatment and disposal of poultry processing waste

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16.1 Introduction

Poultry processing plants vary both in their capacity and the type of bird that can be processed. The larger plants process broiler chickens at a rate of over 10 000 per hour, which can amount to well over one million birds per week. The smallest plants are equipped for only a few batches of birds each week and may be run solely for a particular seasonal market, such as Christmas turkeys. These small plants, which are often farm-based, may process more than one species and often provide products for niche markets, such as the organic sector, products from extensively reared birds or from unusual species, such as guinea fowl. The larger plants for chickens and turkeys are capital intensive, with a considerable degree of mechanisation, including that for handling waste. Small, on-farm types of plant invariably rely upon manual labour and have only a small amount of powered equipment for any purpose. The flexibility that manual labour allows can enable a plant to process several species for seasonal markets and still be cost effective. It is obvious that the dedicated, larger plants will handle processing waste in a more systematic manner than smaller plants.

16.2 Types of material for disposal and the environmental pollution hazards from processing plants

Where possible, any unwanted material should be considered as a potential by-product rather than a waste without value. This applies to feathers, blood, fat or carcass tissues. Profit margins are small and, if there is a way of selling a

by-product, rather than paying for its disposal, this is clearly worth exploring. Most large processing plants invest in mechanised systems to handle material for disposal and are equipped to keep the different waste streams separate, thereby facilitating collection of by-products. Small plants will have difficulty in obtaining sufficient amounts of material to make selling worthwhile and often they rely upon manual scraping of the floor at the end of the day, which may lead to considerable mixing of waste materials that would be difficult to treat separately.

If a by-product can be sold, this will influence the type of handling system used. Examples are feathers to be used for pillows, and hens' feet and heads, which, if collected hygienically, can be exported to regions such as West Africa. Like the rest of the poultry industry, the by-product business is volatile, possibly even more so, and plant operators should consider how to handle by-products as waste, in case an existing market collapses. Also, possible opportunities for turning waste materials into by-products should be under constant review. The main types of waste and by-products from a poultry processing plant are set out in Table 16.1. Renderers that collect both solid wastes and blood often use transport vehicles designed to keep blood, feathers and other materials separate. This ensures that they can either process the material as a by-product or use the most appropriate treatment and disposal method for each individual waste.

An over-riding aspect of the handling of poultry processing waste is the large amount of water used for washing equipment and carcasses, or as a medium for transporting by-products. Live-bird transport crates are pre-soaked and then spray washed to remove the faecal matter present. Plucked feathers are transported by flume, as are harvested giblets. Where water is used to transport waste, it may be re-used but, particularly in the later stages of processing, it becomes a major component of the waste stream itself, when its main use is to wash carcasses and processing equipment, and sometimes to chill carcasses, and

Table 16.1   Types of by-products produced at different stages of poultry processing (Adapted from Nielsen, 1989)

Processing stage	Type of waste or by-product
Lairage and hang-on	Manure, feathers, cleaning water, dead-on-arrivals
Slaughter	Blood (by-product), blood/grease, cleaning water
Scalding and plucking	Feathers (by-product), dilute blood and grease, cleaning water
Initial dressing	Heads, necks, feet (by-products), cleaning water
Evisceration	Viscera (including harvested by-products), blood, grease, flesh debris, manure, cleaning water
Chilling	Wet chilling – grease, blood, flesh debris, and water. Air chilling – cleaning water (including that sprayed onto carcasses)
Inspection, grading, portioning and packaging	Carcasses and organs not fit for human consumption, cleaning water, packaging waste

consequently cannot be re-used. At the end of the day's processing, there is always a major release of heavily contaminated water, as scald tanks, water chillers and waste-transport systems are emptied. Finally, there is the plant wash-water, which, like that from crate washing, is contaminated with cleaning agents from plant cleansing.

As public perceptions of environmental issues continue to evolve, the acceptability and costs of pollution from livestock production and associated industries, such as poultry processing, are coming under increasing scrutiny. For example, in the UK, it has been estimated that the total environmental cost of agriculture amounted (in 1996) to at least £1.5 billion per year (Pretty *et al.,* 2000). This estimate identifies air pollution as the major component, accounting for over 47% of the total. In turn, the air pollution costs are dominated by greenhouse gas emissions, particularly methane and nitrous oxide. It is also estimated that almost 10% of the total annual costs are incurred as a result of agricultural pollution of watercourses and groundwater, including water supplies.

16.2.1   Water

The most important polluting agents in poultry processing effluents are excessive concentrations of:

- nitrate ions
- phosphate ions
- potassium ions
- organic matter (especially that with a high biochemical oxygen demand (BOD))
- microbial pathogens.

In general, the threshold of acceptability will depend on the subsequent use or fate of the water (Barnden, 1984), although, as general levels of public concern increase, limits of acceptability are likely to become more stringent; examples include the EU Nitrate and Bathing Water Directives.

The water pollution risks directly associated with processing operations include: chronic and acute leakages from tanks, drains and other systems; incomplete treatment of effluent prior to permitted discharge to a water course and uncontrolled, contaminated run-off from roofs and yard areas. However, these are not the only important aspects of water pollution associated with processing operations; it is also important to adopt a responsible approach towards the subsequent management of waste material that is removed from the premises by a waste contractor. In many countries, responsibility for any pollution subsequently caused by these materials is shared by all individuals or organisations involved in the production, handling and disposal or utilisation of the wastes. This means that operators of poultry processing plants must be aware of the possible impact of their wastes, even when these have been removed by contractors.

16.2.2   Air

Odours are often the main cause of complaint from poultry processing operations, although emissions of ammonia (for example, from any accumulated waste materials) and greenhouse gases, such as methane and nitrous oxide (for example, from poorly designed or managed waste treatment plants), also merit attention. However, whereas water pollution is usually a real hazard to aquatic life, odours are more often a nuisance than a hazard. Processing odours are usually caused by low concentrations of volatile organic chemicals, such as acetic acid, mercaptans, indole and skatole. These substances arise from a variety of sources, including live-bird reception and shackling areas, scald tanks, plucking systems and from waste collection and handling operations.

Odours may often be associated with aerosols, and research has shown that the relationship between aerosols and odour is complex. Although the minimisation and/or filtration of aerosols can help to reduce odour problems, these measures alone will not guarantee odour removal, although some reduction in odour intensity is usually possible (Williams, 1984). In some cases, odour nuisance can be reduced by careful planning and management, without the need for expensive technology. For example, planting trees around potential odour sources can diffuse airflows and thus reduce the intensity of odours leaving the site. The trees may also have an aesthetic benefit. If odour emissions are associated with particular operations, such as waste collection or transfer, it is best to avoid such activities at times when complaints are most likely to arise. In some situations, atmospheric pollution from livestock can be more serious than simply causing an odour nuisance. For example, in The Netherlands, where the population density of intensively reared livestock is very high, there is evidence that the ammonia given off by livestock wastes contributes significantly to the problem of acid rain (Voorburg, 1985). This occurs because ammonia can be oxidised in the atmosphere to produce nitrogen oxides, NO and NO_2, for example, which are acidic when dissolved in water.

16.2.3   Soil

Generally, the term 'soil pollution' refers to any accumulation of a material up to a concentration that causes a detrimental change in the soil environment. For example, high concentrations of potassium can prevent some crops, for example, vegetables and grass, from taking up other important elements, particularly magnesium. This effect may influence not only the health of the crop, but also, in the case of grass, that of grazing animals. Soil pollution differs in one very important respect from pollution associated with air and water: it is largely confined to the locality in which it occurs, that is, it is non-mobile. Therefore, any pollution of soil becomes an immediate concern to those responsible for the land, especially when such pollution is detected by the appropriate environmental authorities, who may then compel certain action to be taken to remove the hazard. This is a particular issue at poultry-processing sites, where remedial action can be very expensive, due to the inherent cost of cleaning

contaminated land and any periods of associated plant closure. The concept of shared responsibility for any pollution arising from exported wastes is also highly relevant to soil pollution. Unlike water and air pollution, which are somewhat ephemeral, the long-term and possibly cumulative nature of soil pollution means that responsibilities and potential liabilities can remain long after specific action has ceased in connection with managing a particular polluting waste.

Application of biological wastes to agricultural land is a good example of an operation that requires careful monitoring and management to avoid long-term soil pollution. For instance, excessive application can pollute soils, not only with organic material, but also with potassium, phosphorus and heavy metals. All of these latter materials can be bound firmly by top soils and are thus resistant to leaching. In addition, there are the risks associated with various pathogens in soil that result from the spreading of wastes. Under some circumstances, these may affect crops or livestock produced subsequently on the land. Concerns over these issues are expected to lead to greater restrictions on land-spreading, with consequent impact on waste producers, such as poultry processors.

16.3   Waste management obligations and key features of current legislation

16.3.1   Water pollution

All processing plant operators face a legal obligation to avoid water pollution. For example, it is an offence in the UK to cause or knowingly permit a discharge of poisonous, noxious or polluting matter or solid waste into any controlled waters, without the proper authority. Controlled waters include groundwater and all coastal or inland waters (including lakes, ponds, rivers, streams, canals and ditches). Proper authority is usually a 'consent to discharge' in the case of the UK Environment Agency. Diffuse-source pollution of water (for example, by leaching through the soil, following land application) can also lead to penalties.

16.3.2   Air pollution

Legislation on odour nuisance in the UK is enforced by the environmental health departments of local authorities. These have a responsibility to detect any 'statutory nuisances' and to investigate complaints. The main, relevant features of a statutory nuisance in connection with poultry processing operations are:

- the premises, and/or emissions of smoke, dust, steam, smell or other effluents that are prejudicial to health or cause a nuisance;
- animals kept in a place or manner so as to be prejudicial to health or be a nuisance.

Where it is shown that a statutory nuisance exists, an abatement notice can be issued requiring action to abate the nuisance or prohibit or restrict the processes

that cause the problem. In response, it may be an effective defence for processing plant operators to show that 'best practicable means' have been adopted. Best practicable means are defined with regard to local conditions and circumstances, current state of knowledge and financial implications. Similar principles apply to 'best available techniques' in connection with international legislation.

Planning laws also include provisions relating to the avoidance of nuisances and, therefore, the construction of new poultry processing units or the extension of existing ones will be subject to particular scrutiny, sometimes requiring a detailed Environmental Impact Assessment.

16.3.3   Soil pollution

The current trend in many Member States of the European Union is to integrate laws and regulations concerning waste disposal and various forms of pollution control. This has the benefit of providing an improved framework for harmonising pollution control measures and also helps to highlight situations where requirements to solve one problem may impinge adversely on another aspect of environmental protection. For example, the EU Landfill Directive means, essentially, that more solid organic waste will need to be disposed of via alternative routes including land spreading, although this, too, will be regulated closely.

16.4   Sources of pollution in the broiler industry

The main waste streams from the broiler industry that can give rise to environmental concerns are set out in Fig. 16.1. Most of these relate to waste management, but there are also environmental concerns relating to the general operation of poultry farms and processing factories. Emissions from farm buildings (item 1 in Fig. 16.1) include a range of gases, dusts and odours, but it is ammonia that has received the greatest attention, with many detailed studies. In a review, Groot-Koerkamp (1994) concentrated on abatement via better management of the manure within the house (for example, drying, frequent removal and avoiding high temperatures), and some of these practices may be applicable to processing plants. Avoiding ammonia at source is particularly important, as it governs conditions within the building (item 2 in Fig. 16.1) that affect both birds and staff. Wathes (1998) discusses the importance of adequate ventilation as part of a management package to both keep ammonia concentrations in the building within acceptable limits (for example, 25 ppm for an eight-hour exposure) and to tackle the equally important problems of dust levels and the endotoxins contained therein. This, though, moves the problem outside, highlighting a common theme in environmental control: 'solving one problem can cause another'.

The manure itself (item 3 in Fig. 16.1) is an expected environmental hazard from broiler production, but one which can often be minimised by good land-
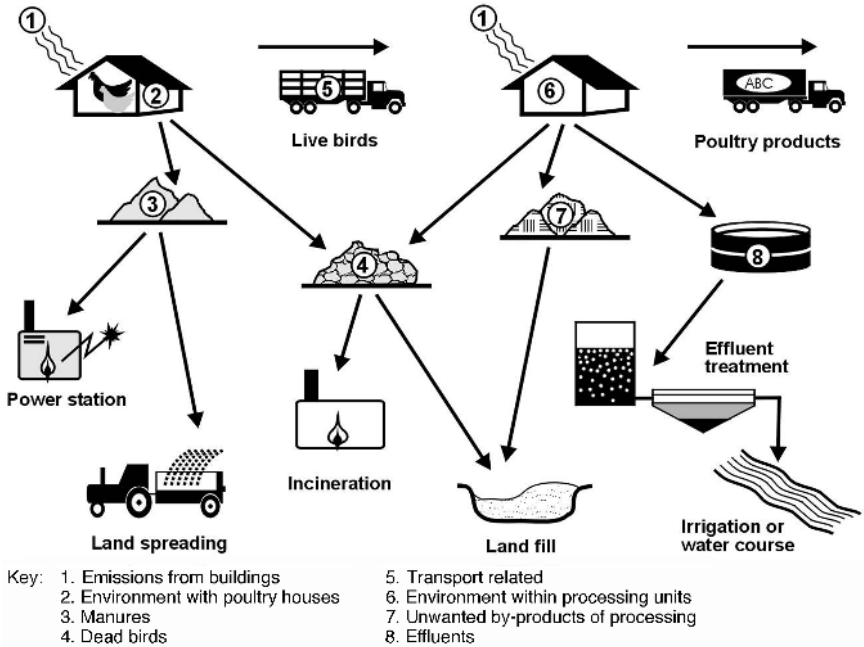
Fig. 16.1   The principal waste streams from the broiler industry, showing the most likely causes of environmental impact.

spreading practice, as specified in available codes of practice (for example, Ministry of Agriculture, Fisheries and Food 1998a, 1998b). However, a shortage of local land to receive the manure and to utilise it in crop-growing can lead to serious problems, with a real risk of water pollution from excess nitrogen and especially from phosphorus (Sharpley, 1999). The disposal of fallen stock and reject birds from processing operations (item 4 in Fig. 16.1) presents a particular problem, because of the disease risk. Transportation (item 5 in Fig. 16.1) should also be included in any environmental audit to allow for engine emissions. Within processing units (item 6 in Fig. 16.1), hygiene and cross-contamination issues are of special importance, as they impinge on product quality (Mead *et al.*, 2000). However, a greater use of water, to improve general hygiene, will, in turn, increase the volume of effluent generated (item 8 in Fig. 16.1). This also presents a range of environmental hazards, especially if the intended route of disposal is to a water course.

16.4.1   Microbial contamination of processing wastes
All organic wastes must be regarded as being contaminated with pathogenic microbes, unless satisfactorily treated. The major pathogens are associated with the gut and gut contents, are practically everywhere in the processing plant and include *Salmonella* and *Campylobacter* spp. At the hang-on stage, they are

present in the faecal material and also in the scald tank water, which, at a typical operating temperature of 50–55ºC, is insufficient to eliminate these organisms. In the pluckers, many microorganisms are carried away with the feathers, but, at later stages, they will be on the viscera and other by-products removed from the carcasses. Although modern eviscerating machines are much improved, some intestines will be ruptured and the contents will cross-contaminate the cleaning water, as well as the machines and following carcasses.

When poultry processing wastes enter the wider environment (for example, for utilisation or disposal), concerns arise, not only from environmental perspectives, but also from that of maintaining public safety. For example, there are potential risks to humans from exposure to livestock pathogens, not only via the food chain, but also through direct or indirect contact with the environment, animals and animal wastes. The main risks arise from a range of zoonotic microorganisms, including: *Salmonella, Campylobacter* and *Listeria monocytogenes.* These can be transferred via almost all forms of processing waste. Hence, the likely sources of pathogens that infect people include land application of wastes (using slurry and solid-manure spreaders, for example), transport of waste material, run-off from soil and grazing livestock. Contamination of food is a major concern, but people may also become infected through farming and recreational activities.

At the larger plants, feathers from the plucking area are transported by flume and can be available as a by-product. A major problem with feathers collected in this way is that they retain a considerable amount of water, which increases transport costs and makes storage and disposal both unpleasant and difficult. An improvement is to use a feather press, a machine that compresses the feather waste to a small volume and removes most of the water present.

16.5   Utilisation of water in processing and cleaning

Water is the main medium by which feathers, faecal deposits and microorganisms are removed from carcasses and processing equipment. Also, fats, body-tissue debris and partially digested food will be transported by wash and flume water, and only particles that are large enough will be collected as screenings for disposal with other, solid wastes. For some operations, the water will also act as a lubricant between machine components and carcasses. Once processing has stopped for the day, plant walls, floors and equipment will be thoroughly pressure-washed, chemical sanitisers will be applied and, after sufficient time, they will be rinsed down before processing resumes. Again, large quantities of water are involved and, invariably, this is for single use, going straight to the drains. The crate-washer, water-bath stunner, scald tank and water chiller (if used) all have fixed-volume tanks that are constantly topped up with fresh water during the operating period and drained at the end, before rinsing to remove deposits of organic material. Some of the transport flumes that are not in contact with carcasses or other edible parts use recycled water.

Water from the mains or a bore-hole is used in most stages of poultry processing and must be of potable quality in the EU. This currently applies not only to all direct applications to the carcass (for example, washing after evisceration and spraying in the air-chilling operation), but also to many indirect applications that could affect the product, such as the washing of meat trays. However, supply and disposal costs of water are appreciable and processing-plant operators will endeavour to minimise water use, without impacting on hygiene standards for the plant or product. Wash-water, with care, can be re-used for certain purposes. The soak-water in the crate-washer uses water from the sprayer in the crate-wash system, and the flume-water for transporting feathers can be recycled continuously, with a steady top-up coming from potable water fed into the plucking machinery. Water used for washing carcasses, processing equipment and the plant is difficult to re-use, other than occasionally in flumes to transport wastes.

16.5.1   Typical pollution loads

Poultry litter on farms typically contains about 40% water, 3% nitrogen, 2.5% phosphate (P_2O_5) and 1.8% potash (K_2O): this represents material of significant value as a fertiliser and it is not surprising that, in most cases, it is applied to the land. A small amount of this material remains on the surfaces of the transport crates used. This, along with any faeces from the birds, will end up in the wash water used for cleaning the transport crates. However, a large degree of dilution can be expected and it would be unusual for the final wash-water sent for treatment to exceed 1% (10 g/litre) in dry matter. For the general wash-down water, the effluent produced would be even more dilute, probably below 1 g/litre, but this would depend on the part of the plant being cleaned. There would be some entrained fat in the wash-down water, but most of the organic matter would be from blood, which will easily account for over 90% of the total BOD_5 load going to the treatment works. In larger processing plants, blood will be collected separately and sent to the renderer. Solid wastes from the factory comprise mainly feather waste, offal and unwanted parts of the carcass.

16.6   Waste treatment strategies and techniques: primary, secondary and tertiary processes

Few effluent treatment processes can be completed in a single stage. More often, and especially when there are demanding targets, two or more stages in sequence are required, with recycling streams used to optimise the process. Effluent treatment plants discharging to a watercourse would be one example, but, even where land disposal is intended, multi-stage processes may prove to be more effective. As such, it is useful to separate the operation into three distinct phases. The *primary process* usually refers to the first treatment stage, which is typically some form of separation of the undissolved solids that may involve

mechanical screening or sedimentation. Dissolved organic matter is most effectively removed by a biological process (either aerobic or anaerobic), and this is often referred to as a *secondary process*. The same term would apply to any subsequent sedimentation, such as that used in the activated-sludge process. If a very low concentration of organic matter is required in the treated effluent, a final step (or steps) would be provided by a *tertiary treatment* (also known as 'polishing').

16.6.1   Primary processes
Process intensification
Many treatment systems used in agriculture and related industries are necessarily low-intensity, low-cost processes. The implication here is a long treatment time, with the benefit of lower running costs, but with very large volumes of waste retained in the system. Whilst this is not a particular problem for livestock farms (land being available), faster treatment is often desirable for red-meat abattoirs, poultry processing plants and food factories. Accelerating the various stages of treatment can often be achieved, but with the penalty of a higher cost. Better treatment may come as a further benefit in some cases. For example, physical separation can be accelerated by the use of a centrifuge, which has the additional advantage of producing a concentrated sludge, with a dry matter content of up to 30%. Intensive aeration can shorten treatment time from weeks to 3–4 days, but at the cost of a poorer aeration efficiency, which can more than double the energy cost of supplying the oxygen. However, the heat of reaction generated over a shorter period of time then allows for a higher temperature, even up to the thermophilic range (over 50ºC), with the additional benefit of enhanced pathogen reduction. Thus, it is often important to consider the whole of the waste treatment system for a particular plant (that is, integrated waste management).

Removal of particulate and other material
Mechanical screening.   Screening is a simple way of removing the coarse matter (particle size of 5 mm diameter or more) from an effluent and thereby greatly improving its ease of handling, as well as reducing the organic load. If large quantities of fibrous matter are present, then the separated material may be suitable for subsequent composting processes. In this case, it is important to ensure a high solids concentration in the separated fibre (25% or more), which leads to the selection of more elaborate equipment, such as screw presses or belt presses, rather than simple sieve-like, inclined screens. However, if the main purpose of the operation is the removal of relatively small quantities of coarse matter (to protect the equipment, for example) then simple screens will suffice. These have the advantage of higher throughput, but yield a wetter fibre.

Separation and clarification.   Improved separation of solids from waste-water effluent is based on settlement. This can be by natural gravitation or enhanced
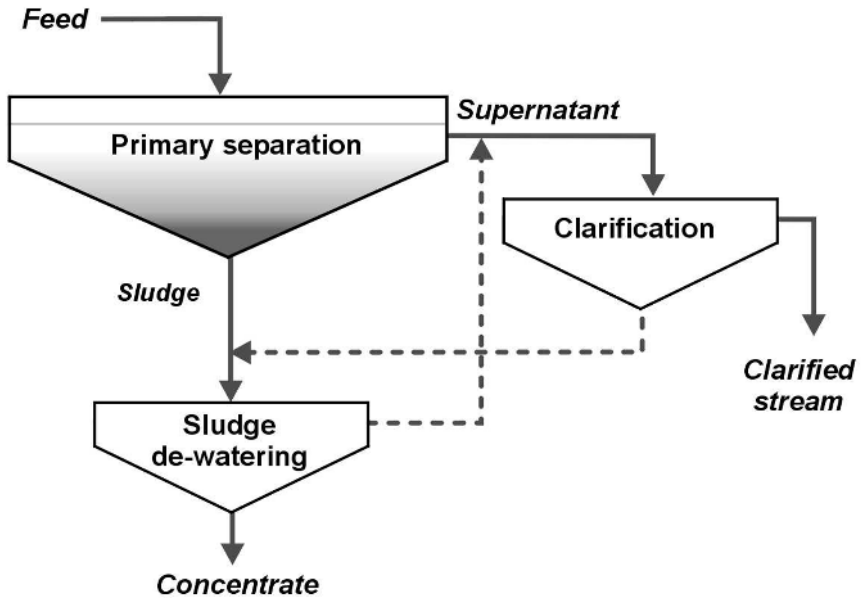
Fig. 16.2   Principles for the separation of suspended matter from a liquid phase. A single process is rarely sufficient to achieve both a concentrated sludge and a clarified effluent; additional stages with recycling are usually necessary, if both objectives are important.

by the use of flocculants, centrifuges or hydro-cyclones. In any case, it should be noted that *it is difficult to achieve both a concentrated sludge and a well-clarified supernatant in one treatment step*. The general scheme for effective treatment is set out in Fig. 16.2, which indicates the importance (and benefit) of multi-stage processing; in this case, a centrifuge would be better for achieving the dewatering step after the initial sedimentation.

Gravity settling works best with dilute effluents (for example, total solids concentrations below $25 \, kg/m^3$), otherwise large volumes of sludge are produced (Martinez *et al*., 1995). Centrifugation can produce concentrated sludges and also a high degree of clarification, but the equipment is expensive and throughput modest. In either case, separation is more complete than with simple screening, because finer particles are included in the separated sludge layer. Whereas the screens and screw presses only make a significant difference to the coarse solids (the press leading to less water in the separated solids), a decanter centrifuge also removes some organic nitrogen and phosphorus that is present in the finest particles.

Dissolved air flotation (DAF) and flocculation.   For dilute effluents, chemicals are commonly used to enhance separation. For settling processes, it has long been the practice to de-stabilise colloidal matter by adding a strongly ionising substance, to provide, for example, ferric or aluminium ions that will induce flocculation and therefore settlement. The DAF process uses a flocculant and a

small stream of air, which is bubbled through the effluent, leading to the removal of suspended matter as a foam rather than a settled sludge. The foam is then allowed to settle further in a separate vessel to form a sludge, the supernatant being recycled back to the feed effluent. This process is less suitable where there is a large amount of dense fines within the effluent: in such a case, a preliminary sedimentation stage would be necessary. In treatments involving electro-flotation, the effluent is passed through an electrolytic cell with iron and aluminium electrodes. The combination of a charged field and the generation of aluminium and ferric ions induce flocculation; the treated effluent is then pumped to a flotation tower, where separation takes place. The electro-flotation unit itself enhances flocculation and may also remove some of the dissolved matter by precipitation. However, this process is not suitable for treating concentrated waste-water (over $10 \, kg/m^3$ total solids), due to fouling and blockage problems.

16.6.2   Secondary biological treatment systems and associated factors

Mesophilic and thermophilic aerobic treatments: the oxidation process

Adequate aeration involves dissolving enough oxygen in the effluent in order to replace an anaerobic system (chemically reducing) with an aerobic environment for the appropriate microbial activity. As a result, organic matter, characterised by BOD_5, is rapidly oxidised to relatively harmless products, such as carbon dioxide and water. Removal of this material also takes away the main cause of the offensive odours associated with organic effluents, and many of the anaerobic pathogens are destroyed. As a rule, the removal of one kg of BOD_5 requires one kg of dissolved oxygen. Heat is produced as the process proceeds, which will raise the temperature of the aerated liquid. If the biological load is high – a BOD_5 concentration over 20 000 ppm, as would occur with wastes containing blood – a temperature rise of 20ºC or more is easily possible, taking the process into the thermophilic range of operation (over 50ºC). Under certain conditions (for example, treatment times of three or more days and a dissolved oxygen concentration above 1% of saturation level), nitrification of ammonia to nitrites and/or nitrates can occur. Gaseous nitrogen may be released in the subsequent de-nitrification process, although the pollutant gas, nitrous oxide (N_2O) can also be produced as an unwanted by-product (Burton *et al*., 1993).

Aerobic treatment

Continuous aerobic treatment is nutrient-limited and, therefore, within limits, is independent of both temperature and aeration level. In the case of temperature, the process should be kept within the mesophilic range (15 to 45ºC). At higher temperatures, thermophilic activity takes over, sometimes leading to poorer performance (Burton and Farrent, 1995). Unless nitrification is desired, the aeration level (indicated by the concentration of dissolved oxygen or the redox potential) is not critical, provided that enough oxygen is supplied to meet the demand. For all but the most dilute effluents, this still implies large volumes of

air, based on the anticipated reduction of the organic load, expressed as COD. Short treatments (residence times of less than three days) have the additional problem of requiring a high *intensity* of aeration, that is, the hourly oxygen requirement per unit volume; this tends to rule out the more efficient, but gentler bubble-type, diffuser aerators.

Aeration systems are commonplace at sewage treatment works, and some experimental units are also being used to treat stronger effluents, such as farm-livestock slurries. Trials with this system, using pig slurry, revealed degradation of 93% of the ammoniacal nitrogen, 67% of the Kjeldahl nitrogen, 43% of the COD content but only 8% of the total dry matter present (Burton and Farrent, 1998). The implication is that aeration only removes the *reactive* part of the organic matter, leaving much of the relatively inert material (including the suspended matter) unaffected.

Batch aeration is straightforward and sometimes preferred for dealing with small effluent volumes. It is also relatively cheap to install in existing storage tanks or lagoons. However, it can result in control problems and foaming, due to the variable load, and the treatment tends to be inconsistent. A compromise might be sequential batch processing (Lo *et al.,* 1990), which can also incorporate a settling stage.

Mesophilic and thermophilic anaerobic digestion and energy recovery
In the absence of oxygen, microbial activity changes to an anaerobic process. The process is slower, but reactive organic matter is again broken down, thus leading to a reduction in the BOD_5 value, while biogas (methane) can be produced as a bonus. In the simplest form of an anaerobic lagoon system, biogas is not collected and the main benefit is a reduction in the organic load plus removal of some phosphate, along with other insoluble matter, if settlement is encouraged. However, even if unwanted, the free emission of methane is generally unacceptable and some means of gas collection and burning is needed. Usually, however, the gas is a valued by-product, and the design of digesters to maximise yield is important. This involves agitation and the maintenance of temperatures in the range 30–40ºC. The performance of digesters varies widely, reflecting the feed material as much as the design, but the example described by Montuelle *et al.* (1992) summarises the main features; reductions in BOD_5 and COD were reported to be 84 and 58%, respectively. No real effect was reported on the nitrogen (including ammonia) and phosphorus components, as might be expected, since there was no obvious means of removal. Anaerobic digestion can have the benefit of odour abatement, in that many of the organic chemicals linked to offensive odours are degraded. Furthermore, some of the pathogens that are likely to be present can be destroyed in the digester environment, but the reduction is less than that of aerobic systems at the same temperature.

Composting
The biological method of composting is often used for solid wastes and sludge concentrates produced from effluent treatment processes. The principles follow

closely those of the aerobic treatment of waste-waters. Composting is an aerobic process in which the more reactive organic components are degraded, leaving a stabilised mass. Adequate oxygen must be supplied, either by regular agitation or forced aeration, to avoid anaerobic conditions, which would inhibit the process. In addition, the structure of the solid material needs to be open to allow air movement, while the dry-matter content should be above $250 \, kg/m^3$. Therefore, blending with other materials may be needed to produce an adequate substrate. An important feature of a successful process is the rise in temperature of the solids as a result of exothermic activity. Ideally, the temperature should exceed 60ºC, thus destroying pathogens and most weed seeds. The fate of the ammoniacal nitrogen depends on the overall C:N ratio in the solid mass; more carbon encourages retention of ammonia. Indeed, nitrogen losses can be avoided completely with very high levels of carbon (C:N ratios over 60:1), but the fertiliser value is then much lower (Csehi *et al.,* 1996).

16.6.3   Tertiary treatments

Filtration

Filtration processes are subject to the same limitations as those used for physical separation, in that they affect only the insoluble components. There is a wide range of equipment available that can be divided roughly into those that aim to produce a 'cake' of low moisture (often the desired product) and those that aim to clarify a liquid stream (frequently resulting in a dilute sludge). The latter applies in the case of final treatment of low-strength effluents containing only small amounts of suspended matter, with little or no value. It follows then that the concept of a filter press (Fig. 16.3) is appropriate, with the potential for a high degree of clarification. Equally, it follows that this is not a process for effluent streams carrying large amounts of suspended matter (over 100 ppm). Inevitably, periodic cleaning is required.

Filtration can also be carried out using low-cost systems, such as sand filters. As with filter presses, regular cleaning (by back-washing in this case) will be necessary. Soil filters are an alternative form, providing biological activity that leads to a breakdown of the dissolved organic material. This principle is used, for example, in the Solepur process for the treatment of pig slurries (Martinez, 1997). A limitation of soil filters is that they can generate a nitrate-rich leachate. Therefore, this process should include the collection and separate de-nitrification of the water before it is finally used to irrigate land.

Membrane filtration.   A development of the filtration method is the membrane process, which differs in two ways from conventional filtration: the use of membranes allows the physical removal of some of the *dissolved* materials in the waste-water, and the flow pattern is often cross-flow (Fig. 16.3), which means that a proportion of the untreated effluent must be purged as a waste product. The implication of this is that only a proportion of the feed effluent can pass through as a purified stream: this can be as low as 80%, depending on the
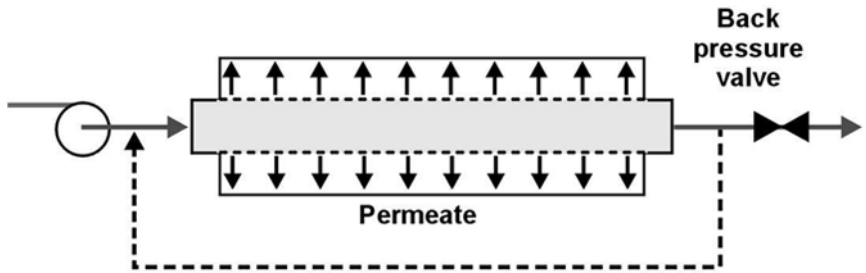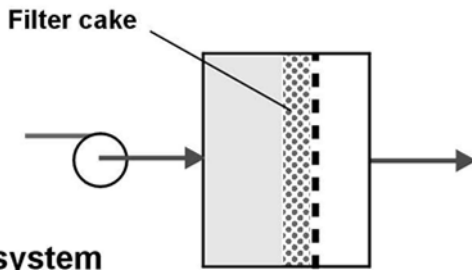
Fig. 16.3   Scheme for the operation of a membrane-filter system compared to a filter press. Only a proportion of the feed effluent will pass through the membrane, leaving behind a concentrate.

concentration of total matter (dissolved and undissolved) in the feed, which is concentrated by the process. The extent of the filtration is also a function of the membrane: the more open, ultrafiltration type will only retain the larger molecules, whereas the highest quality reverse-osmosis type can lead to a virtually pure water. However, the application to waste-water treatment is limited, due to the cost of the equipment and the relatively low throughput. In poultry processing, there may be a role for membrane filtration in the treatment of very dilute effluent, prior to disposal to a water course or to enable its re-use.

Aerobic trickling filters.   Aerobic treatments are limited by the need to maintain a minimum level of active biomass to keep the process going. For very dilute effluents, there is always the risk of 'wash-out', when the in-flow rate is relatively high compared to the growth-rate of the bacteria, which are gradually swept out as a consequence. This problem can be dealt with by using the activated-sludge process, where the biomass is recovered in a succeeding settlement stage and some is recycled. Alternatively, the biomass can be grown on a static bed of packing material, over which the effluent is passed – the trickling filter (Fig. 16.4). There are many versions of this available, but all have the strict limitation of a low level of suspended solids in the feed effluent. As with physical filters (above), the filter bed will slowly become clogged with
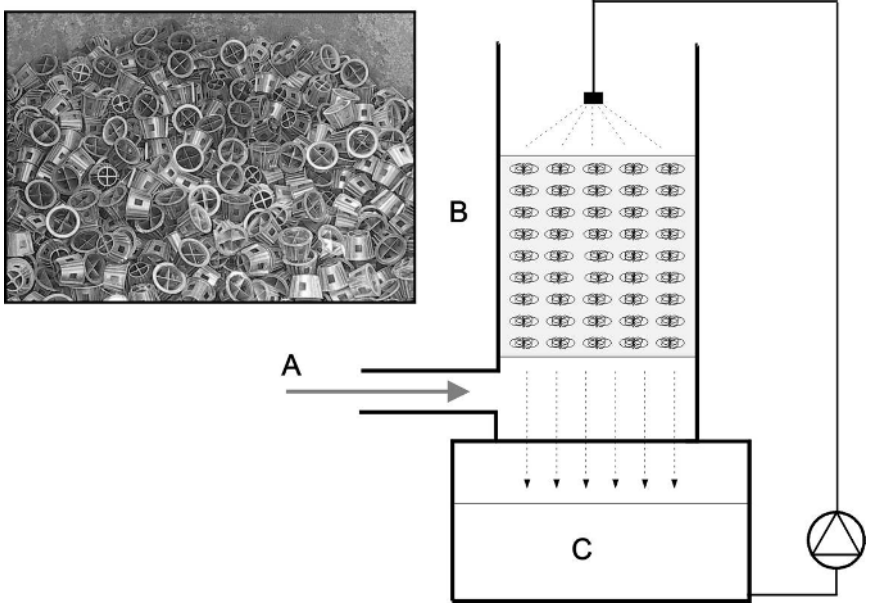
Fig. 16.4   Trickling tower for the tertiary treatment of waste-water effluents. The upward flow of air (A) may be natural or via a blower. The effluent trickles down over the packing (B), where it interacts with bacteria on the surface and organic matter is broken down aerobically. There is the option of recycling collected effluent (C), but some mixing with the feed is then inevitable. The photograph gives detail of a typical packing used.

solid debris, leading to a requirement for periodic cleaning. If designed well, aeration by natural ventilation may be sufficient to maintain an aerobic environment; otherwise, air-flow supplemented by blowers may be necessary. However, there is a limit to the amount of air that can be supplied, which is determined by

1. the cross-sectional area of the bed
2. the desired down-flow of effluent
3. the size and porosity of the packing used.

Excessive air-flows will lead to flooding and/or run-off, as liquid is prevented from draining away freely.

Use of wetlands and reed beds

In the operation of constructed wetlands, the effluent is passed through a defined zone containing selected plants, which provide a suitable environment and a carbon source for microbes attached to their roots. Wetland plants oxygenate the substrate immediately adjacent to their roots and increase the aerobic portion of an otherwise anaerobic zone. In addition, these plants remove nutrients from the in-coming waste-water during the growing season. While plant-nutrient uptake is usually not the major pathway of total nitrogen and phosphorus removal, it has

been credited with 16–75% of the former and 12–73% of the latter (Reddy *et al*., 1987).

The location of a wetland treatment facility may be predetermined by the local land form, access, environment hazards and, not least, land availability. Nonetheless, the soils in the chosen area should be tested and their hydraulic permeability measured. If too much leakage is expected, a clay or plastic liner may be necessary in order to retain standing water and prevent contamination of groundwater. In some instances, compacting the clay layer may provide sufficient water retention initially; in due course, the wetland substrate will seal off the subsoil, as process conditions develop. If plastic materials or geo-textiles are used to line the basin, a soil layer must still be added to provide a plant substrate.

One type of wetland that is gaining in popularity is the reed bed, which forms the basic design for many installations. The flow pattern can be horizontal (where the flow proceeds from one end to the other) or vertical (where the flow direction is downwards). The latter is preferred with stronger effluents, where there is a risk of overloading and damaging the herbage at the entry end of the bed. In trials by Biddlestone *et al*. (1991) a horizontal, sub-surface-flow reed bed, which initially received only dairy parlour washings, reduced the BOD_5 content by 17% and total suspended solids (TSS) by 57%. After six months, farmyard run-off was added to the waste. Initial BOD_5 and TSS concentrations were more than doubled, but the reed bed became *more* effective and it reduced BOD_5 by 49% and suspended solids by 70%, possibly due to growth of the reeds.

Evaporation and drying
Evaporation will produce a concentrate from the effluent, as well as leading to a heat-treated condensate for disposal or re-use. However, evaporation has many drawbacks, including the need for an energy-efficient operation that can result in very elaborate equipment. De-watering of dilute effluents will be required and further treatment of the condensate may be necessary, since it can include a proportion of the volatiles from the raw effluent. The economics and technical demands of this approach will limit its application, although it will be an important first step, if drying is intended.

The production of a dry, stable product from waste concentrates has many attractions. Storage, transport and safe disposal are greatly facilitated and there may be an opportunity to market an organic product as an alternative to inorganic fertilisers. Revenue from sales is unlikely to pay for the process, but at least it will defray the overall treatment cost. Moreover, the approach has considerable environmental credibility in terms of nutrient re-use. Schemes have been piloted for processing of sewage sludge (Boniface, 1990) and animal manures. Blending is important, with the addition of deficient components to provide a balanced fertiliser. A drawback is that processing is very elaborate and requires a dedicated operator, who will probably manage a variety of effluents from different sources.

16.7   Pathogen inactivation techniques: methods of decontamination

16.7.1   Thermal decontamination

The process of pasteurisation involves the heating of wastes/sludges to a relatively high temperature, but well below boiling point and, indeed, often below the point at which protein starts to denature, thus reducing the fouling of the heat-transfer system. By pasteurising at 70ºC for 30 minutes, *Salmonella* and enteroviruses in sewage sludge were completely killed (Bruce *et al*., 1990). Typically, the temperature range is 55–70ºC. Convention sometimes requires a four-hour process at 55ºC or 30 minutes at 70ºC, but, for specific bacteria and viruses, more precise conditions can be specified.

Sterilisation implies a higher treatment temperature, usually at or above the boiling point of water. Sometimes, heat treatment is carried out at an increased pressure to achieve temperatures in excess of 150ºC, which are held for extended periods (for example, in the autoclaving of contaminated equipment). Thus, the destruction of all but the most resistant spores is guaranteed. However, such extreme conditions are rarely necessary for processing-plant effluents, unless there is an intention to use the treated waste-water in food processing. It should be noted that the inevitable protein degradation can be expected to foul the heat-transfer surfaces rapidly, so that regular cleaning is required.

Heat treatment is often carried out in batch or semi-continuous systems. The advantage of this is the high degree of control and confidence in total decontamination. However, for large volumes of effluent, the logistics of batch treatment rapidly render it impractical. Continuous processing enables a high throughput, a consistent treatment and lower cost via savings from heat recovery. The main drawback of the continuous approach is back-mixing, which leads to some contamination of the treated product by pathogens in the raw feed. Although this may seem low, even in simple systems (for example, below 1%), the impact in microbiological terms is to limit the reduction in pathogen numbers to just two $\log_{10}$ units. The broad strategy to negate this effect is to reduce the residence time distribution by the use of a modified design, such as the inclusion of baffles (Fig. 16.5), which effectively changes the flow-pattern through the vessel, making it closer to one resembling plug flow. For example, research by Turner *et al*. (1999) used this approach in a series of pilot-scale trials to decontaminate pig slurry inoculated with African swine fever and swine vesicular disease viruses. The requirement for a continuous process arose from recognition of the importance of heat recovery. The heating requirement for slurry at 15ºC to reach, say, 65ºC can be calculated easily as 50ºC × the specific heat capacity (around 4000 J per kg of slurry), which is 55 kWh per tonne. A heat recovery of 90% is attainable and would reduce the fuel requirement to a tenth, or 5.5 kWh per tonne of treated effluent. By contrast, the cost of using additional mains water instead of recycled heat-treated water could double this cost.
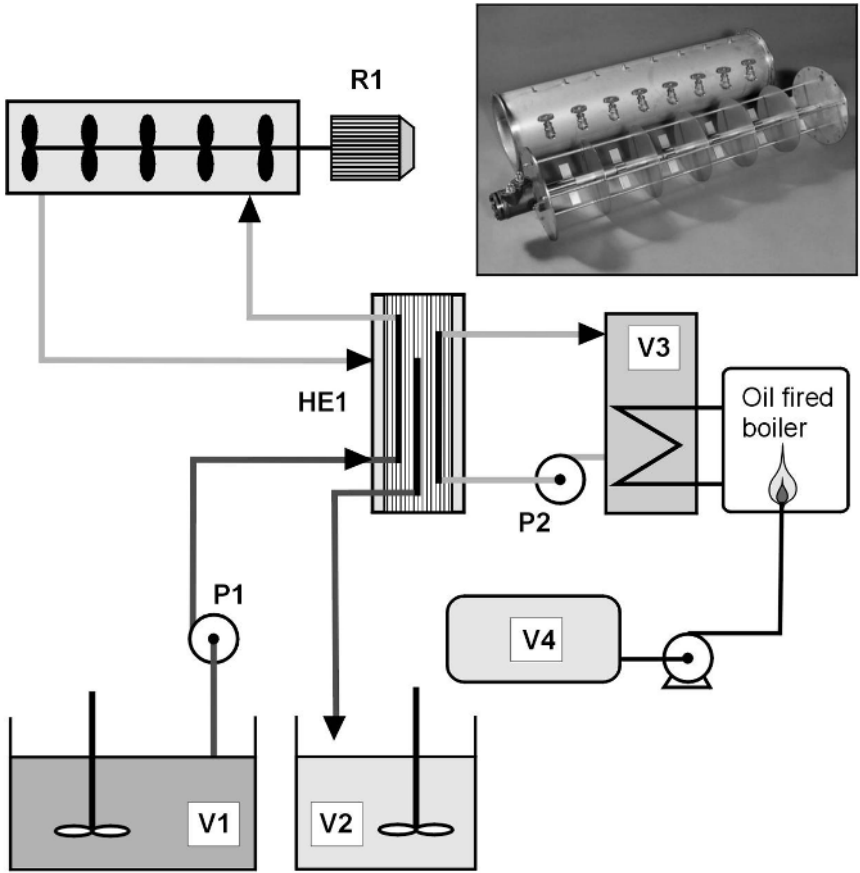
Key

V1	Raw slurry	R1	Retention vessel (detail shown
V2	Treated slurry		in photograph); a key feature is
V3	Heating liquid		the design of a baffle system to
V4	Fuel store		ensure that 99.99% of the
P1	Feed pump		effluent is retained for the
P2	Heating-liquid circulation		specific minimum time period
	pump		
HE1	Heat exchanger		

Fig. 16.5   Continuous thermal treatment plant for the inactivation of a range of viruses in pig slurry.

16.7.2   Other methods of decontamination

These include use of ultraviolet (UV) radiation, ozone and certain chemicals. Turner and Burton (1997) reviewed the processes involved, along with a wide range of other techniques for the inactivation of viruses in farm effluents. Other than thermal treatment (discussed above), only relatively large doses of sanitising chemicals have proved to be both reliable and effective (such as 1–3% sodium hydroxide). As well as cost, there are also health and safety issues and environmental consequences. It should be noted that, where chemically-treated effluent drains into a treatment plant, the added chemicals can be expected to have a detrimental effect on the biological treatment process.

Ozone is a proven disinfectant, but is readily neutralised by any organic matter present. Thus, large quantities will be required for disinfecting effluent streams, with the inevitable problems. Ozone will decompose residual organic matter, but simple aeration may achieve similar benefit at a lower cost.

UV light has also been shown to have disinfecting properties and is used in water treatment. It may have a role for disinfecting service water in poultry-processing plants, but the presence of anything more than slight turbidity will quickly reduce its effectiveness, as the radiation becomes absorbed before it can penetrate far into the water.

16.8   Disposal and utilisation of wastes and emission control

Whatever system is used to manage poultry processing wastes, it is important to consider what happens eventually to the material that is being managed and to seek positive benefits in harmony with environmental objectives. For example, the plant-nutrient content (nitrogen, phosphorus and potassium) of sludges from some treatment processes may be utilised by applying the material to agricultural land. However, the environment has a limited capacity and spreading sludge on an insufficient area of land will cause pollution. In the case of nutrients, such as nitrogen, land-spreading should be carefully planned, taking account of the following factors. The nitrogen contained in wastes applied to a crop will be:

- taken up in plant growth
- accumulate in the soil (in the short term)
- lost through emission to the air (for example, ammonia, nitrous oxide or di-nitrogen gas)
- lost to surface water and/or groundwater (for example, nitrate leaching).

To a large extent, the balance of behaviour will determine the waste management strategies that can be used. Provided there is no nutrient surplus, the main problems are to use the nutrients efficiently for crop production, without causing pollution, or any hazards to either human or animal health, as a result of pathogens present in the waste. However, if there is a nutrient surplus, then other disposal approaches will be needed, including use on alternative land

areas, landfill or disposal techniques, such as pyrolysis or incineration, enabling energy production.

16.8.1   Abating aerial emissions

Prevention of odour or ammonia emissions from within buildings is always more effective than applying technological 'cures' to deal with the emissions. For example, removing wastes regularly, rather than allowing them to accumulate can reduce odour and is also good practice from several other perspectives. However, regular manual cleaning is costly and so automated and/or mechanised systems are worth considering. These systems will generally involve washing with water, often including cleaning agents, such as detergents and disinfectants. Since the use of clean water for all stages of a cleaning operation increases the total volume of effluent to be handled and stored, there are benefits in using recycled water for this purpose, provided that it does not compromise hygiene requirements.

Inevitably, there will always be some generation of odorous air within buildings, so abatement or control methods must be considered. These are generally applicable to the exhaust ducts of ventilation systems and can include:

- biofilters
- bioscrubbers
- chimneys
- the use of masking agents
- chemical treatments (for example, ozone, zeolites)
- entrapment of particles (for example, filters, precipitators, adsorbers)
- thermal processes (for example, catalytic oxidation).

In a biofilter, the odorous air is passed through a chamber packed with a fibrous or granular medium of high surface area, which supports a population of naturally occurring bacteria. The bacteria decompose the odorous substances, as the air passes through. In some cases, these systems can also remove ammonia. The associated processes result in acidification of the medium, which will inhibit the reaction. Hence, such biofilters often include marble chips or some other alkaline material in the medium.

A bioscrubber is similar to a biofilter, except that the packing medium is kept well irrigated with water, which is re-circulated. For a given purpose, bioscrubbers can be more compact than biofilters, because they have a higher capacity. They are also more robust and can remove fine particles and other pollutants. However, bioscrubbers have a major drawback, in that they result in an effluent that must be treated separately. Both biofilters and bioscrubbers were originally developed to abate odours, but they can also be used to abate ammonia emissions. Ammonia removal requires closer control of pH (Scholtens and Demmers, 1991).

In exceptional cases, chimneys can be used to increase the height at which the odorous air is discharged into the atmosphere, thus minimising the impact on

close neighbours. It is also possible to dilute the odorous air with fresh air before discharge, thus reducing odour concentrations to levels below nuisance thresholds. However, although this may alleviate local nuisance problems, it does not address wider pollution issues.

Where odour problems are intermittent, it may be possible to reduce their effects with masking agents. These are either synthetic or naturally occurring mixtures and/or compounds with powerful, but pleasant aromas. They can be released via automatically controlled spraying systems at times when the risk of complaints about unpleasant odours is known to be greatest (for example, when certain operations take place, or when the wind blows in a particular direction).

Neutralisation of unpleasant odours is also possible using chemical and thermal methods. Chemical methods include absorption of odorous gases onto minerals, such as zeolites, that have a high cation-exchange capacity, or the ability to form chemical bonds with various substances (activated carbon, for example). Zeolites work best when the odorous air is moist, and ammonia will be trapped most effectively, if it is first able to dissolve in water. All of the absorption techniques require periodic replacement of the absorbent with either new or recharged material.

Oxidation of odorous material with ozone is another form of chemical treatment for odour reduction. However, since ozone is toxic, even at low concentrations, and is a serious atmospheric pollutant, if released into the troposphere, its use should be confined to enclosed ducts. On release, it will oxidise pollutants, while any unreacted ozone will transform into oxygen over a period of hours. Often, a degenerator (such as a UV source) will be required to accelerate the transformation.

16.9   Waste management: selecting the right approach

16.9.1   Integrated approaches

Water management

The use of fresh water at any food factory will directly affect the volume of effluent generated. For a poultry-processing plant, any waste-water must be treated as an effluent, and disposal will be via the sewer or a dedicated treatment system. If disposal is to the sewer, some degree of pre-treatment may be required, depending on the water company concerned. Where disposal to a local water course is possible, the treatment process and the final water quality criteria will be given in a consent document issued by the relevant environmental authority. In this case, there will be strict limits for effluent quality and it will remain solely the responsibility of the plant operator to ensure that they are met consistently.

The inevitable link between water usage and effluent generation affects the economics of various investment decisions, such as those involving water recycling. Such investments are justified from the 'two ends' of the process: cost savings in water supply and also in effluent disposal. The latter can be

subdivided into treatment costs and disposal costs (for example, the fee charged by the water company to receive the effluent). Thus, there is clear scope for an optimisation exercise to achieve the lowest overall management cost, where the inputs are

- cost of water consumption
- cost of water re-use and/or economies
- cost of on-site treatment
- cost of disposal.

This must be done in such a way that the primary purpose of the plant, to produce safe food products, is not compromised.

Solid wastes
Solid wastes from food factories are often collected and sent either for landfill or for rendering. Waste products, such as feather waste, may also be taken by the renderer as part of an overall service, and initiatives for improved waste management usually lie with such companies. For example, the company can undertake the development of a centralised waste processing unit that can use new technologies. Current legislation on the use and disposal of wastes containing meat do not encourage food companies to invest in solid waste management technologies. However, with the largest food producers, there may be scope to take on some of this work, albeit as a separate exercise.

16.9.2   Factors affecting choice of disposal system and control requirements

Effective treatment
A large number of treatment processes now exist for organic wastes, some of which have been reviewed already (Burton, 1992, 1996, 1997). However, evaluating their effectiveness can be easily confused by the interpretation of the term 'treatment'. Colloquially, this term can become very imprecise, and it can be relegated to implying that no more than *something* has been done to the waste by the process. What this amounts to, however, is often not clear. The remedy is to focus on the purpose of the treatment, rather than how it is done. For example, it is not the practice of bubbling air through effluent that brings about any benefit, but the subsequent odour abatement, reduction in organic matter or pathogen numbers. There is a need to identify and set unambiguous targets for the treatment process. In this way, any given process can be scored as inadequate, successful or even, possibly, excessive, and objective comparisons between different processes become possible. The most cost-effective package can then be identified.

The starting point in dealing with an organic waste stream should be to establish a clear definition of the problem (for example, disease, odour nuisance, excess nitrogen, water pollution). This will depend on the intended disposal route – to farm land, a water course, land fill, for re-use. The second step is to set

the treatment target necessary to resolve the problem (for example, a reduction in the suspended matter in waste-water to below 200 ppm; reduction in specific pathogen numbers to below the limit of detection). Such targets can be set, even for the subjective area of odour abatement (Williams, 1984; Pain *et al.,* 1990). Only when the purpose of the treatment is clear, should the various methods and necessary equipment be considered. However, a system that works, that is, that fulfils the requirements, may not be a realistic option, owing to cost or some other factor. A cheaper and less effective option may still be considered, but only if this is an acceptable compromise. The danger of using an inadequate treatment is that it can present the operator with a cost, without fully resolving the underlying problem.

Evaluating the options

There are two criteria that serve to evaluate a waste management option:

1. the overall cost to the company
2. the effectiveness of the process in meeting its aims.

It may be assumed that the evaluation exercise involves a comparison of option A against option B (where B may be the current arrangement), but selection of the best one is no guarantee that the technology is justifiable economically, or even that it works. Concerning the former, it is important to ensure that *all* factors are taken into account in the costing exercise. No waste management plant will ever pay for itself by generating by-products, such as compost or biogas, and any investment will always present both an additional capital cost and a new running cost. However, even if not immediately apparent, there may also be financial implications in the current situation. In some cases, there can be direct restrictions on the size of the company or type of operation as a result of waste management issues.

In the case of waste-water, the water treatment companies are likely to become increasingly restrictive, as they themselves face legislation from international agreements that seek to improve the quality of the environment in a fair and consistent way across Europe. This may result in higher disposal charges; in some cases, there may be a limit on the amount of effluent that can be received. In both instances, the economic considerations supporting on-site measures are strengthened as the least-cost option is pursued.

16.10   Future trends

Future trends in water and waste management are difficult to predict with confidence, because the poultry industry is so volatile. In developed countries, it is likely that there will be little overall growth in business, although there may be more consolidation, as individual processors merge. There may also be new plants that are able to offer high quality products to dedicated retailers. It is likely that small processing plants serving niche markets for unusual species,

products from extensively reared birds and those from organically produced birds will grow in number, although not necessarily in size. In all such cases, any change in waste management practices will occur only as a result of external pressures from, for example, retailers or government departments. Such changes will not be easy, because there will be little reward for the necessary investment or change in existing practices. The main scope for the uptake of new waste management practices lies with those schemes that offer some financial return from processing wastes, or a cheaper route of disposal. The most likely change in this respect is the pressure to improve water management and re-use schemes that will reduce both the volume of effluent produced and the cost of using mains water. The impetus for such management changes can be expected to come from growing constraints on water supply and use in many parts of the world.

In developing countries around the world, poultry production is expanding and large plants will be built to meet the demand for poultry meat for both the home market and export purposes. The same environmental issues apply to new installations as to any existing plant, but there is an opportunity with the former to include such considerations at the design stage. It might be expected that new plants will include greatly improved waste management facilities. On the other hand, there are fears that the temptation to relax regulations to attract new business in certain regions of the world might result in this opportunity being missed.

16.10.1   Changes to handling of solid waste

Rendering is certain to continue, but concerns over by-product utilisation will increase, leading to further bans around the world on feeding carcass by-products to livestock. This may result in increasingly technological means of dealing with the materials at large centralised sites and/or more separation procedures at poultry processing plants to use the wastes on-site, possibly as low-grade fuel in combined heating and power plants. Overall, rendering and other means of waste processing are unlikely to recover more than a small fraction of the costs incurred. Therefore, this part of the industry would become a waste-disposal service for other businesses, with operating costs covered by gate fees that would need to be included in the cost of the poultry products being produced. However, there would be additional responsibilities and liabilities for any company or group of companies that operate in this way. Of course, it will be necessary to minimise any costs involved in the processing of waste, whilst meeting legislation on public health and the environment. This is particularly likely in developed countries with high population densities. In countries where poultry production is expanding, it would appear logical to seek cheaper solutions, especially if suitable land is available to enable simpler methods to be used.

There may be a change in the type of solid waste produced. It is to be expected that hot-boning of uneviscerated carcasses will be undertaken in some plants, whether to reduce cost, improve food safety or both. This may be

achieved by the use of robotics. It is conceivable that benefits from higher levels of true automation, rather than more mechanisation, will permit more specific procedures to be carried out, possibly leading to greater separation of solid wastes, with less contamination from other wastes, especially water.

16.10.2   Water management and re-use

The potential for recycling and re-using water within the plant is considerable. However, current EU legislation insists that *all* water used in processing is potable and this is a major constraint on improvements in water usage. It may even be assumed that the rule applies to the cleaning of live-bird delivery crates, even though it can be argued that the birds do not come into direct contact with the water used and the crates are disinfected before re-use. The rule may seem sensible overall as a precautionary measure because, where re-use of water depends on treatment between uses, there is always the risk of a breakdown and untreated water coming into contact with carcasses. However, there is also the growing need to use water more efficiently, even in the food industry, implying the need for some recycling. This may be limited to cleaning purposes but, with the availability of increasingly reliable treatment methods and control procedures, it is possible to envisage wider use of recycled water in all but the most vulnerable parts of the poultry processing operation.

The water demand for the three areas of crate washing, scalding and plant cleaning (as identified above) could each be met in part by recycled water that was treated to an appropriate standard. Whilst it is technically possible to treat water to meet standards necessary for some of the direct food applications, this is unlikely to be attractive, because of the cost, perceived risk and general impression of unsatisfactory practice. In the case of water for plant washing, some of these factors are less critical and development of a treatment process that achieves a high quality, clean water may be enough to enable such water to be used in the future. Arguably, any collected waste-water could be upgraded for this purpose, but the main limiting factors would be the extent and reliability of the treatment required. Water is currently used in plant cleaning at the end of a production shift, usually via jet washers. However, specifying the quality of this water as 'potable' does not necessarily guarantee good hygiene. The power of the jets required to ensure good cleaning can cause bacteria to be re-distributed via aerosols formed from the treated surfaces.

Suitably upgraded, recycled water could be suitable for the scalding process and especially for washing live-bird transport crates. In the case of scalding, the water comes into direct contact with the birds and cross-contamination of carcasses is a problem at this stage of processing. A closed re-circulation loop in which used water was treated to remove suspended matter prior to pasteurisation would not bring any additional risk to the process. As the water is already heated, increasing the temperature briefly to 70–80ºC to ensure the destruction of vegetative pathogens is readily achievable, without incurring a high cost, and it is likely that heat-recovery options could reduce the cost involved.

The water used for transport-crate washing also becomes heavily contaminated very quickly, thus removing any advantage in using potable water other than for final rinsing. The washing process involves large amounts of cold water and a modest use of disinfectant in the final stages. The primary objective is to produce a crate that is visibly clean, but there are increasing fears over the residual levels of bacteria. The chief concern is cross-contamination with *Campylobacter* and other pathogens, which could be transferred to rearing farms via the crates. Improvements in the process are clearly required, but better water management might lead to a more effective process, without using larger amounts of water. The use of recycled water in crate washing is already practised to some extent by re-using water within the washing process. The quality of such wash-water is poor, since there is little treatment other than a screening operation. The main issue here is how to achieve better water treatment, so that an improved washing process for the crates can be developed. Also, advances in carcass processing could allow less water to be used without compromising carcass or plant hygiene. Foaming has been beneficial in enhancing the effectiveness of chemical disinfectants and does not increase the amount of water needed or effluent produced.

16.11   Sources of further information and advice

16.11.1   Websites

Many of the larger suppliers of environmental services and equipment have helpful sites but, where free advice is given, there will always be a disclaimer, and responsibility will lie with those implementing waste management practices. This can even be the case with the sites provided in the UK by the Environment Agency (environment-agency.gov.uk), the Department of Trade and Industry (dti.gov.uk/jemu) and Department for the Environment, Food and Rural Affairs (defra.gov.uk). Other useful UK sites include ADAS (adas.co.uk), the Compost Association (compost.org.uk) and those of the main water and waste magazines. The latter includes some subscription websites, such as the useful, if general, environmental review, the Ends Report (endsreport.com).

16.11.2   Trade and professional associations

Several trade and professional associations include waste management amongst their portfolios, but relatively few specialise in this area. Those that do tend to be based around water supply and municipal waste-water (for example, the Institution of Water and Environment Management or the Institute of Waste Management), but other professional organisations, such as the Institution of Chemical Engineers, have large sub-sections that deal with wastes and go beyond the subject area of the former water companies. The Environmental Services Association also has a broader remit and deals with food wastes.

16.11.3   Research and development organisations

There is no R&D organisation in the UK that deals solely with waste management, but there are several that have departments carrying out research into many aspects of the subject. Both the Campden & Chorleywood Food Research Association and the Institute of Food Research have programmes studying waste issues related to food. Likewise, Silsoe Research Institute, with its long history of research into the management and treatment of agricultural wastes, now extends into wastes from primary food production, including poultry processing.

16.11.4   Universities and colleges

Much research is carried out in UK universities and a few have specialist departments in waste management, Cranfield University, for example. Those that underpin research with regular courses in waste engineering can be expected to present a sustained programme of research and a broader expertise in the subject.

16.12   Glossary

The polluting power of wastes and the capacities of treatment processes to reduce pollution risks are assessed using a range of properties. These are outlined below, and further details can be obtained from sources such as *Standard Methods for the Examination of Water and Wastewater* (20th Edition), edited by L. S. Clesceri, A. E. Greenberg and A. D. Eaton, and published by the American Public Health Association, the American Water Works Association and the Water Environment Federation: http://www.apha.org/media/science.htm#standard_methods

Five-day biochemical oxygen demand (BOD$_5$)   The amount of oxygen used by microorganisms in the biological oxidation of organic matter within five days, at a specified temperature (20ºC), and under specified conditions. This is a standard test, used in assessing waste-water.

Carbon-nitrogen ratio (C:N)   The weight ratio of carbon to nitrogen in a waste material.

Chemical oxidation demand (COD)   A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or waste-water. Its value represents the amount of oxygen consumed from a chemical oxidant in a specified test. The test does not differentiate between stable and unstable organic matter and thus values do not necessarily correlate with BOD$_5$. COD is also known sometimes as 'oxygen consumed' or 'dichromate oxygen consumed'.

Colloidal matter   Finely divided solids that will not settle, but may be removed by coagulation, biochemical action or membrane filtration.

Fertiliser value   The potential worth of plant nutrients (especially nitrogen, phosphorus and potassium) contained in the waste that could become available to plants when applied to the soil. A monetary value assigned to a quantity of organic waste represents the cost of obtaining the same quantity of plant nutrients in their commercial form as that found in the waste. The worth of the waste as a fertiliser can be estimated only for given soil conditions and other pertinent factors such as land availability, time of year, and handling requirements.

Odour threshold   The point at which, after successive dilutions with an odourless medium (for example, air), the odour of the sample can just be detected. The threshold odour is expressed quantitatively as the number of times the sample is diluted.

Organic matter   Chemical substances of animal or vegetable origin, comprising cellular matter and the products of cell decay.

Organic nitrogen   This collective term represents the mass of nitrogen in various compounds in a waste, except ammoniacal nitrogen, nitrate and nitrite. It is measured as the total (Kjeldahl) nitrogen minus ammoniacal nitrogen.

Population equivalent   A means of expressing the amount of organic material in waste-water. Equivalence can be estimated on the basis of a number of parameters, most commonly flow, BOD_5 or suspended solids. For example, domestic waste-water consumes, on average, 0.08 kg of oxygen per capita per day, as measured by the standard BOD_5 test. This figure has been used to measure the 'strength' of organic, industrial waste in terms of an equivalent number of people. For example, if an industry discharges 480 kg of BOD_5 per day, its waste is equivalent to the domestic waste-water from 6000 people (480/ 0.08 = 6000). Caution must be exercised in using population equivalents, because of the difficulty in comparing processing-plant wastes directly with municipal wastes.

Redox potential (sometimes known as Standard Redox Potential)   This is a measure of the electrical voltage (or potential) at which a substance or mixture of substances will be reduced by electrons, relative to that at which hydrogen ions will be reduced. It applies to solutions containing both reactants and products and is given the symbol E^o. Redox potentials are expressed using a standard hydrogen electrode as a reference ($E^oH = 0v$). For convenience, redox potential is usually measured using a calomel electrode, consisting of an Hg/ Hg_2Cl_2 electrode in a saturated solution of KCl. At 25°C, the potential of a calomel electrode (E^o cal), is related to the potential of the standard hydrogen electrode, E^oH, according to $E^oH = E^ocal + 0.242\,V$. In the context of waste

treatment, redox potential indicates the tendency towards aerobic or anaerobic activity.

Settleable solids
1. The matter in waste-water that will not remain in suspension during a prescribed settling period, such as one hour, but either settles to the bottom of the container or floats to the top.
2. In the Imhoff cone test, the volume of matter that settles to the bottom of the cone within one hour.

Supernatant   The clarified liquid left after the removal of a sediment or precipitate.

Suspended solids
1. Solids that either float on the surface of, or are suspended in, water, waste-water or other liquids, and that are largely removable by laboratory filtering.
2. The quantity of material removed from waste-water in a laboratory test, as prescribed in Standard Methods for the Examination of Water and Wastewater, and referred to as non-filterable residue.

Total ammoniacal nitrogen   This is a chemical test to measure the amount of nitrogen present in the form of dissolved ammonia and ammonium ions. The test involves alkaline distillation and absorption of the distillate in acid, followed by back-titration of the absorbing acid.

Total (Kjeldahl) nitrogen   This is a chemical test that measures the combined amount of organic and ammoniacal nitrogen in a waste. It also detects other nitrogen compounds, including azides, amines, hydrozones, oximes, semi-carbazones and azonitrile, nitro and nitroso compounds. However, it does not detect nitrogen in the form of nitrite or nitrate. The test involves acidic digestion with a catalyst (normally mercuric sulphate), followed by back-titration of the absorbing acid.

Total solids   The sum of filterable and non-filterable solids in water or waste-water, usually stated in milligrams per litre. It is measured as the weight fraction of residue remaining, when a sample of waste is dried at a specified temperature, usually 105ºC for 24 hours.

Volatile acids   Fatty acids containing six or less carbon atoms that are soluble in water and can be steam-distilled at atmospheric pressure. Volatile acids are commonly reported as the acetic acid equivalent.

Volatile solids (VS)   The quantity of solids in water, waste-water or other liquids that are lost in ignition of the dry solids at 550ºC. VS are an indication of the amount of organic matter present.

Volatile suspended solids   That portion of the suspended-solids residue driven off as volatile (combustible) gases at 550ºC.

16.13   References

BARNDEN A D (1984), 'Environmental Quality Objective theory in practice', *Effluent and Water Treatment Journal*, November, 409–416.

BIDDLESTONE A J, GRAY K R and HURAIRAJAN K (1991), 'A botanical approach to the treatment of wastewaters', *Journal of Biotechnology*, 17(3), 209–220.

BONIFACE A (1990), 'Turning sewage sludge into soil', *The Chemical Engineer,* 479, 16–17.

BRUCE A M, PIKE E B and FISHER W J (1990), 'A review of treatment process options to meet EC sludge directive', *Journal of the Institute of Water and Environmental Management,* 4 (1), 1–13.

BURTON C H (1992), 'A review of the strategies in the aerobic treatment of pig slurry: purpose, theory and method', *Journal of Agricultural Engineering Research*, 54, 248–271.

BURTON C H (1996), 'An overview of the problems of livestock manure in the EU and the methods of dealing with it', *Proceedings of the Manure Management Symposium, Winnipeg, Canada*, 27–38.

BURTON C H (ed.) (1997), *Manure Management – Treatment Strategies for Sustainable Agriculture,* Silsoe, Bedford, UK, Silsoe Research Institute.

BURTON C H and FARRENT J W (1995), 'Evaluation of thermophilic aerobic treatment as a pollution abatement process' *Proceedings of the Seventh International Symposium on Agricultural and Food Processing Wastes, Chicago, USA,* pp 34–43.

BURTON C H and FARRENT J W (1998), 'Continuous aerobic treatment of pig slurry; evaluation of the long treatment time and two stage process options', *Journal of Agricultural Engineering Research,* 69, 159–168.

BURTON C H, SNEATH R W and FARRENT J W (1993), 'Emissions of nitrogen oxide gases during aerobic treatment of animal slurries', *Bioresource Technology*, 45, 233–235.

CSEHI K, BECK J and JUNGBLUTH T (1996), 'Ammonia emissions during composting of separated solids from liquid manure – Investigation about compost quality', *Agricultural Engineering Conference, Madrid, Spain,* Paper 96E-011.

GROOT-KOERKAMP P W G (1994), 'Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling', *Journal of Agricultural Engineering Research,* 59, 73–88.

LO K V, LIAO P H and VAN KLEECK R J (1990), 'Aerobic sequencing batch reactor treatment for swine wastewater', *Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes, Chicago, USA,* pp 348–352.

MARTINEZ J (1997), 'Solepur: a soil treatment process for pig slurry with subsequent denitrification of drainage water', *Journal of Agricultural Engineering Research*, 66, 51–62.

MARTINEZ J, BURTON C H, SNEATH R W and FARRENT J W (1995), 'A study of the potential contribution of sedimentation to aerobic treatment processes for pig slurry', *Journal of Agricultural Engineering Research*, 61, 87–96.

MEAD G C, ALLEN V M, BURTON C H and CORRY J E L (2000), 'Microbial cross contamination

during air chilling of poultry', *British Poultry Science*, 41, 158–162.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, (1998a), The Water Code – Welsh Office Agriculture Department, Code of Good Agricultural Practice for the Protection of Water, London, MAFF Publications.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, (1998b) The Air Code – Welsh Office Agriculture Department, Code of Good Agricultural Practice for the Protection of Air, London, MAFF Publications.

MONTUELLE B, COILLARD J and LEHY J B (1992), 'A combined anaerobic-aerobic process for the co-treatment of effluents from a piggery and cheese factory', *Journal of Agricultural Engineering Research,* 51, 91–100.

NIELSEN V C (1989), 'Treatment and disposal of processing wastes', in *Processing of Poultry,* ed. Mead G C, London, Chapman & Hall, 361–411.

PAIN B F, PHILLIPS V R, CLARKSON C R, MISSELBROOK T H, REES Y I and FARRENT J W (1990), 'Odour and ammonia emissions following the spreading of aerobically treated pig slurry on grassland' *Biological Wastes,* 34, 149–160.

PRETTY J N, BRETT C, GEE D, HINE R E, MASON C F, MORRISON J I L, RAVEN H, RAYMENT M D and VAN DER BIJL G (2000), 'An assessment of the total external costs of UK agriculture', *Agricultural Systems*, 65, 113–116.

REDDY K R, TUCKER J C and DEBUSK W F (1987), 'The role of egeria in removing nitrogen and phosphorus from nutrient enriched waters', *Journal of Aquatic Plant Management*, 25, 14–19.

SCHOLTENS R and DEMMERS T G M (1991), 'Biofilters and air scrubbers in the Netherlands', in *Odour and Ammonia Emissions from Livestock Farming,* eds Neilsen V C, Voorburg J H and L'Hermite P, London, Elsevier Applied Science Publishers, 92–96.

SHARPLEY A (1999), 'Agricultural phosphorus, water quality and poultry production: are they compatible?', *Poultry Science*, 78, 660–673.

TURNER C and BURTON C H (1997), 'The inactivation of viruses in pig slurries: a review', *Bioresource Technology,* 61, 9–20.

TURNER C, WILLIAMS S M, BURTON C H, CUMBY T R, WILKINSON P J and FARRENT J W (1999), 'Pilot scale thermal treatment of pig slurry for the inactivation of animal virus pathogens', *Journal. Environmental Science. Health*, Part B, 34(6), 989–1007.

VOORBURG J H (1985), 'Odour research and ammonia volatilisation', in *Odour Prevention and Control of Organic Sludge and Livestock Farming*, eds Nielsen V C, Voorburg J H and L'Hermite P, London, Elsevier Applied Science Publishers, 27–32.

WATHES C M (1998), 'Aerial emissions from poultry production', *World's Poultry Science Journal,* 54, 241–251.

WILLIAMS A G (1984), 'Indicators of piggery slurry odour offensiveness', *Agricultural Wastes,* 10, 15–36.

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