Gaining the edge in pork and poultry production

Enhancing efficiency, quality and safety

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Square pegs in round holes: the problems of variable pig performance

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Pig production management is often designed around the assumption that all pigs perform equally and thus efficient management of a population can be defined by modelling and making estimations for the average pig. Thus we can provide one temperature, one housing type and one feed to an age cohort of pigs and assume that the outcome is optimal from economic and productivity perspectives. These are overstatements, but many interventions are based on modelling the mean performance of a population of pigs and little attention is paid to the requirements of the full range of pigs within that population. Moreover, it is assumed that even if there is variation, that variation will not affect an economic outcome. Conversely, variation is recognised and the inputs are modified to meet the needs of the majority of the population. For instance, temperatures in nurseries may be designed to meet the needs of the 90^{th} percentile of pigs. In this case there is an inefficient use of inputs for much of the population, and often that is not identified as a cost of variation.

This problem is not only seen in characterising the population but is also seen in the assumed responses of that population to interventions. A case in point is the analytic methods by which we evaluate proposed changes in production methodologies, whether they are nutritional, health-related or environmental. Our commonly used statistical methods assume three things. The first is that the distributions of performance in the population, both before and after the intervention, are normally distributed. Secondly, we assume that the distributions are equal, and in most cases, we assume that the intervention has no effect upon the distribution of the outcome. Thus we also assume that the effect of the intervention is equal across all pigs in a population. Finally, when economic modelling is performed, it is assumed that the economic value of that response is equal across all pigs in the population.

There are occasions when in the assumption of equality of responses and the assumption of equal and normal distributions before and after an intervention are true. In some cases, responses to temperature, some nutritional interventions, and genotype changes can actually follow these assumptions. Where these assumptions fail particularly is in the area of health management. Compromised populations are rarely normally distributed in weight. Skewed distributions are common, with a subpopulation of pigs that deviates significantly from the mean and that deviation is always unidirectional to the left-hand side of the distribution. Furthermore, when health management is improved, the shape of the distribution changes and a subpopulation of pigs are more affected by interventions than others in that population. Many distributions of weights have a distinctive left skew due to a respiratory disease outbreak. Therefore simply monitoring the mean effects of health interventions are poor measurements of success. Finally, our ability to derive value out of changes in distributional aspects of pig production may exceed the value of simply changing mean performance (Deen, 1999).

All in all out production has created a situation where lightweight pigs are difficult to value in the production stream. Therefore we are seeing significant demerits on pigs that under perform. This is carried through to the slaughter plant and, at least within North America, these demerits continue to increase. Most of the economic benefits of improved average daily gain are actually concentrated in the left hand side of the distribution of weights within a barn.

Therefore, we in pig production are faced with the real choice in our accounting, record-keeping and analytical techniques. We can simply assume that every pig is the same. When we do that, the analogy of square pegs in round holes is a fair one. There are two real choices when faced with variation in the pigs in the system. One choice is to increase the size of the hole, or the capacity of the system, to handle the range of pigs. This results in inefficiency in that the physical capacity of the unit is not being effectively used. Conversely, we can use a big mallet and force the square pig into the hole causing some of the pig to be wasted, as they under-perform. Finally, we can modify the system by modifying the shape of the pig and the hole to more consistently match each other. It is this latter approach that appears to be an optimal answer to the problem.

This paper is going to focus on the pig characteristic of weight in age cohorts. In all in all out production we are faced with age cohorts that are not equal in weight. However, the decisions on how to manage that population have not been fully evaluated or optimised. There are three main steps to be taken to allow producers to optimise the system and manipulate variation in pig weight. The first is a recording system that recognises that variation and characterises it appropriately. The second is an economic model that recognises the losses associated with deviations from target weight, with that target being designed or defined by the system. Finally, we need analytical methodologies that address the economic and productivity needs in terms of design requirements that take variation into account.

Though the prior requirements may sound foreign to us in pig production, they are far from being foreign in most industrial protocols. The language of the methodologies which are being increasingly used most commonly in production management, are in the area of quality control, the most common discipline being the Six Sigma discipline which focuses on the DMAIC principles:

- *Define* the Customer, their Critical to Quality (CTQ) issues, and the Core Business Process involved.
- *Measure* the performance of the Core Business Process involved.
- *Analyse* the data collected and process map to determine root causes of defects and opportunities for improvement.
- *Improve* the target process by designing creative solutions to fix and prevent problems.
- *Control* the improvements to keep the process on the new course.

What is evident from this methodology is that the requirements of performance are defined by the customer, which in pig production is the next stage of production. In addition, this approach is based on specifications and the proportion of pigs meeting some minimum expectation set by the system. For instance, the characteristics of an acceptable pig performance in the nursery are defined by the requirements for pig characteristics in the grow-finish barn. What we find quickly is that mean performance or mean pig characteristics have little influence on the expectations of the next stage of production. Pigs need to meet a certain specification to fit into the expectations that is defined by the feed, facilities and availability of time.

What often differentiates pig specifications from other specifications is that upper specifications are rarely a concern; it is the lower specifications resulting in lightweight pigs or pigs that cannot survive or compete due to other conditions. Moreover, quality management argues that the existence of poor quality pigs throws into question the whole production process and the value of the rest of the pigs. We rarely see low-quality foodstuffs on our shelves, especially if they are branded. Instead, the producer will consider that product which is out of specification has no value.

Genichi Taguchi (Taguchi *et al.*, 1989), one of the major proponents of quality management, argues that any quality of concern has attached to it a loss function. For instance, market weight for pigs has real losses associated with it when the optimal weight is not met and our estimate of one such loss function is exhibited in Figure 1, calculated as lost margin over variable costs. Two things should be noted immediately from Figure 1. The first is that additional weight in a pig has different values depending on the initial weight of that pig. In other words, value or marginal profit does not have a linear or constant relationship with average daily gain. Instead, certain pigs are much more open to improvement. The problem is that standardised accounting systems rarely allow us to estimate losses associated with loss of quality. Losses associated with changes in quality are almost always a function of changes in value.

In terms of costs these changes and value are often called opportunity costs. Opportunity costs are not part of a normal financial statement, particularly in pig production. One of the best examples of losses in value is simply mortality. The losses associated with mortality are rarely accounted for in financial statements. Financial accounting does not view losses in value as a concrete number but instead reliant on hypothetical estimations. The opportunity cost associated with mortality is the difference between current profitability of the pig, namely zero and the potential profit when that pig reaches its expected

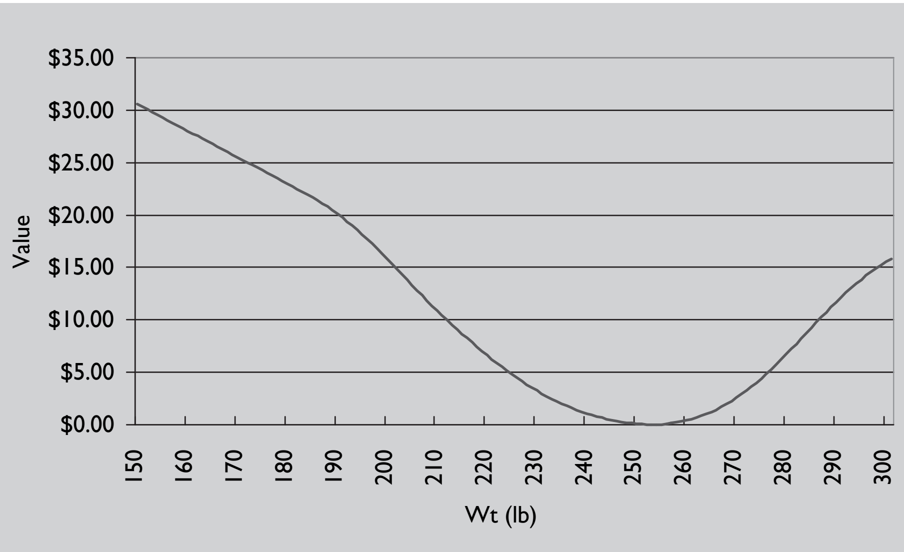

Figure 1. Loss function for pigs going to market for a typical Midwest Packer.

market weight. That profit is the expected value at the optimal market weight minus the additional costs to take that pig to that weight. Normally, this additional cost is almost entirely comprised of marginal feed costs. Likewise, culled and other lightweight pigs are open to substantial losses as the value of these pigs is relatively low. Major losses are consistently in this area and can easily exceed US$ 10 in the grow/finish period alone.

Thus the aim in improving performance, in many cases, is reducing the proportion of out of specification pigs. By creating such a binary classification we can use more powerful analytical techniques such as logistic regression to identify odds ratios associated with failure. Table 1 exhibits one such outcome, where we examined an outcome of mortality, as well as lightweight pigs at exit from the nursery based on characteristics at entry (Larriestra *et al.*, 2006). This table exhibits that there are multiple risk factors associated with the failure to survive and thrive. Weight is a major factor of concern, but other concerns should be taken into account as well. Figures 2 and 3 shows the relationship between the cut-off points for specifications of weight and the resultant risks for

Table 1. Factors associated with mortality and lightweight at week 10 for nursery pigs.

Response variable[b]	Risk factor[a]	Odds ratio	−+95 % CI	*P*
Mortality	Weaning weight (≤ 3.6 kg vs. > 3.6 kg)	2.92	1.87–4.56	0.0001
	Barrow (barrow vs. gilt)	1.75	1.13–2.70	0.01
	Sow unit (A vs. B)	2.14	1.01–4.56	0.04
	Weaning age (≤ 17 d vs. > 17 d)	0.87	0.72–1.06	0.1706
Lightweight at 10 wk of age[d]	Weaning weight (≤ 3.6 kg vs. > 3.6 kg)	8.75	5.84–13.12	0.0001
	Birth weight (≤ 1 kg vs. > 1 kg)	2.66	1.75–4.04	0.0001
	Gilt (gilt vs. barrow)	1.40	0.96–2.04	0.07
	Sow unit (A vs. B)	2.38	1.49–3.70	0.0002
	Gilt (gilt vs sow at weaning)[c]	1.66	1.08–2.56	0.01
	Weaning age (≤ 17 d vs. > 17 d)	1.05	0.94–1.17	0.34

[a]Odds ratio effects are adjusted for remaining factors.
[b]Both logistic models included litter as random effect (Glimmix macro; SAS).
[c]Parity of the nursing sow at weaning regardless of the cross fostering status.
[d]Less than or equal to 14.5 kg.

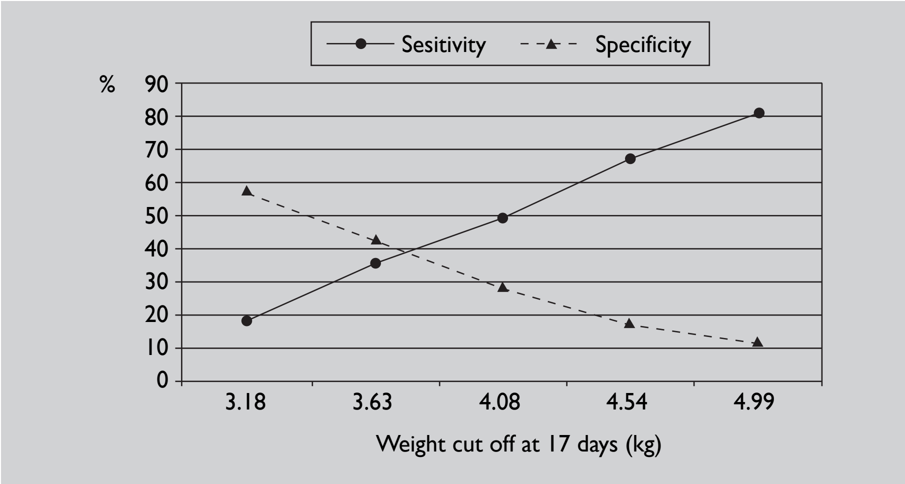

Figure 2. Sensitivity and specificity of predicting death and survival of pigs during the nursery (17 d to 10 wk) by using different weight thresholds at weaning.

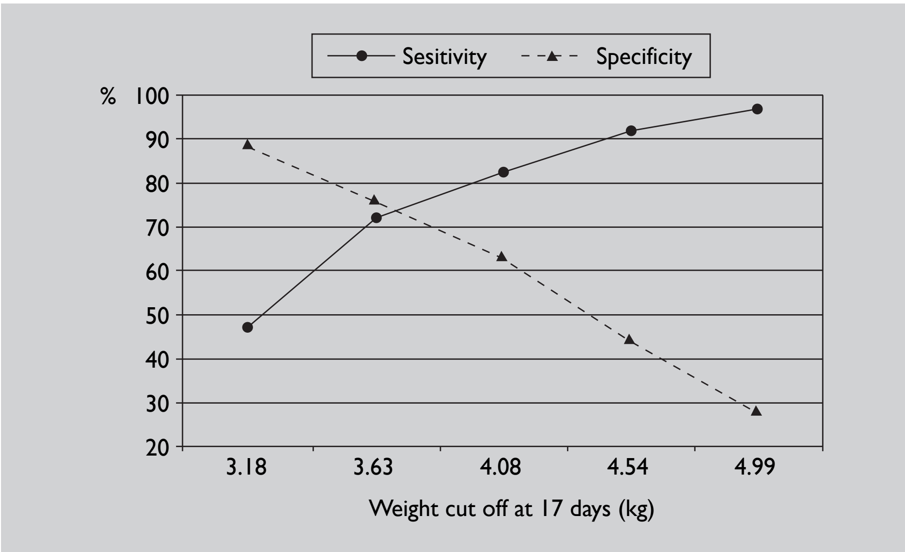

Figure 3. Sensitivity and specificity of detecting light (≤ 14.5 kg) and heavy (> 14.5 kg) weight pigs at exit from nursery (10 wk old) by using different weight thresholds at weaning.

those populations. Again, these analyses showed that the risks and outcomes are far from equivalent for different parts of the population.

In summary, pig production may need to look at new models for analysis to appropriately address concerns about variation in productivity between pigs. Current methodologies are limited and further opportunities for improvement in the quality of pig production are available.

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Recent developments in energy and amino acid nutrition of pigs

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1. Introduction

Pigs have been intensively selected over the last 40-50 years and their potential for producing lean meat or milk has become quite high with a marked reduction of body fatness both in reproductive and growing animals. These genetic changes have affected the protein and energy requirements of the pigs. In addition, new challenges such as attenuation of environmental consequences of pig production, increased frequency of pigs rearing under heat stress, increased competition between pig production areas, availability of new feed ingredients or changes in production systems (ban of AGP, for instance) have stimulated a refinement of feeding strategies and feed characteristics. More generally, feed has remained a major fraction of the production cost (>50%) under most economical systems and it has become more and more important to define precisely both the nutritional value of feeds and the nutrient requirements of pigs.

Protein and energy requirements of pigs used to be described according to empirical approaches and requirements were expressed as average recommendations that could not take into account changes or variability in the actual performance of the pigs that are dependent on genetic changes, health status, ambient temperature or production strategies. It is the reason why more factorial or modelling approaches have been developed. They consist in identifying the "physiological" processes (*i.e.* maintenance and growth in growing pigs) that contribute to nutrient requirements and their variations with environmental or animal factors. With regard to feed evaluation, most attention has been devoted to amino acids and energy and, more recently, to some minerals (P, Cu, Zn). New criteria for improving the accuracy of the evaluation have been proposed, such as digestible/available amino acids or net energy. Overall, this means that knowledge on pig nutrition has improved considerably and new tools are available on both the requirement side and the feed side with subsequent important changes in the approaches of nutrition in pig production.

2. Evaluation of pig feeds

Despite some methods which have been developed for estimating directly and rapidly the nutritional value of feeds (NIRS or *in vitro* methods), most information on feed values for pigs is provided by that are prepared according to variable concepts and more or less updated for both the concepts and the content (with new ingredients, for instance). From that point of view, the most performing feeding table is proposed by CVB with an annual updating (CVB, 2005). In the case of INRA, feeding tables for pigs (and poultry and rabbits) - *L'alimentation des animaux monogastriques* - were produced in 1984. However, since that publication, new concepts have been proposed and documented and new feed ingredients have become available.

The feeding tables published recently in several languages by INRA and AFZ (Sauvant *et al.,* 2002, 2004a,b, 2005)[1] are multi-species tables: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish. In this book, the data concerning the chemical composition of feeds are identical for all species and representative of ingredients available nowadays in Europe; forages are not covered. The data for nutritional values were mainly derived from *in vivo* measurements performed in the INRA laboratories or obtained from the literature. These data were then corrected to make them consistent with the chemical composition of the feed materials.

More or less complex or advanced concepts were used for estimating the nutritional value of feeds. For energy, digestible energy (DE) was used for fish, metabolisable energy (ME) for rabbits and poultry, and net energy (NE) for pigs and ruminant species. In the case of protein value, "digestible" amino acids were used for pigs, poultry and ruminants and total amino acids for the other species. For pigs, more details are available in different review papers produced over the last 10 years (Sève, 1994; Sève and Hess, 2000 for protein and amino acids; Noblet *et al.,* 2003, Noblet and van Milgen, 2004 and Noblet, 2006 for energy).

2.1. Energy value of feeds for pigs

Evaluation of the energy content of pig feeds is firstly and most commonly based on their DE or ME contents. However, the closest estimate of the "true"

[1] The tables are available in French (2002, 2004a), English (2004b), Spanish (2004c) and Chinese languages (2006).

energy value of a feed should be its NE content which takes into account differences in metabolic utilisation of ME between nutrients. In addition, NE is the only system in which energy requirements and diet energy values are expressed on the same basis which should theoretically be independent of the feed characteristics. Methodological aspects of energy evaluation of pig feeds and complementary information have been considered in previous reviews (Noblet and Henry, 1993; Noblet and van Milgen, 2004; Noblet, 2006).

2.1.1. Energy utilisation

For most pig diets, the digestibility coefficient of energy (DCe) varies between 70 and 90% but the variation is larger for feed ingredients (10 to 100%). Most of the variation of DCe is related to the presence of dietary fibre (DF) which is less digestible than other nutrients (<50% *vs.* 80-100% for starch, sugars, fat or protein) and reduces the apparent faecal digestibility of other dietary nutrients such as crude protein and fat. Consequently, DCe is linearly and negatively related to the DF content of the feed (Le Goff and Noblet, 2001). The coefficients relating DCe to DF are such that DF essentially dilutes the diet, at least in growing pigs. In other words, even though DF is partly digested by the young growing pig, it provides very little DE to the animal (Noblet and van Milgen, 2004). Digestibility of energy can be modified by technological treatments. Pelletting, for instance, increases the energy digestibility of feeds by about 1%. However, the improvement is more important for full fat rapeseed or (high oil) corn for which pelletting improves the digestibility of fat with subsequent marked differences in their DE value between mash and pellet forms (Noblet, 2006).

Energy digestibility is also affected by animal factors. In growing pigs, DCe increases with increasing body weight (BW) (Noblet, 2006) and the largest effect of BW is observed when adult sows either pregnant or lactating and (close to) *ad-libitum* growing pigs are compared (Le Goff and Noblet, 2001, Le Goff *et al.*, 2002a). The difference due to BW increase is most pronounced for high fibre diets or ingredients. In the case of adult sows and "60 kg" growing pigs, the DE value is 1.8, 4.2, 6.0, 10.3 and 16.6% higher in sows for wheat, corn, soybean meal, wheat bran and corn gluten feed, respectively (Sauvant *et al.,* 2004a,b). This improvement of energy digestibility with BW is mainly related to an improved digestive utilisation of DF (via a slower rate of passage in the digestive tract; Le Goff *et al.,* 2002) and the DE difference between adult sows and growing pigs is proportional to the amount of indigestible organic matter as measured in the growing pig (Noblet, 2006). The effect of feeding level on DCe is negligible even in adult sows when lactating sows and gestating sows fed at very different energy supplies are compared. Little information concerning comparative digestibility in piglets and growing pigs is available. Considering that piglets are usually fed low-fibre diets for which the effect of BW is minimised, piglets can, from a practical point of view, be considered as growing pigs with regard to digestive utilisation of energy.

The ME content of a feed is the difference between DE and energy losses in urine and gases (methane). In growing pigs, average energy loss in methane is equivalent to 0.4% of DE intake and is about twice this amount in adult sows. Energy loss in urine represents a variable percentage of DE since urinary energy depends greatly on the urinary nitrogen excretion. At a given stage of production, urinary nitrogen excretion is mainly related to the (digestible) protein content of the diet. On average, it represents about 4% of the DE value. However, this mean value cannot be applied to single feed ingredients. The most appropriate solution is to estimate urinary energy (kJ/kg DM intake) from urinary nitrogen (g/kg DM intake) according to the following equation (in growing pigs): Urinary energy = 192 + 31 x urinary nitrogen with urinary nitrogen representing 50% of digestible nitrogen or 40% of total nitrogen (Noblet *et al.,* 2004a,b).

Net energy is defined as ME minus heat increment associated with metabolic utilisation of ME and to the energy cost of ingestion, digestion and some physical activity. It is generally calculated as the sum of fasting heat production and retained energy (Noblet *et al.,* 1994a). The NE content, as a percentage of ME content (k) corresponds to the efficiency of utilisation of ME for NE. The variations in k are due to differences in efficiencies of ME utilisation between nutrients with the highest values for fat (~90%) and starch (~82%) and the lowest (~60%) for DF and crude protein. Measurements conducted in pigs which differed for their BW and the composition of BW gain suggest that the efficiency of ME for NE is little affected by the composition of BW gain, at least under most practical conditions (Noblet *et al.,* 1994b). Similarly, the ranking between nutrients for efficiencies is similar in adult sows fed at maintenance level and in growing pigs (Noblet *et al.*, 1993a; Noblet *et al.*, 1994c). These results have been confirmed in recent trials (Noblet, 2006). Finally, the heat increment associated with protein utilisation, either retained as protein or catabolised, is constant (van Milgen *et al.,* 2001). This means that the NE value of dietary CP is not dependent on its final utilisation.

2.1.2. Energy systems

Apart from direct measurement on pigs, the DE and ME values of raw materials can be obtained from feeding tables (NRC, 1998; Sauvant *et al.*, 2004a,b). But the utilisation of these tabulated values should be restricted to ingredients having chemical characteristics similar or close to those in the tables. As illustrated in the previous section, DCe is affected by BW of the animals. It is therefore appropriate to use DE and ME values adapted to each BW class. However, from a practical point of view, it is suggested to use only two values, one for "60 kg" pigs which can be applied to piglets and growing-finishing pigs and one for adult pigs applicable to both pregnant and lactating sows. The DE content of compound feeds can be obtained by adding the DE contributions of ingredients and assuming no interaction, which is usually the case. When the actual composition of the feed is unknown, the possibility is to use prediction equations based on chemical criteria (Le Goff and Noblet, 2001) or estimates from near infrared or *in vitro* methods (Noblet and Jaguelin-Peyraud, 2007).

All published NE systems for pigs combine the utilisation of ME for maintenance and for growth or for fattening. The system proposed by Noblet *et al.* (1994a) and applied in the INRA & AFZ feeding tables (Sauvant *et al.*, 2004a,b) is based on a large set of measurements (61 diets). The NE prediction equations that have been generated from these measurements are given in Table 1. They are applicable to ingredients and compound feeds and at any stage of pig production (Noblet, 2006). It is important to point out that different DE values or digestible nutrient contents should be used in growing-finishing pigs and adult sows with

Table 1. Equations for predicting NE in pig feeds (NEg; MJ/kg dry matter; composition: g / kg DM).

Equation[a]	% RSD
NEg2 = 0.0121 x DCP + 0.0350 x DEE + 0.0143 x ST + 0.0119 x SU + 0.0086 x DRes	2.4
NEg4 = 0.703 x DE - 0.0041 x CP + 0.0066 x EE - 0.0041 x CF + 0.0020 x ST	1.7
NEg7 = 0.730 x ME - 0.0028 x CP + 0.0055 x EE - 0.0041 x CF + 0.0015 x ST	1.6

[a]CF: Crude Fibre, CP: crude protein, EE: ether extract, ST: starch, DCP: digestible CP, DEE: digestible EE, DRes: digestible residue (*i.e.* difference between digestible organic matter and other digestible nutrients); from Noblet *et al.* (1994; 2004).

two subsequent NE values. Reliable information on digestibility of energy or of nutrients is then necessary for prediction of NE content of pig feeds. In fact, this information represents the most limiting factor for predicting energy values of pig feeds.

The INRA-AFZ feeding tables provide values of digestible energy (DE), metabolisable energy (ME) and net energy (NE), as well as digestibility coefficients of major nutrients and organic matter. Two companion articles to the INRA-AFZ tables were produced later on and more details are provided (Noblet *et al.,* 2003; Noblet and Tran, 2004a). An Excel spreadsheet has also been produced in order to make available all the equations that were used in the preparation of energy values that are presented in the feeding tables (Noblet and Tran, 2004b). It must be stressed that the energy values for energy and digestibility coefficients have been obtained only from literature values, thus excluding a "copy/paste" of previous feeding tables. The concepts used originate from studies conducted at INRA over the last 20 years with two major innovations: net energy and energy value dependent on the pig physiological stage. For simplification purposes, two stages were considered: the 50-70 kg growing pig (the data can be applied to fast growing animals between 10 to 150 kg live weight) and the adult sow (the results can be used for both gestation and lactation) (Le Goff and Noblet, 2001).

2.1.3. Comparison of energy systems

From previous observations on energy utilisation in pigs, it is obvious that the hierarchy between feeds obtained in the DE or ME systems may differ in the NE system according to their chemical composition. Since NE represents the best compromise between the feed energy value and energy requirement of the animal, the energy value of protein or fibrous feeds will be overestimated when expressed on a DE (or ME) basis. On the other hand, fat or starch sources are underestimated in a DE system (Noblet *et al.,* 2001a; Sauvant *et al.,* 2004a,b; Noblet, 2006; Table 2). With regard to NE for pigs, several systems have been proposed over the last 40-50 years. The INRA proposal (Noblet *et al.,* 1994a; 2004) is probably the most advanced system and it has been validated both by calorimetric measurements and growth trials (Noblet, 2006).

As previously mentioned, it is extremely important to use the same energy system for expressing the diet energy values and the animal energy requirements; in addition, energy values provided by different NE systems cannot be combined. From that point of view, the only energy system in which the requirements

Table 2. Relative DE, ME and NE value of ingredients for growing pigs[a].

	DE	ME	NE	% NE/ME
Animal fat	243	252	300	90
Corn	103	105	112	80
Wheat	101	102	106	78
Reference diet	100	100	100	75
Pea	101	100	98	73
Soybean (full-fat)	116	113	108	72
Wheat bran	68	67	63	71
Soybean meal	107	102	82	60

[a]From Sauvant *et al.* (2004a,b). Within each system, values are expressed as percentages of the energy value of a diet containing 68% wheat, 16% soybean meal, 2.5% fat, 5% wheat bran, 5% peas and 4% minerals and vitamins.

are the most independent on the diet characteristics is the NE system. This is illustrated by several growth trials, especially conducted with variable dietary fat or CP levels that show that the energy cost is independent of diet composition when expressed on a NE basis. On the other hand, on DE or ME bases, the energy cost is increased when CP content is increased or fat content is decreased (Noblet, 2006; Table 3).

In conclusion, the use of an appropriate NE system is clearly an improvement in the knowledge and the characterisation of pig feeds. However, most attention should be given to factors that affect the digestibility of nutrients which remains insufficiently documented, especially when technological treatments have to be considered. Most progress in the future will come from this side. Improvement of methods is also necessary, especially for saving time and costs. *In vitro* or NIRS methods are potential alternatives to *in vivo* methods or prediction from chemical characteristics.

2.2. Nutritional value of proteins and ileal digestibility of amino acids for pigs

It is now widely accepted that the total amino acids (AA) content of feeds is an insufficient predictor of the protein value for pigs and the nutritional availability of AA is highly preferred, the availability being estimated from the digestibility at the end of the small intestine. Indeed, AA are absorbed in the

Table 3. Energy requirements of ad-libitum *fed growing-finishing pigs according to energy evaluation system*[a].

	Diet 1	Diet 2
Diet composition, %		
Crude protein	18.8	14.5
Starch	45.9	50.9
Energy intakes, MJ/d		
DE	38.9[b]	37.3[c]
ME	37.1[b]	36.1[c]
NE	27.6	27.5
Nitrogen excretion, g/kg BW gain	50.2[b]	30.9[c]

[a]Performance was measured between 30 and 100 kg at a temperature of 22 °C; energy intakes are adjusted by covariance analysis for similar BW gain (1080 g/day) and carcass composition at slaughter; adapted from Le Bellego *et al.* (2002).
[b,c]Values are different ($P<0.05$) if different letters are used.

small intestine while, in the large intestine, micro-organisms can metabolise some of the undigested amino acids and this prevents them from appearing in the faeces; faecal digestibility of AA is then an unreliable criteria for estimating their availability at the site of absorption. Therefore, "ileal" digestibility is used but with some controversy for its expression and even the definitions.

Apparent ileal digestibility ignores the origin - endogenous or exogenous - of the undigested nitrogen (N) or AA that appear at the end of the small intestine. In addition, apparent digestibility increases curvilinearly with the inclusion level of the AA in the feed with low and even negative values at low inclusion levels and a plateau value at high levels. In fact, it has been shown that losses of N or AA at ileal level include a basal loss that is independent of dietary protein content and is more related to dry matter intake. It is then preferable to subtract this basal loss from the total N or AA ileal loss in order to consider only what is related to the dietary protein fraction of the feed. The "true" or "standardised" digestibility is then calculated and this value is constant whatever the dietary N or amino acids levels. In addition, the standardised digestibility's of amino acids are additive. Values for standardised digestibility's are higher than values for apparent digestibility. This concept is becoming more widely accepted and has been used in the INRA&AFZ feeding tables.

The values provided by the INRA-AFZ feeding tables are derived from experiments started independently in France in the early 1980's by Adisseo, Arvalis and INRA. All of these data were compiled between 1996 and 1999 and published as a CD-ROM (AFZ *et al.*, 2000)· In all studies, a common methodology consisting of measuring the ileal digestibility in termino-terminal ileo-rectal anastomised growing pigs was used (Laplace *et al.*, 1994). A total of 430 products were measured in the three experimental sites; they were classified in 51 different feed materials and average values were calculated. The methodology involved total collection of ileal digesta in pigs fed diets usually based on protein free ingredients (starch, sugar, vegetable oil, minerals and vitamins) in which the ingredient supplying proteins was included. The difference method was then used to estimate the apparent digestibility of the protein source. The AA composition of the basal loss was measured for each site and is reported in the INRA-AFZ feeding tables (Noblet *et al.*, 2002; 2004a,b).

In practice, it is highly recommended to use standardised ileal digestibility values to estimate the protein value of a feed and to meet the requirements that correspond then to the sum of requirements for "maintenance" (or basal loss) and for protein deposition. Table 4 indicates that the hierarchy between ingredients for their protein value is totally different when either crude or

Table 4. Protein value of some ingredients for pigs, expressed either as total amino acid or as standardised digestible amino acids[a] (from Sauvant et al.*, 2002, 2004a,b; AFZ* et al.*, 2000 feeding tables).*

	Lysine		Threonine	
Ingredients	Total	Digestible	Total	Digestible
Maize	29	26	49	47
Wheat	36	33	52	50
Wheat bran	68	53	75	57
Soybean meal	340	353	294	304
AA mixture[b]	4580	5180	4015	4680

[a]Expressed as % of the lysine or threonine value of a diet containing wheat (67%), soybean meal (16%), fat (2.5%), wheat bran (5%), peas (5%), HCl-lysine (0.10%), methionine (0.05%), threonine (0.05%) and minerals and vitamins.
[b]Mixture of 50% HCl-lysine, 25% threonine, 25% methionine.

digestible AA levels are considered. But, as for energy (see above), little is known about the effect of technology on protein availability or at least the available literature information does not allow any general correction for the effects of particle size, pelletting, heat treatment, etc. on "true" digestibility and/or endogenous losses. Therefore, the INRA-AFZ feeding tables provide values that are applicable to at least mash feed; they can be extended to other presentations. Unlike energy (see above), there is no evidence for using different protein values in piglets, growing-finishing pigs and reproductive sows. Finally, the digestible AA contents in the feed materials considered in the feeding tables are fixed values and they do not apply systematically to the same ingredient with a different chemical composition. However, for simplification, it can be considered that the amino acid composition of the proteins of a given ingredient is rather constant and so are the standardised digestibility coefficients of amino acids. The digestible amino acid contents can then be calculated according to these assumptions.

In conclusion, the change from total amino acid content to standardised digestible amino acid level has led to a better estimate of the "true" protein value of feeds for pigs; this change offers possibilities for reductions of the safety margin in feed formulation. Uncertainties remain about the effects of technological treatments (particle size, heat, enzymes, etc.) and anti-nutritional factors on ileal digestibility and/or ileal loss of amino acids. Improvements in methods of evaluation are also recommended in order to save time and costs induced by *in vivo* measurements and amino acids analyses. The NIRS approaches are promising but they will have to rely to important data base of *in vivo* values.

3. Energy and protein requirements of (growing) pigs

3.1. Energy requirements

As for protein needs, energy requirements of growing pigs can be considered as the sum of the requirements for maintenance and those for growth, the latter corresponding to energy accretion as proteins and lipids. The energy requirement for maintenance (MEm, expressed as ME) is proportional to metabolic body weight, the most appropriate exponent for its expression being 0.60 in growing pigs (Noblet *et al.,* 1994; 1999); it is highly preferable to the commonly used 0.75 exponent that is more adapted to interspecies comparisons or estimations for adult animals within one species. The value to be considered for pigs raised indoor and at an environmental temperature within the thermoneutral zone, is about 1.05 MJ ME / kg $BW^{0.60}$ (Noblet *et al.*, 1999). The ME requirements for body protein or lipid accretion (MEp) can be estimated from the amounts of deposited protein or lipid and the efficiencies of utilisation of ME for energy gain as protein and as fat (k_p and k_f, respectively). For a conventional cereals-soybean meal diet, Noblet *et al.* (1999) proposed 60 and 80% for k_p and k_f, respectively. The energy content of body proteins and lipids are approximately 23.8 and 39.5 kJ/g, respectively. The ME requirements are then about 40 and 50 kJ ME per g of protein and fat, respectively.

As an example, the estimated energy needs of a 60-kg pig with an accretion of 160 g of protein and 200 g of lipids per day is 28.4 MJ ME/day with 43, 22 and 35% of the total requirement for maintenance, protein accretion and lipid accretion, respectively (Table 5). This example also shows that the MEm fraction of the energy requirements is important (more than 40%) whereas the ME fraction used for body protein accretion usually represents less than 25% of the total energy requirements.

The energy requirements for maintenance, when expressed per kg of metabolic body size ($BW^{0.60}$), is almost constant over the growth period with small differences between breeds or sexes. Differences are significant only for extreme breeds with lower values for slow growing and/or fat pigs such as Meishan animals and higher values for fast growing and lean type pigs (Noblet *et al.,* 1999). Therefore, for most intensively-reared pigs, MEm can be considered as constant under standardised conditions (conventional housing, thermoneutrality). That level of maintenance includes a standard level of physical activity whose energy cost averages 200 kJ ME/ kg $BW^{0.60}$; it corresponds mainly to the energy cost

Table 5. Energy and lysine requirements of the growing pig: an example.

Item	Energy[a], MJ ME/d		Digestible lysine[a], g/d	
Maintenance	12.2	(43)	0.8	(4)
Protein gain	6.3	(22)	17.3	(96)
Lipid gain	9.9	(35)		
Total	28.4	(100)	18.1	(100)

[a]Between brackets, as a percentage of total requirement; calculated for a 60 kg BW pig depositing 160 g of protein and 200 g of lipid per day; its BW gain would then average 1000 g per day.

of the standing position (van Milgen and Noblet, 2003). If for any reason (outdoor rearing, behaviour disorders, etc.), the physical activity is markedly increased, the additional cost due to that additional activity should be added to the maintenance requirement. Factors of correction have been proposed by Noblet *et al.* (1993b) in adult sows; in growing pigs, it is proposed to increase heat production (HP) related to physical activity by about 10 kJ/kg BW/100 minutes additional duration of standing (Le Goff *et al.,* 2002b).

The most important factor of variation of maintenance energy requirements in growing pigs corresponds to the thermoregulatory need when they are raised below their lower critical temperature (LCT). Different values have been proposed for LCT and they may be affected by pig BW, air speed, type of floor, feeding level, group size, etc. Further information on this topic can be obtained in the review of Noblet *et al.* (2001b). For simplification, it can be assumed that LCT averages 22-23°C over the growing period for conventionally raised pigs (Quiniou *et al.,* 2001). These latter authors also proposed a method for evaluating the additional feed supply for maintaining energy gain and performance in pigs raised below their LCT. An illustration of the approach is given in Figure 1. However, it should be mentioned that cold temperature has become a negligible problem in most practical situations with improved insulation and quality of the buildings in temperate countries. On the other

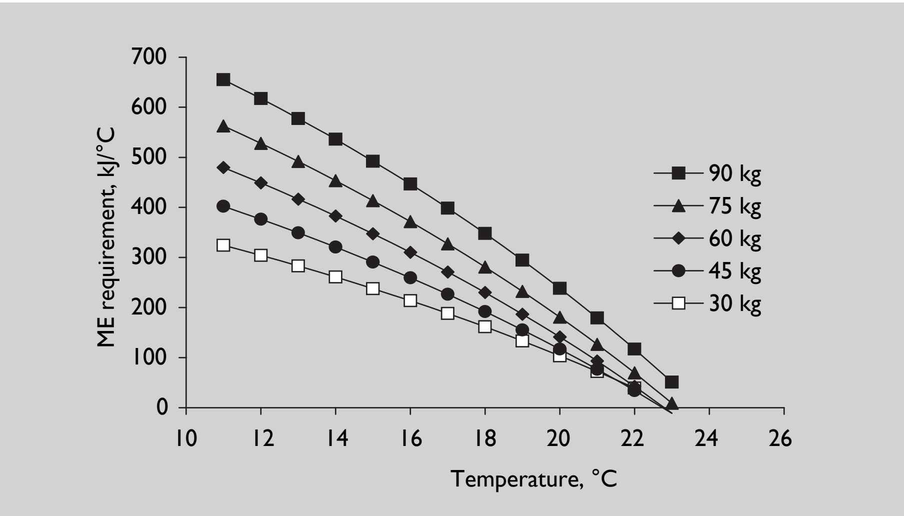

Figure 1. Energy requirement for thermoregulation in growing pigs according to their body weight (30 to 90 kg) (from Quiniou et al.*, 2001).*

hand, heat stress becomes increasingly important with the rapid development of pig production in tropical or subtropical areas or during the summer period in temperate countries.

From a nutritional point of view, pigs deposit protein, fat, ash and water in their BW gain. However, from technical and economical points of view, the growth of tissues (lean and adipose) is the most important with efforts to increase the amount of lean tissues in the carcass and concomitantly to reduce the amount of adipose tissues. Measurements of the chemical composition of lean and adipose tissue weight gain and the associated feed energy costs calculated according to the above hypotheses for protein and lipid gain indicate that the feed cost of adipose tissue gain is about 3.5 times the cost of lean tissue gain (Table 6). This emphasises the efforts for reducing the body fatness of growing pigs by either genetic selection or nutritional manipulations. These marked differences in energy cost of tissue gain also explain the improvement of feed efficiency with reduced adiposity of the carcass, even though the overall energy efficiency is usually reduced (Noblet *et al.*, 1994d).

Table 6. Chemical composition of tissues and BW gain in growing pigs; consequences on energy requirements for tissue gain[a].

	Entire males			Castrated males		
Chemical composition	Lean[b]	Adipose	eBW[b]	Lean[b]	Adipose	eBW[b]
Water, %	69.9	18.7	58.5	65.6	14.9	51.0
Ash, %	1.0	0.2	3.1	1.0	0.2	3.0
Protein, %	17.9	5.4	16.7	18.2	4.1	16.0
Fat, %	10.2	75.4	21.1	15.3	81.8	30.4
Energy, kJ/g	8.5	31.3	12.3	10.4	33.3	15.6
Energy requirement, kJ ME/g[c]	12.2	39.8	17.2	14.9	42.6	21.6

[a]From Noblet *et al.* (1994d) and J. Noblet (unpublished data): over the 20 to 95 kg BW period and according to the comparative slaughter technique.
[b]Lean includes intermuscular fat; eBW for empty body weight.
[c]Calculated as 40 and 50 kJ ME per g of protein and fat, respectively.

Similar to protein gain, daily lipid gain and the associated energy cost are highly variable in growing pigs. It should also be noted that lipid deposition is markedly affected by genotype and sex and by pig BW. In addition, the general trend is that genetic selection has resulted in a marked reduction of lipid gain and, to some extent, a chemical composition of additional BW rather constant and much less variable with BW. These aspects will not be detailed here.

3.1.1. Expression of energy requirements

Energy requirements are expressed on different bases. In *ad-libitum* fed pigs, they consist mainly in fixing the diet energy density according to regulation of feed intake (appetite) or growth potential of the pig, to climatic factors or to economical conditions. In restrictively-fed growing pigs or in reproductive sows, it is necessary to define feeding scales according to expected performance. In more sophisticated or more theoretical approaches (factorial or modelling approaches), it is necessary to determine the components of energy requirements (maintenance, growth, milk production, thermoregulation, etc.). Whatever the level of approach, most trials and the subsequent recommendations were conducted according to DE and ME estimates for feeds and conclusions were expressed as DE or ME values. In addition, the recommendations were obtained with rather conventional feeds, *i.e.* cereals-soybean meal based diets whose efficiency of ME utilisation in growing pigs is 74-75% according to the system proposed by Noblet *et al.* (1994a). The proposal is then to estimate the NE recommendations (diet energy density, daily energy requirements, components of energy requirements, etc.) as DE or ME requirements multiplied by 0.71 or 0.74, respectively. This proposal is applicable at any stage of pig production, including pregnant or lactating sows, since NE value is calculated for any stage from one single set of equations (Noblet, 2006).

3.2. Protein requirements

Protein requirements of pigs correspond to the requirement for essential amino acids that are retained in the body tissues and to an "undifferentiated" nitrogen requirement for the synthesis of non-essential amino acids. In addition to requirements for protein accretion, requirements for maintenance functions have also to be met. According to the concept of ideal protein partly based on the fact that the amino acids composition of body proteins is relatively constant (Mahan and Shields, 1998), the relative ratios between essential amino acids for protein gain and for maintenance remain constant (Fuller *et al.,* 1989) and therefore, only the amount of all amino acids to be supplied daily varies as a function of certain characteristics of the pig (live weight, sex, etc.) or with production level or environmental conditions. However, the optimal ratios between essential amino acids for protein gain and for maintenance differ for some amino acids with subsequent changes of the optimal ratios in the feed according to the importance of both types of requirements. But the impact of most factors is limited in growing pigs, even for threonine that contributes highly to the maintenance fraction (van Milgen *et al.,* 2005). The ratios between essential amino acids can then be considered as relatively constant in most practical situations. The only exceptions would be in unhealthy pigs for which requirements for some amino acids (tryptophan) would be increased (Melchior *et al.,* 2004). The requirements for "undifferentiated" nitrogen, supplied by non-essential amino acids or the excess of essential amino acids, should represent at least the amount of nitrogen supplied by essential amino acids (Lenis *et al.,* 1999).

The composition of the ideal protein for swine has been described by several authors (Fuller *et al.,* 1989; Henry, 1993). In most feeds for swine, lysine is usually the first limiting amino acid. Protein requirements are then based on lysine requirement and the requirements of the other amino acids are expressed relative to lysine. Henry (1993) and Sève (1994) recommended supplies of methionine + cystine, threonine, tryptophan, isoleucine, leucine and valine of 60, 65, 18, 60, 100 and 70% of lysine supply, respectively. These values are close to those proposed for instance by NRC (1998). The ratios are also rather close to those recommended for pregnant or lactating sows (Dourmad *et al.,* 2005).

The lysine requirement corresponds to the sum of the requirement for lysine accretion (Lys_p) and for maintenance (Lys_m). If we consider that the lysine content of accreted protein (Pd) is relatively constant (Lys %) and that digestible lysine is deposited according to a constant efficiency (kLys), Lys_p is equal to Pd x Lys % / kLys. Values proposed for Lys % and kLys average 7.05 and 65% (Sève, 1994); Lys_p is then be equal to Pd x 0.0705 / 0.65. There are very few published data on the estimation of Lys_m in pigs. The value of 36 mg/kg $BW^{0.75}$ proposed by Fuller *et al.* (1989) is the most commonly used. Based on these considerations, and as an example, the digestible lysine requirements of a 60-kg pig, with a protein accretion of 160 g per day, is about 18.1 g per day, of which only 0.8 g corresponds to the supply for maintenance requirements (Table 5). This simple and fast calculation shows that the lysine requirement depends almost completely on body protein accretion and that maintenance requirements are virtually insignificant relative to total requirements.

In a complementary attempt to simplify the estimation of protein needs, we can also assume that protein content of weight gain in a growing pig averages 16% with little variation with live weight (allometry coefficient is very close to 1.0; Table 7), sex or genotype. Consequently, lysine requirement becomes directly proportional to weight increase, *i.e.*, about 18 g of digestible lysine per kg of body weight gain.

The rate of protein deposition depends on nutritional factors such as protein and energy supply and any factor that affects directly the appetite of the pig: health status, ambient temperature and relative humidity, housing conditions, feed palatability or feed characteristics, etc. A heat stress (Le Bellego *et al.,* 2002b) or a deterioration of the health status (Le Floc'h *et al.,* 2004) have also direct (*i.e.*, independent of feed intake) and negative effects on Pd. But the most important factors of variation of Pd with subsequent variations in daily lysine and amino acid requirements are related to the characteristics of the animal.

Table 7. Effect of type of pig on performance and the mean digestible lysine requirement over the 25 to 90 kg BW period (adapted from Noblet et al.*, 1994d).*

Genotype	Synthetic line	LW		
Sex	Males	Males	Females	Castrates
DE intake, MJ/d[a]	26.8	27.6	28.3	30.9
BW gain, g/d	960	890	745	770
Protein gain, g/d	161	141	115	117
Protein in BW gain, %	16.8	15.9	15.6	15.2
Lipid gain, g/d	140	177	176	221
Lysine requirement[b]				
g per day	18.2	16.0	13.3	13.4
g per MJ DE	0.68	0.58	0.47	0.44
% of diet	0.91	0.78	0.63	0.58
Allometry coefficient of protein gain[c]	1.05	1.01	0.99	0.98
Allometry coefficient of lipid gain[c]	1.29	1.36	1.43	1.62

[a]DE was measured and corresponded to 90-95% of *ad-libitum* intake.
[b]As digestible lysine: calculated as the sum of Lys_m and Lys_p; diet contains 13.4 MJ DE per kg.
[c]Growth of protein mass or lipid mass relative to growth of empty body weight.

Examples of the effects of genotype, sex and castration are given in Table 7; the effect of BW in connection with animal characteristics on daily protein and AA requirements is also quite important; however, this aspect will not be detailed here.

The essential amino acids can be totally provided by proteins from the major ingredients (cereals and meals). However, the balance between essential amino acids in proteins, especially those from plant origin, is not adequate to meet the animals' requirements. This is most pronounced for cereals which represent the predominant protein fraction in most pig diets but which possess low contents of essential amino acids such as lysine, sulphur amino acids, threonine or tryptophan in their proteins; these amino acids are therefore considered as the first limiting ones in most pig diets. According to this situation, proteins are then provided in excess in order to meet the nutritional constraints for these first limiting essential amino acids. However, these first limiting amino acids can be industrially synthesised and directly incorporated into the diets as free amino acids. The crude protein (CP) level can then be lowered and a major consequence of using such low protein diets is a reduction of urinary nitrogen excretion (Table 3). The compilation of literature data suggests a 8-10% reduction of nitrogen waste per one percent reduction of the dietary CP level. Other advantages of low CP diets such as health improvements of early-weaned piglets (less digestive disorders), or the reduction of water intake have also been shown. Finally, most trials when designed correctly indicate that performance of growing or reproductive pigs are maintained. The only point that would deserve further studies is the effect of reduced crude protein level on the regulation of feed intake. Indeed, under some unknown circumstances, pigs over consume feed or at least net energy with a subsequent increased carcass fatness.

3.3. Protein: energy ratio in pig feeds

In previous sections, protein (and amino acids) and energy requirements have been described independently. But, in practical terms, the same feed must provide both energy and protein and also other nutrients (minerals, vitamins, etc.). This means that for formulating the feed, an optimal or minimal ratio between protein and energy has to be defined. Since lysine is usually the first limiting amino acid, the ratio can be more simply defined as the ratio between lysine and energy (Lys/E) and the requirements for the other essential amino acids are expressed as a percentage of lysine and according to the ideal protein concept. This approach is illustrated in Table 5; in this example, the minimum ratio between digestible lysine (g) and ME (MJ) is 18.1/28.5 or 0.64 g per MJ

ME. As suggested above, the other aspect for defining the diet characteristics consists of fixing the diet energy concentration. This depends on economical considerations (ingredient availability and cost), strategy for controlling energy intake and carcass composition, ambient temperature and, more generally, environmental constraints of feed intake and growth potential expression of the pig.

Protein and energy needs do not usually change in parallel with BW, feed restriction and any factor that affects the partition of energy gain between protein and fat and subsequent protein and energy requirements. This means that the ratio between protein (or lysine) and energy is highly variable and specific to each situation. In the next paragraphs, the impact of some important factors on Lys/E ratio in the feed will be considered.

3.3.1. Effect of pig growth potential

Body composition - chemical and tissular - of weight gain in pigs depends primarily on sex and genotype. Some examples of both effects on weight gain composition are presented in Table 7. The data indicate that castration of males results in a reduction of daily protein accretion and an increase in lipid accretion, at least while the pigs are being fed close to the *ad-libitum* level. The consequence is a decrease in the daily lysine requirement, an increase in energy requirements and a reduction of Lys/E ratio after castration. In general, the differences between castrated and intact males are more important in conventional genotypes than in highly selected genotypes. Females have protein requirements intermediate between castrated and intact males. With regard to the effect of genotype, it can be concluded that protein needs (expressed as a % of feed or relative to energy) increase with selection for reduced backfat and lower lipid accretion, or more precisely, when the lipid/protein ratio of weight gain is reduced. However, it must be noted that the results presented in Table 8 correspond to average values over the entire period.

3.3.2. Effect of live weight

Allometry coefficients presented in Table 7 indicate that in pigs derived from intense selection (synthetic line), the composition of weight gain varies very little with live weight increase, while in animals of lower genetic potential (castrated Large White males), weight gain contains increasing levels of lipids (and constant protein content) and, therefore, more energy. In addition, with increased BW, the energy requirement for maintenance increases steadily while the maintenance requirement for protein remains negligible. These variations in the chemical composition of weight gain that occur with live weight increase and the increasing importance of energy requirement for maintenance result in important differences on Lys/E. Results are illustrated in Figure 2 for the types of pigs presented in Table 7. This figure indicates a small, almost insignificant, decrease in lysine requirements in animals with high growth potential, while the decrease is far more important in animals with lower genetic potential. It can also be inferred that the lowest decrease in protein requirements with live weight are observed in animals with higher absolute protein requirements.

The practical consequence of that reduction of Lys/E ratio with increased BW is that growing pigs should be fed several diets over the growing period in order to adapt the diet characteristics to the animal requirements with a subsequent optimal utilisation of dietary protein and minimal nitrogen losses in the excreta. This reduction of N in the excreta can also be accentuated by improving the amino acid balance in the feed with the supplementation of free essential amino acids (lysine, methionine, threonine and tryptophan; see previous paragraph on "low protein diets").

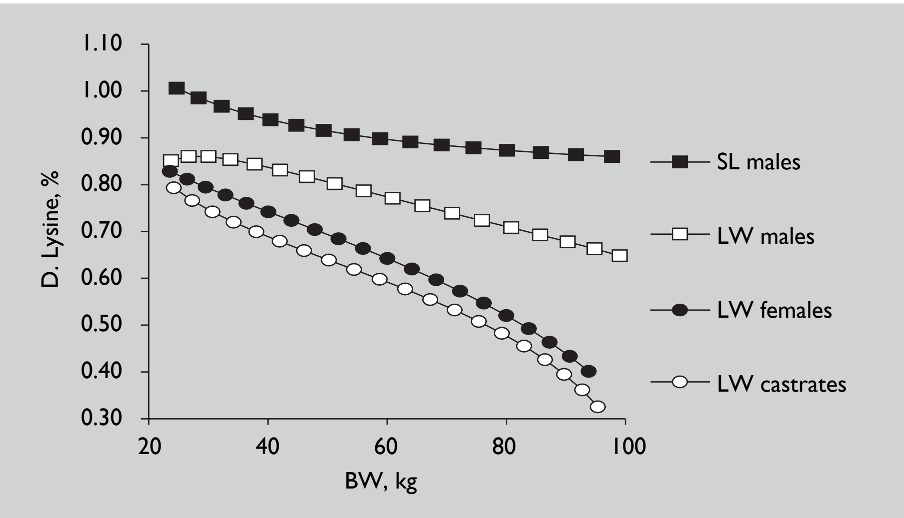

Figure 2. Effect of body weight (BW) and sex or genotype on digestible lysine requirement (D Lys, % of diet) (LW for Large White; SL for Synthetic Line; calculated from Noblet et al.*, 1994d; DE of diet is 13.4 MJ/kg).*

This reduction in Lys/E ratio with BW increase over the so-called growing-finishing period should also be extended to the immediate post-weaning period with the highest recommendations in weaning diets. On the other hand, the lowest Lys/E recommendation is obtained in pregnant sows. The situation of lactating sows is close to recommendations for growing-finishing pigs with values depending on the importance of energy deficit. All these aspects will not be detailed in the present paper.

3.3.3. Effect of feeding level

From the results of Campbell *et al.* (1985) in young growing pigs, it can be calculated that the minimum protein:energy ratio at each energy level is relatively constant. More generally, these results combined with other literature data indicate that energy restriction does not affect the minimum lysine or protein: energy ratio in growing pigs, at least when they are young or from a high genetic merit. Other results obtained in heavier pigs and/or in conventional breeds (Campbell *et al.,* 1984) suggest that the minimum lysine or protein: energy ratio would increase slightly with energy restriction. The only situation with a clear increase in Lys:E ratio with reduction of feed intake is obtained in pigs whose feed intake is beyond the feed intake that maximises the daily protein gain (Quiniou *et al.,* 1999). But, from a prospective point of view, we can consider that most pigs are/will be highly selected for lean deposition and increasingly immature over the growing period; in addition, if we exclude unconventional housing conditions such as individual housing (no competition), excellent environment and animal health, the actual feed intake will be beyond the feeding level that maximises protein deposition (Quiniou *et al.,* 1999). Therefore, from a practical point of view, the minimum lysine to energy ratio should be considered as relatively independent of energy intake (Quiniou *et al.,* 2006).

3.3.4. Effect of ambient temperature

Pigs are homeotherms and they adapt to their climatic environment in order to maintain their body temperature. The lower value of the "comfort temperature" (LCT) would be 22-24 °C in young growing pigs (<30 kg) and 20-22 °C during most of the remaining growing-finishing phase (Noblet *et al.,* 2001b; Quiniou *et al.,* 2001). When fed *ad-libitum*, growing pigs increase their intake at temperatures below LCT and reduce their intake when the temperature increases above LCT. The higher feed intake at the low ambient temperatures allows maintaining BW gain while growth is severely depressed at high temperatures (above LCT). This is illustrated in Table 8.

The consequences of the changes of feed intake related to changes in ambient temperatures on Lys/E are illustrated in Table 8. They indicate that above LCT, the Lys/E ratio does not change; the effect is then equivalent to the effect of feed restriction. On the other hand, at temperatures below LCT, additional energy loss related to thermoregulation induces an increase of energy requirements with no change in protein requirement; the consequence is a reduction of the protein: energy or Lys/E at low ambient temperatures.

3.3.5. Effect of health status

Apart from severe diseases inducing marked reductions of feed intake and performance, the health status of most pigs in commercial operations is not excellent. But, it must be mentioned that the precise description and quantification of health status are quite difficult to characterise. Nevertheless, a series of experiments conducted at the Iowa State University has clearly quantified the impact of improvement of health on performance and nutrient requirements of piglets and growing pigs. In general, feed intake is increased and BW gain is markedly improved in connection with an important increase of protein deposition (Table 9). Daily fat deposition is also increased but to a smaller extent than protein gain, so that carcass adiposity at slaughter is reduced. The minimum protein:energy ratio is subsequently increased. The results

Table 8. Effect of ambient temperature on feed intake, growth and lysine requirement in 22 to 105 kg growing pigs fed ad-libitum *(adapted from Massabie* et al.*, 1996).*

Temperature, °C	17	20	24	28
DE intake, MJ/d	33.1	32.1	29.8	26.7
BW gain, g/d	900	915	876	793
DE/gain, MJ/kg	36.8	35.1	34.0	33.7
Lysine requirement[a]				
g/d	16.2	16.5	15.8	14.3
% of diet	0.66	0.69	0.71	0.72

[a]Diet contained about 13.5 MJ DE per kg; requirement calculated as 18 g digestible lysine per kg of gain.

presented in Table 9 were obtained on conventional breeds. Other results from the same research group (Stahly *et al.*, 1994) indicate that the impact of poor health on performance is as pronounced as pigs are from an improved breed. Even the applicability of the results of these studies is questionable from both technical and economical perspectives - the production of very healthy pigs requires a lot of constraints - they clearly demonstrate that the improvement of health is an important tool for improving the performance of growing pigs; in addition, nutritional characteristics of the feed must be adapted to the health status.

Table 9. Effect of sanitary status on performance and lysine requirement of piglets and growing pigs (adapted from Williams et al.*, 1997)*[a].

Growth stage	6-27 kg		6-112 kg	
Sanitary status	High	Low	High	Low
DE intake, MJ/d	14.21	12.45	31.32	27.75
BW gain, g/d	654	507	854	688
DE/gain, MJ/kg	21.7	24.6	36.7	40.3
Protein gain, g/d	106	80	117	88
Lipid gain, g/d	83	70	241	211
Lysine requirement[b]				
g/d	11.8	9.0	13.5	10.3
% of diet	1.15	1.00	0.60	0.51

[a]Mean of results obtained at the two highest lysine levels.
[b]As digestible lysine requirements and for a 13.8 MJ DE/kg diet.

4. Conclusions

This review indicates that (1) new tools for estimating the nutritional value of feeds have been developed over last years (net energy, digestible amino acids) and they have been documented in order to be used in practice; feeding tables have been proposed, (2) daily protein and energy requirements of growing swine (and reproductive sows; not considered in this paper) are affected by many factors, which results in quite variable recommendations of protein to energy ratios in pig feeds, in addition to specific recommendations in terms of diet energy concentration. With regard to amino acids, it can be accepted that the optimal balance between essential amino acids is fairly constant. In addition, the dietary protein level can be reduced according to an improvement of the amino acid balance with the supplementation of free amino acids; this strategy allows the impact of pig production on nitrogen excretion into the environment to be minimised.

The major uncertainties in the field of pig nutrition concern (1) the effects of "technological" treatments on the nutritional values of feeds (and to a smaller extent on metabolism and requirements) and (2) the evaluation of the pig health status and its impact on metabolism and requirements, via some specific requirements related to inflammation, immunity reactions, etc. and changes in the efficiencies of nutrients. Present recommendations do not take into account these factors and would apply to relatively healthy growing swine.

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Pork quality: meeting the consumers' needs

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1. Introduction

The consumers' decision to purchase pork is based on a number of intrinsic cues such as colour, fat level, marbling, and extrinsic cues such as food safety, price, nutritive value, meal convenience etc. While the consumers' decision to purchase the pork product again is to some extent dependent on both intrinsic and extrinsic cues, the predominant factor is undoubtedly the eating quality experience or sensory quality such as tenderness, juiciness, flavour and aroma. However, in light of a number of negative media stories relating to animal welfare, disease and food safety issues, the role of extrinsic cues are becoming increasingly important to the extent that perhaps this is having a negative effect on the eating quality of pork. In this paper, the author highlights some of the key aspects of consumer preferences to fresh pork and reviews some of the key factors that affect pork quality as defined by the consumer. Finally, this paper outlines the role of eating quality pathways to help deliver a high quality pork product that consistently meets the consumers' needs.

2. Defining pork quality

The term "pork quality" is defined and interpreted differently by pork producers, processors, retailers and ultimately the consumer. Hammond's (1955) definition "Quality can best be defined as that which the public likes best and for which they are prepared to pay more than average prices" only takes the aspects of the consumer need and profitability into account. Such a definition however, cannot be accepted as it only concerns the "degree of goodness" rather than the objective characterisation of quality. A suitable definition for pork quality must encompass all of the different factors involved from the producer to the final consumer. Pork quality can thus be defined as "the totality of all properties and characteristics of pork that are important to its nutritional value, acceptability, human health and the processing of pork" (European Organisation for Quality Control, 1976).

Hofmann (1987) classified pork quality characteristics into four main quality groups (technological, nutritional, hygienic and organoleptic). Technological characteristics include those factors that determine the suitability of pork for preparation and packaging for distribution, as well as for cooking and processing into various products and for storage. Hygienic characteristics are concerned with the presence (or ideally) absence of micro-organisms, drugs and pesticides. Nutritional characteristics deal with the chemical composition and nutritional properties of the pork. Organoleptic characteristics include the appearance (colour, marbling, external fat and exudate) and the sensory quality (aroma, tenderness, juiciness and flavour). Based on these characteristics, pork quality can thus be defined as "the sum of the technological, nutritional, hygienic and organoleptic properties of pork" (Hofmann, 1973), or "pork quality is the sum of all the quality factors" (Hofmann, 1987).

There is intense competition in the food industry to attract and retain consumers, and it is this that has driven the meat industries to produce what the consumer requires, rather than what we think might be required. But, is that the case with the pork? Do pork producers, processors and the retailer truly understand the consumers' needs and preferences when it comes to pork quality? Based on Hofmann's definition (1987) most pig production systems are heavily focused on the technological, nutritional and hygienic properties of pork whilst little attention has been paid to the enhancement of organoleptic characteristics of pork. Most pig production systems still mainly use technological quality parameters such as lean meat as the main basis of payment. Whilst technological, nutritional and hygienic characteristics of pork are very important, especially in light of some of the recent negative press related to the animal industries, the organoleptic characteristics such as the sensory quality of the product are the main factors that influence the consumer to repurchase that pork product.

3. Fresh pork: consumer needs and preferences

The consumption of pork varies widely, from an annual per capita consumption of less than 3 kg in South Africa to over 60 kg in Austria, Denmark and Spain (FAO, 2002). In Europe, pork is the most consumed meat, comprising almost half the total meat consumption. Pork in some European countries is seen as an ordinary meat which is not expensive, but equally not suitable for special occasions (Bryhni *et al.*, 2002; Ngapo *et al.*, 2002). Hence the challenge is to ensure that the pork industry consistently delivers a high quality pork product that meets the consumers' needs. Consumer perception of pork quality has traditionally been based largely on intrinsic cues like the colour of the meat, the visible fat and the cut. This is not mainly because consumers have been very competent in determining quality from these cues but because fresh pork is a largely unbranded product, and there are few extrinsic cues available. However, the use of extrinsic cues to "assess" pork quality are increasing and this trend will continue.

Grunert *et al.* (2002) conducted a study with German consumers in a focus group discussing parameters that influence pork quality. The consumers were confident that they could judge the sensory quality of pork themselves. The consumers were then presented with 22 cues and asked to (1) indicate whether the consumers understood what the cue was all about, (2) rank order the cues by perceived importance for pork quality. The results however indicate that of the top 5 cues as measured by both knowledge and importance, none of them are related to sensory quality but are, instead, related to technological, nutritional, and hygienic quality of pork (Figure 1).

Ngapo *et al.* (2007) have conducted one of the few global consumer preference studies, and have identified and compared the most important characteristics of fresh pork that determined consumer choice in 23 countries from all five continents. Briefly, photographs of 16 commercial pork chops were computer-

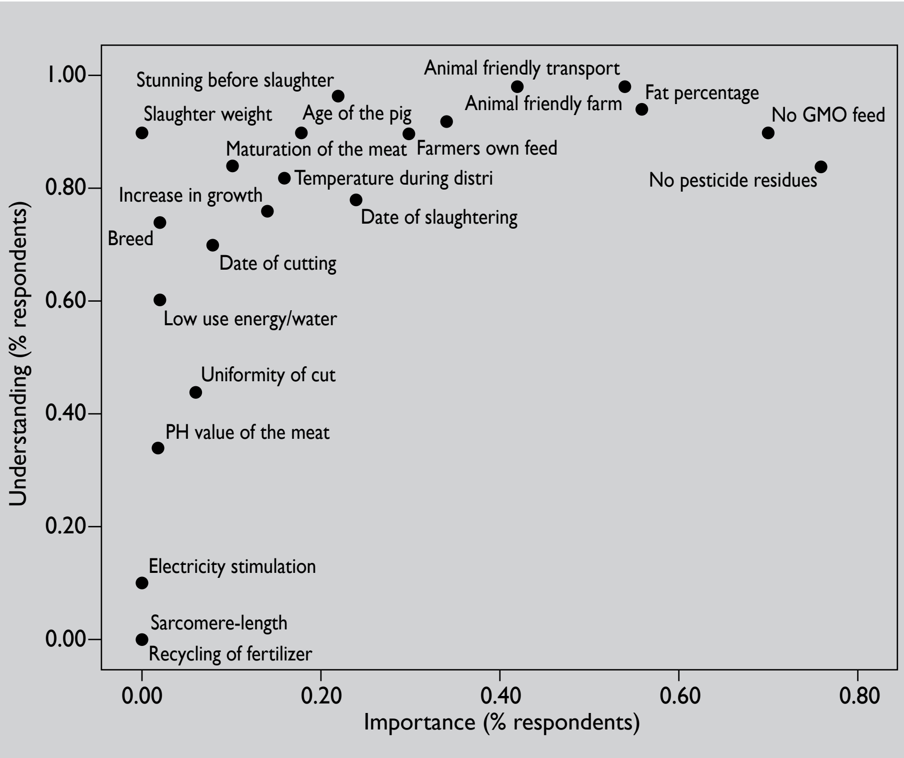

Figure 1. Understanding and importance of 22 extrinsic pork cues (Grunert et al.*, 2002).*

modified to give two levels of each of the characteristics (1) fat cover (averages of 8% or 17% chop surface area for lean or fat chops, respectively), (2) colour (average CIELAB L* of 64 or 56, and a* of 18 or 24 for light and dark red chops, respectively), (3) marbling (absent or approximately 1.5% of the muscle area) and (4) drip (absent or 5.5% of the chop area). Each double-page contained 16 different chop shapes and each chop shape represented one of the combinations of the four characteristics studied. Therefore every double-page contained a complete set of all 16 combinations of the two levels of each of the four characteristics. Both the order of representation of the characteristics with respect to the chop shape and the position of the chops in a double-page were randomised. Consumers were pork eaters older than 15 years of age and chosen at random. Consumers were surveyed at a range of sites, including agricultural shows, supermarkets and at their workplaces. In total 12,590 consumers completed the survey.

Ngapo *et al.* (2007) reported that across all countries, colour was the most consistently chosen characteristic, followed by fat cover, marbling and drip loss characteristics (Figure 2). The Australian consumers were by far the most consistent with 84% giving consistent choices in contrast to only half of the Yugoslavian consumers. Over all countries, similar numbers chose the dark as choose the light red pork. Australian (73%), Irish (67%) and Polish (63%) consumers showed the strongest preference for the light red pork whilst the Taiwanese consumers (66%) showed a strong preference for the dark red pork. Although the largest differences were found between countries, there was little evidence that ethnic origins were strong, except for the similarities of the Asian (Taiwan, Japan and Korea) countries which were different from the other countries. However, these countries were also very different from one another. Irish and Polish consumers clearly had quite different preferences and both had different preferences to those of the other European countries in this survey.

The studies by Grunert *et al.* (2002) and Ngapo *et al.* (2007) certainly provide an understanding of some of the consumer preferences for fresh pork. However, are there demographic differences when it comes to the eating experience or sensory quality of pork? A feasibility study conducted in Australia (Bennett, 1997) indicated that the Australian pork consumer preferred pork that was "tender, juicy and free from unpleasant odours or flavours". Is the sensory preference for tender, juicy and unpleasant odour/flavour-free pork applicable to Australia alone or does it reflect the pork eating quality needs of the global pork consumer? Whilst no global pork sensory evaluations have been conducted to date mainly due to the cost of such testing, a global consumer

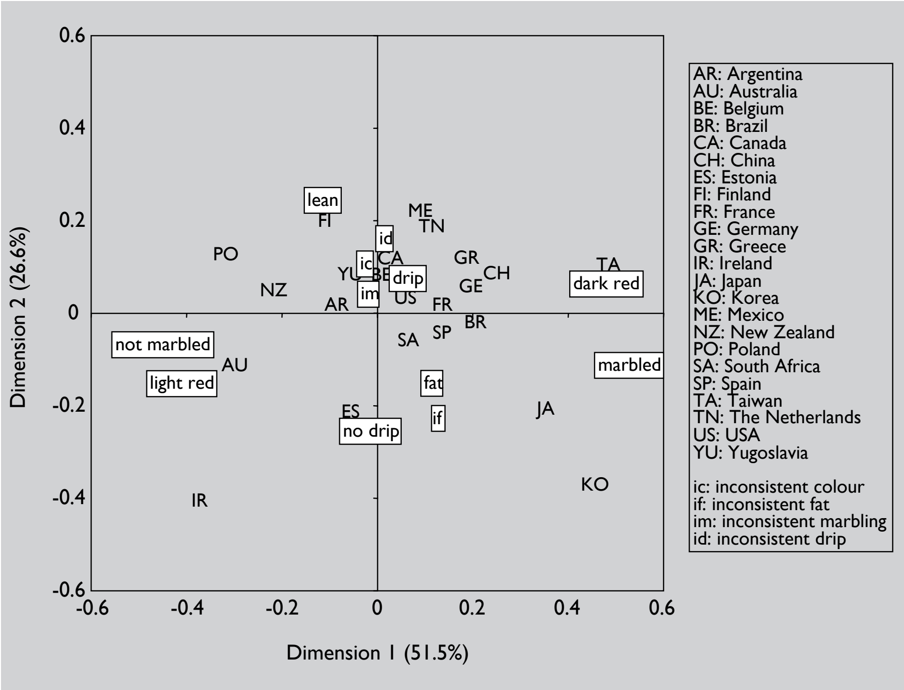

Figure 2. Preferences for 4 pork characteristics from surveys conducted in 23 countries (Ngapo et al.*, 2007).*

study is underway for beef. The initial sensory evaluations indicate that there were no differences between consumers in Japan, Korea, Australia and Ireland when assessing the eating quality of beef as defined by the Meat Standards Australia (MSA) eating quality system (Pethick, personal communication).

4. Factors affecting objective and sensory pork quality

A complex interaction of animal, pre-slaughter and post-slaughter factors can have a significant influence on pork quality (Table 1). Meat quality defects such as pale, soft, exudative (PSE) pork and dark, firm, dry (DFD) pork still remain issues even though considerable research has been directed at identifying best practice to optimise pork quality. In this section some of the key animal, pre-slaughter and post-slaughter factors that affect objective and sensory pork quality are reviewed.

Table 1. Quality control points and intervention strategies to improve pork quality (Meisinger, 2002).

Quality control points	Opportunities for intervention
QCP 1. Genetic inputs	Choices of breeds, lines, and genotypes Choice of sires within breed Stress gene/Napole gene Loin intramuscular fat Fibre type DNA technology
QCP 2. Nutritional inputs	Vitamin & mineral supplementation Amino acid levels pre-market Dietary fat sources & levels Dietary starch Metabolic modifiers Feed withdrawal
QCP 3. On-farm pig handling	Health/stress management Slaughter weight Facility construction
QCP 4. Handling pigs during transport	TQA training Electric prods Truck/trailer type Load size Weather extremes
QCP 5. Pre-slaughter handling	Facility construction Water sprays Electric prods Rest times Pre-stun handling
QCP 6. Stun, stick & early post-mortem handling of carcasses	Stunning system Stun to stick interval Horizontal vs. vertical sticking/bleeding Bleeding time Scald temp/time or skin time Time on buffer rails

Table 1. Continued.

Quality control points	Opportunities for intervention
QCP 7. Handling of carcass during evisceration	Evisceration time Splitting accuracy Faecal contamination Trimming Measuring carcass composition Measuring pork quality
QCP 8. Chilling of carcasses	Chilling system Chilling time/temperature
QCP 9. Fabrication of pork cuts	Workmanship
QCP 10. Further processed fresh pork	Enhancement of fresh pork Irradiation of fresh pork Freezing of fresh pork
QCP 11. Packaging of fresh pork	Ageing Packaging
QCP 12. Cooking of fresh pork	Cooking procedure End point temperature Cooking loss & raw meat quality

4.1. Genotype

4.1.1. Halothane gene

Pigs carrying the Halothane (Hal) gene (homozygous recessive – nn (reactors); heterozygous – Nn (carriers)) are leaner, grow faster and have better carcass conformation compared to 'normal' (homozygous dominant – NN) pigs (Wood, 1993). However, the introduction of the Hal gene in pig breeds has seen a dramatic increase in the incidence of pork quality defects such as PSE pork (Wood, 1993). Pigs carrying the Hal gene (nn and Nn) are stress susceptible (Porcine Stress Syndrome) due to disorders in muscle calcium (Ca^{2+}) regulation, which results in the muscle being hypersensitive to stimulation by various stressors (Fuji *et al.*, 1991). Normal conditions during transport and at the abattoir can stress Hal pigs causing a rapid rate of pH decline post-slaughter while muscle temperature is still high (>36 °C), resulting in PSE pork (Briskey and Wismer-Pedersen, 1961). Pale, soft, exudative pork is characterised by its unusually pale colour, soft or sloppy texture and excess exudation (Bendall and Wismer-Pedersen, 1962; Channon *et al.*, 2000). Carcasses exhibiting PSE pork characteristics also tend to have a higher incidence of colour variations between portions of the same muscle (especially in the hams) and between adjacent muscles of PSE carcasses; this is referred to as "two-toning" (Briskey and Kauffman, 1971). Consumers are hesitant to purchase pork that is pale or "two-toned" and relate such pork to be of inferior eating quality. Most studies also indicate that PSE pork has inferior eating quality with reduced tenderness and juiciness (Bejerholm, 1984; Sather *et al.*, 1991). Studies have also shown that the improvements in tenderness associated with ageing of pork are not applicable to PSE pork (Fernandez and Tornberg, 1994; Warner *et al.*, 1997, Channon *et al.*, 2000).

4.1.2. Hampshire gene

The Hampshire gene or the "Rendement Napole" (RN) gene is a dominant gene and was first found in two commercial pig bloodlines in France (LeRoy *et al.*, 1990). The RN gene was found at a higher frequency in Hampshire pigs compared to other breeds such as Large White, Landrace, Yorkshire and Peitran. Pigs carrying the RN gene were found to have significantly higher muscle glycogen concentrations (70%) compared to "normal" pigs (Estrade *et al.*, 1993). As a consequence RN pigs exhibit an extended period of muscle pH decline post-slaughter leading to an extremely low ultimate muscle pH and water holding capacity, rather than the increased rate of pH decline and protein denaturation observed in PSE pork (LeRoy *et al.*, 1990). While the RN gene reduces muscle pH and water holding capacity of pork, the RN gene has been shown to improve pork tenderness and juiciness (Lundström *et al.*, 1998).

4.2. Breed

4.2.1. Duroc and intramuscular fat

It is generally accepted that higher levels of intramuscular fat or marbling in pork have been shown to positively influence the juiciness, tenderness and flavour of pork (Wood, 1993; Table 2). This relationship is by no means clear-cut, with some studies reporting no effect of marbling on the eating quality of pork (Goransson *et al.*, 1992). However, in the case of Australia for example, the production of leaner pigs over the last 30 years has seen marbling levels at <1% (Channon and Baud, 2000), which has coincided with a deterioration in the eating quality of Australian pork.

Table 2. Effect of increasing intramuscular fat % on eating quality of loin pork chops (Wood, 1993).

Intramuscular fat %	Flavour[1]	Tenderness[1]	Juiciness[1]	Acceptability[1]
1.47	2.5[a]	1.3[a]	1.7[a]	0.6[a]
2.89	2.9[b]	3.1[b]	3.2[b]	2.0[b]
4.34	2.8[b]	2.4[c]	2.5[c]	2.0[b]

[1]Taste panel scores on a scale from -5 to 5 with low = undesirable.
[a,b,c]Different superscripts within columns are significant at P<0.001.

Fast growing "white" European pig breeds (Large White, Landrace, Yorkshire) have lower levels of marbling compared with the darker skinned breeds, such as Duroc (Wood, 1993; NPPC, 1995) and Berkshire (NPPC, 1995). The Meat and Livestock Commission (MLC), UK, evaluated the Duroc breed and found that tenderness of pork was improved in pigs with Duroc gene proportions above 50%, while juiciness increased when the proportion of Duroc genes was increased to 75% (Meat and Livestock Commission, 1992b; Table 3). Similar improvements in juiciness, tenderness and flavour were also reported by the National Genetic Evaluation Program (NPPC, 1995). In addition, Candek-Potoker *et al.* (1996) reported that pork from Duroc pigs not only had higher marbling levels but also better colour and texture compared to Large White and Landrace pigs.

Table 3. The influence of % Duroc genes on pork eating quality (Meat and Livestock Commision, 1992b).

	% Duroc genes				
	0	25	50	75	l.s.d.
Tenderness	4.96	5.03	5.32	5.38	0.25
Juiciness	4.09	4.11	4.18	4.38	0.17
Flavour	3.88	3.99	3.96	3.98	0.12

Evaluated on an 8 point scale (lower = undesirable).

Studies also indicate that the inclusion of Duroc bloodlines in predominantly 'white' European breeds can also result in improvements in pork eating quality. Recent studies conducted in Australia, indicate that Large White x Landrace x Duroc crossbred pigs with a high proportion of Duroc genes (50%) had higher marbling values, better juiciness, tenderness and flavour compared to pork from Large White x Landrace x Duroc crossbred pigs with a low proportion of Duroc genes (<25%) (D'Souza and Mullan, 2002).

4.3. Castration

The major compounds responsible for boar tainted pork are androstenone and skatole (Patterson *et al.*, 1990). Castration is the only effective method to eliminate boar taint especially at heavier slaughter weights. In Europe, increasing interest in farming practices has highlighted the welfare issues surrounding this form of castration and has consequently increased the pressure on legislators to introduce controls and ultimately to ban surgical castration. At present, a number of EU countries are re-examining the practice of surgical castration, while countries such as Norway will cease to use castration by 2009.

Another alternative is immunological castration using the vaccine Improvac® which was developed in Australia. Improvac® is a vaccine against gonadotropin-releasing hormone (GnRF), which stimulates the pigs' immune system to produce specific antibodies against GnRF. Consequently, testis function is inhibited and the production of all boar taint compounds are suppressed. Boar taint compounds which have accumulated within the pigs' system at the time of the vaccination are rapidly metabolised and eliminated, leaving the pigs free of any boar taint at the time of slaughter. Pork from entire male pigs castrated by using Improvac®, had lower androstenone and skatole concentrations, higher marbling levels and lower surface exudate compared to pork from entire male pigs (D'Souza *et al.*, 2000; Table 4). D'Souza *et al.* (1999b) reported that pork from entire male pigs tended to have poorer odour compared to pork from surgical and immunological castrates (Table 4).

4.4. Feeding regimes

4.4.1. Ad-libitum feeding

The benefits of *ad-libitum* versus restricted feeding in terms of growth performance and carcass quality are significant. Pigs fed *ad-libitum* during the grower and finisher phase (30 – 100 kg live weight) grow faster (Trezona, 2001).

Table 4. The effect of sex (entire male - EM, surgical castrate male - SCM and immunological castrate male - ICM) on eating quality of pork loin steaks (D'Souza et al.*, 1999b).*

Sex (S)	EM	SCM	ICM	l.s.d.	P-value
Odour[1]	56	62	62	6.13	0.093
Flavour[1]	58	62	66	7.01	0.101
Tenderness[1]	52	59	62	7.44	0.016
Juiciness[1]	60	59	64	7.05	0.304
Overall acceptability[1]	58	62	67	6.41	0.025

[1]Acceptability score (line scale) for all attributes, 0 = dislike extremely and 100 = like extremely.

The *ad-libitum* feeding of protein deficient diets 30 days prior to slaughter improved the eating quality of pork by increasing marbling levels in the loin (Cisneros *et al.*, 1996). The increase in marbling reported by Cisneros *et al.* (1996), however, was also accompanied by an increase in carcass fatness. However, D'Souza *et al.* (2004a) reported that feeding pigs a 15% reduced protein:energy diet during the grower growth phase only increased intramuscular fat levels without any detrimental effect on growth performance or carcass quality, and improved the eating quality of pork compared to pork from the control and Vit A restricted diet treatments D'Souza *et al.* (2004b).

Studies have also shown that feeding high energy diets, especially in the latter stages of growth, can elevate the rate of protein synthesis and degradation which may accelerate *post-mortem* proteolysis and improve the tenderness of pork (Tarrant, 1998).

4.5. Feed additives

4.5.1. Magnesium

Studies have shown that dietary magnesium (Mg) supplementation alleviates the effects of stress by reducing plasma cortisol, norepinephrine, epinephrine and dopamine concentrations (Niemack *et al.*, 1979; Kietzman and Jablonski, 1985). Consequently, studies have been conducted to investigate the influence of dietary Mg supplementation on reducing the effects of stress and improving pork quality. Numerous studies have shown that dietary Mg supplementation in pigs resulted in improved pork quality (Otten *et al.*, 1992; Schaefer *et al.*, 1993; D'Souza *et al.*, 1998). Whilst dietary supplementation using inorganic Mg sources such as $MgSO_4$ and $MgCl_2$ (D'Souza *et al.*, 1999a) and magnesium mica (Apple *et al.*, 2000) have also been shown to reduce drip loss, improve colour and reduce the incidence of PSE pork, best results have been achieved using organic Mg supplementation. The use of dietary Mg supplementation has been shown to improve objective measures of pork quality such as drip loss, colour and the incidence of PSE, however, there is no data relating the improvements in objective measures of pork quality with improved pork eating quality. As the relationship between low water holding capacity and increased meat toughness is well established (Lawrie, 1998), it is reasonable to assume that the reduced drip loss and the lower PSE % observed with dietary Mg supplementation could have a positive influence on the eating quality of pork.

4.5.2. Vitamin E

Dietary vitamin E (*all-rac-α*-tocopheryl acetate) supplementation has been shown to reduce drip loss, improve colour stability and reduce the off-flavours of both fresh and processed pork products (Asghar *et al.*, 1991; Monahan *et al.*, 1992). While dietary vitamin E supplementation can have a positive impact on the eating quality of fresh pork, the real benefits are the improved lipid and colour stability and improved water holding capacity in pork products which require frozen storage for extended periods. There are a range of factors that contribute to the deterioration in pork quality and loss of shelf life as a consequence of lipid oxidation occurring in pork and pork products. These factors include the state and content of pro-oxidants such as Fe and myoglobin, level of antioxidants such as *α*-tocopherol and enzymes such as glutathione peroxidase, superoxide dismutase and catalase present in muscle, composition and amount of muscle lipids and the storage conditions of meat and meat products (Lawrie, 1998).

4.5.3. Selenium

Inorganic selenium (sodium selenite) is regularly used as a source of selenium (Se) in diets for pigs of all ages, however, extensive research by Mahan and colleagues has shown that the use of organic Se (Sel-Plex®, Alltech Inc.) has additional benefits that surpass that of selenite. When organic Se was fed to growing pigs, a linear and significant increase in the Se content of muscle tissue was observed (Mahan *et al.,* 1999). In the same study, supplementation with inorganic Se gave only a minimal increase in muscle selenium concentrations.

Additionally, there were indications that when inorganic Se was fed it was bound to muscle tissue in a form that may be detrimental to muscle tissue and pork quality (increase drip loss). In a recent study, D'Souza (unpublished), investigated the use of Mg and Se in feed to enhance pork quality. Pork from pigs fed diets supplemented with Mg (16g Mg Bioplex™ and 0.4g Sel-Plex®/kg of feed) had significantly improved meat colour at 24h post-slaughter and reduced drip loss at 24h, 7 and 21days post-slaughter compared to pigs fed the control diet. Apart from effects on pork quality, perhaps the greatest interest in feeding grower pigs organic Se is to increase Se concentrations in the meat, with subsequent health benefits to consumers. Schrauzer (2002) presented evidence that a daily extra-dietary supplement of 200 µg of Se reduces cancer risk and increases resistance to viral infections in humans.

4.6. Metabolic modifiers

4.6.1. Porcine somatotrophin

Intramuscular administration of porcine somatotropin (pST) is an effective management strategy to reduce backfat in pigs (Campbell *et al.*, 1990) and is one that is quite widely used in Australia. Porcine somatotrophin increases protein deposition and decreases subcutaneous, intermuscular and intramuscular fat deposition resulting in leaner carcasses (Dunshea, 1994). Studies by Lefaucheur *et al.* (1992) and Ender *et al.* (1992) have reported reductions in both carcass fat and marbling levels in pork from pigs administered pST without any detrimental effects on the eating quality of pork. The above studies (Lefaucheur *et al.*, 1992; Ender *et al.*, 1992) are in contrast to that reported by D'Souza *et al.* (2002) who found that pork from pigs administered pST had lower consumer preference scores for tenderness, juiciness and overall acceptability. Solomon *et al.* (1990) reported that pST administration increased muscle fibre size and subsequent shear force, an objective measure of tenderness of fresh pork. The use of pST has also been reported to reduce calcium – activated proteolysis in the *Longissimus* muscle, thereby preventing improvements in tenderness during the ageing process (Weikard *et al.*, 1992). Porcine somatotrophin administration remains an important management strategy in some countries such as Australia, enabling pork producers to better meet the demands of the consumers for leaner pork. However, additional attention to the potential negative influence of such management strategies on the eating quality attributes of pork must be considered.

4.6.2. Ractopamine

Ractopamine is a β-agonist that increases the protein deposition rate in pigs (Dunshea and King, 1994; Dunshea *et al.*, 1993; Dunshea and Walton, 1995). Ractopamine has recently been registered as a feed additive to improve carcass leanness (Paylean®) for use in the United States of America and is currently under consideration for registration in Australia. Dietary ractopamine supplementation had no effect on muscle pH, colour, water holding capacity or marbling levels (Dunshea *et al.*, 1993; Sainz *et al.*, 1993; Xu *et al.*, 1998; Xiao *et al.*, 1999). Smith *et al.* (1995) reported that loin muscle from female pigs had higher muscle pH, lower cooking loss and darker colour, while that from entire male pigs fed ractopamine had higher drip loss and paler colour. A negative effect of ractopamine on objective measures of tenderness was also reported by Uttaro *et al.* (1993).

4.7. Moisture enhancement

Moisture enhancement is the process of adding non-meat ingredients to fresh pork, to improve the eating quality (juiciness, tenderness, and flavour of the pork) of the final product. Enhancement typically consists of a solution of water, sodium phosphates, salt, sodium lactate and varying flavouring agents injected into the muscle (Miller, 2001). It should be noted that moisture enhancement is not a method to improve low quality pork, but it is a method to improve the overall quality of fresh pork in the retail case. This technique is especially useful for protecting pork from the temperature abuse that is typical when most U.S. consumers cook fresh pork (Meisinger, 2002). Studies by D'Souza *et al.* (2003) indicate that moisture enhancement of pork significantly improved the tenderness, juiciness and overall eating quality of pork.

4.8. Ageing

Ageing is another factor that can influence the tenderness of pork (Dransfield *et al.*, 1981). Ageing is necessary, as pork is unacceptably tough immediately *post-rigor*. The tenderisation process that occurs during ageing is due to protein degradation and/or proteolysis occurring within the myofibrillar component (Koohmaraie *et al.*, 1995). The main factors that can influence the ageing of pork include the rate and extent of pH decline, chilling temperature and ageing duration. A rapid decline in muscle pH also accelerates the calpain system, which would result in lower subsequent ageing rates (Marsh *et al.*, 1987). Generally, an ageing duration of between 3-5 days at 4 °C is usually sufficient to tenderise pork (Faustman, 1994). However, PSE pork has reduced protein solubility, irreversible binding of myosin to the actin filaments and functional damage to the myosin ATPase which severely hinders ageing and consequently the pork tenderisation process (Sung *et al.*, 1981).

5. Eating quality pathways

Over the last decade, pork retailers, processors and producers have recognised that they must collectively provide a product that meets clearly defined consumer specifications that maximise consumers' purchase and re-purchase intentions. As seen in Table 5, a range of factors affect pork quality (objective and sensory) and a number of strategies have been shown to enhance pork quality. However, it is just not economically viable to implement all the strategies that enhance pork quality. In addition, the pork industry needs to take into account some of the consumer preferences such as leanness of pork that are clearly at odds with the consumers' requirement for tender and juicy pork. As a consequence a number of countries have researched and developed pork eating quality systems that incorporate a number of key strategies to produce a high quality pork product that is consistently acceptable to the consumer.

The Meat and Livestock Commission, UK, has developed the "Blueprint for Lean and Tender Pork". The key elements of the standard specifications include

Table 5. The effect of the Select Pork eating quality pathway on the sensory quality of the Longissimus thoracis muscle (D'Souza et al.*, 2003).*

Brand	Generic Pork	*Select Pork* (Stage 1)	*Select Pork* (Stages 1&2)	l.s.d	Significance
Aroma[1]	55	63	57	6.54	0.002
Flavour[1]	54	66	76	6.11	<0.001
Juiciness[1]	43	58	75	6.85	<0.001
Tenderness[1]	41	59	75	7.40	<0.001
Overall acceptability[1]	48	64	76	6.67	<0.001
Quality grade[2]	2.9	3.5	4.0	0.279	<0.001

[1]Acceptability score (line scale); 0 = dislike extremely and 100 = like extremely.
[2]Quality grade; 1 = unsatisfactory, 2 = below average, 3 = average, 4 = above average, 5 = premium.

(1) *ad-libitum* feeding of pigs from 30 kg to slaughter, (2) careful live animal handling, (3) minimum fatness at the P2 site of 8 mm, (4) considerate chilling (deep muscle temperature above 10 °C in first 3 hours), (5) no PSE carcasses, (6), pelvic suspension within 1 hour for 12 hours, (7) ageing (4 days-legs, 7 days-loins), and (8) dietary constraints (maximum 2.5% fishmeal, 10% peas). For the Premium standard, MLC have added a genetic component, pig breeds used must contain 50-75% Duroc (Meat and Livestock Commission, 1992a).

In Denmark, processors define the feed, genetics and production specifications of pigs that are required, and producers are then bound to adhere to these specifications. Items addressed in the specifications include lean meat percentage, PSE, slaughter weight, intramuscular fat content, colour and pH values. The Swiss have included intramuscular fat into the selection indices, whilst in Germany, the Westfleisch group includes no growth promotants in feed after 40 kg liveweight and two specific genotypes (BHZP and Deutsche Pig -PIC).

The above examples are "generic" in their application and have been designed to suit a wide range of production, processing and retail environments. However, a number of companies have developed more specific eating quality pathways to produce a high quality pork product required by the consumer. "*Select Pork*" is one such example of an eating quality pathway that was implemented by a consumer focused alliance in Western Australia. The *Select Pork* alliance was formed between a group of ten producers, a processor and a retailer (35 outlets). The eating quality pathway used by the *Select Pork* alliance involved eating quality interventions at the producer and processor level and was implemented in two stages. The Stage 1 eating quality pathway stipulated (1) Halothane-free pigs, (2) pigs with minimum of 50% Duroc sire lines, and (3) no entire males (pork from immunological castrates, surgical castrates and females only). Stage 2 involved moisture enhancement of fresh pork.

The results from a benchmarking study indicate that the branded pork from *Select Pork* (Stage 1) and *Select Pork* (Stage 1 and 2) were considered by consumers to have better eating quality compared to generic pork (Table 5). *Select Pork* (Stage 1) was considered to have better odour compared to generic and *Select Pork* (Stages 1 and 2). However, *Select Pork* (Stages 1 and 2) was considered to have the best flavour, juiciness, tenderness, overall acceptability and quality grade followed by *Select Pork* (Stage 1) and then generic pork. In addition, the incidence of consumers rating the pork as being below average or the pork eating quality 'fail rate' was 30%, 15% and 3% for generic pork, *Select Pork* (Stage 1) and *Select Pork* (Stages 1 and 2) respectively.

An effective eating quality pathway should implement strategies that significantly enhance the eating quality of the end product, with each eating quality intervention having an additive effect. More importantly however, all eating quality intervention strategies should improve the consistency of the eating experience.

6. Conclusions

There is more pork consumed in the world than any other meat, yet there is still intense competition for the pork industry world-wide to attract and retain consumers. Food safety, price, nutritive value, meal convenience and appearance play an important role in determining whether consumers purchase pork but the pork industry must also ensure that the end product also meets the consumers' requirements for tender, juicy pork that is free from any off-taints and aromas. The implementation of eating quality pathways is one way to ensure that that all the consumers' needs for high quality pork are consistently being met.

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Considerations on the environmental impact of minerals in manure from pigs: strategies to minimise environmental load by nutrition and management

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1. Introduction

There is an increasing awareness of the impact of livestock production systems on the environment, especially in countries or regions with a dense animal population, e.g., in Denmark and The Netherlands (Jongbloed *et al.,* 1999). In the past, animals were fed home-grown feeds and the manure produced was regarded as a scarce and valuable commodity for maintaining soil fertility. This ensured nutrient recycling except for losses associated with storage, transport and nutrients deposited in milk and meat.

Livestock production per hectare has increased by using more nitrogen (N) and phosphorus (P) on dairy farming systems in the form of inorganic fertilisers and purchased feeds, or in pig and poultry farming by purchased feeds. Thus, crop and animal production were specialised and separated, in many cases by large distances. As a consequence, large amounts of nutrients excreted in animal manure, are not fully utilised in the soil-plant-animal system and finally lost to the environment, resulting in accumulation. Therefore, legislation in some countries and states was introduced to limit the use of animal manure or the number of animals per hectare of cultivated land (Jongbloed and Lenis, 1998).

Environmental concerns can be divided into three categories: concerns related to the soil (accumulation of nutrients), the water (eutrophication) and the air (global warming, ammonia, odours). The major concern in many countries such as The Netherlands, is finding an acceptable balance between the input and output of N and minerals per hectare of cultivated land. Some minerals, such as P, copper (Cu), and zinc (Zn) accumulate in the soil and contribute via leaching and run-off to eutrophication of ground and fresh water sources. Table 1 lists the contributions of N and P from animal manure and fertilisers in The Netherlands, together with the surplus of these minerals per ha of cultivated land (CBS, 2002; LEI, 2005). Table 1 demonstrates that an increase

Table 1. Amount of N and P in animal manure and fertilisers in The Netherlands (kg/ha cultivated land; CBS, 2002; LEI, 2005).

	Nitrogen				Phosphorus			
Year	1970	1980	1990	2003	1970	1980	1990	2003
Manure	133	190	239	141	35	50	47	27
Fertiliser	185	240	201	122	22	17	16	10
Other	14	17	19	41	2	3	3	3
Total input	332	447	459	304	59	70	67	39
In crops	167	210	248	164	22	29	31	23
Surplus	165	237	211	140	37	41	36	16

of N and P output from manure took place to 1990, after which a substantial decrease was obtained (primarily as a result of legislation). Nevertheless, there is still a significant excess of these minerals. Accumulation of P in the soil leads to eutrophication and may cause excessive growth of algae, which sometimes results in massive fish mortality (Roland *et al.,* 1993).

Because of excessive application of manure per hectare of land, not only P but also heavy metals accumulate in the top layer, with consequences for plant growth and potential risks for human and animal health (e.g., copper intoxication of sheep; Henkens, 1975), and soil life (earth worms, Van Rhee, 1974; soil microbiology, Bouwman *et al.,* 1999). Furthermore, because of excessive application of manure and fertilisers per hectare of land, surplus precipitation and leaching, nitrate often exceeds tolerable values in fresh water (50 mg nitrate/l; EU, 1991). Generally, the enrichment of the environment leads to less biodiversity. This aspect is stressed more and more in The Netherlands.

Ammonia and greenhouse gases, together with noxious odours from animal husbandry are also of concern. Animal husbandry causes 90% of the total NH_3 emission in The Netherlands (Anonymous, 2006). The contribution of agriculture in The Netherlands to emissions of CH_4 primarily from ruminants, and gases like N_2O which contribute to global warming (greenhouse effect) are 48% and 54%, respectively (Anonymous, 2006). Dust, noise, visual pollution, and animals and their manure as carriers of pathogens, may also be regarded as environmental concerns. Furthermore, the loss of organic matter in the soil predominantly due to erosion may also be regarded as one of the major environmental threats (Pimentel *et al.,* 1995).

Protein (nitrogen/amino acids) and the minerals like P, Cu and Zn are essential dietary nutrients for maintenance and production of animals. However, to avoid unnecessary excretion of these nutrients, there should be a close balance between the animal's genetic requirement and the quantity and quality of nutrients consumed (Jongbloed *et al.*, 1999).

The aim of this paper is to describe the environmental concerns associated with intensive animal production with special reference to minerals such as P, Cu and Zn. Excretion of these minerals in manure by different categories of pigs at several dietary options are presented. Consequently, examples will be presented concerning nutritional methods to reduce the excretion of P and other minerals. Only nutritional aspects will be discussed here, although the authors are aware that aspects such as housing, mechanisation, labour and economy are also important. Finally, some insight into the European and Dutch environmental legislation will be given.

2. Legislation

The aims of governmental policies in the European Union (EU) are mainly based on the nitrate directive of the EU (1991) for the protection of water. A maximal allowed level of 50 mg NO_3^-/l is given. For P a maximal level of 0.15 mg total P/l is allowed in The Netherlands. In 2000, a directive was established in the field of water policy by the EU (EU, 2000). In this directive a framework is given which aims to maintain and improve the aquatic environment in the EU, and concerns the quality of the waters. Furthermore, each member state of the EU may impose additional legislation.

Recently, in The Netherlands, legislation was adopted regarding concentrations in soil and ground water for minerals (Staatscourant, 2004). In this document the target values for Zn in shallow and deep ground water are 65 and 24 μg solubilised Zn/l, respectively. In their review, De Vries *et al.* (2002) showed that leaching of Cu and Zn from dairy farms in The Netherlands on sandy soils may range from 80 - 220 and 160 – 1000 g/ha, respectively. An amount of 1000 g Zn/ha results in The Netherlands in about 330 μg solubilised Zn/l, which is far above the maximally tolerable risk level. However, more recent estimates of Zn load show this to be eight times lower in surface water, however this largely depends on the height of the water table level (Bonten and Brus, 2006). It is evident that with continued accumulation of micro-minerals in the top soil, the concentrations of these minerals in surface water will increase over the long term.

In 2003, the EU adopted new maximum authorised levels of micro-minerals in animal rations, which for pigs are presented only for Cu and Zn (Table 2). The physiological requirements as mentioned in this document should be the basis for the maximum authorised dietary levels in the EU and not pharmacological doses such as those for Cu and Zn. One of the reasons was that Cu and Zn in animal manure can form a considerable environmental hazard now or in the future.

Furthermore, a summary of the (partly proposed) Dutch legislation on the maximal allowed quantity of minerals per hectare of land is presented in Table 3. This table shows clearly the limitations on the amount of nutrients and heavy metals in manure that can be applied per hectare of arable land to prevent accumulation and leaching. This may result in reduced amounts of manure of a particular origin that can be applied.

Table 4 lists the contribution of several sources on the load of agricultural area in The Netherlands by Cu and Zn in 1980 and 2003 (g/ha of utilised agricultural area; Anonymous, 2006).

Table 4 shows that compared with 1980 the input of Cu and Zn from manure has decreased substantially, mainly by setting lower maximum levels in the diets for pigs. However, animal manure is still the main contributor to the load of these minerals per ha of land. The net load of the minerals listed has more than halved since 1980, however, accumulation still occurs.

Table 2. Overview of maximum allowed concentrations of Cu and Zn in diets for specific categories of pigs (mg/kg; EU, 2003).

	Copper (mg/kg) total diet		Zinc (mg/kg) total diet	
	EU till 2004 total	EU ≥2004 total	EU till 2004 total	EU ≥2004 total
Piglets till 12 weeks of age	175	170	250	150
From 12 - 16 weeks of age	175	25	250	150
Fatteners from 16 weeks of age	35	25	250	150
Breeding sows	35	25	250	150

Table 3. Proposed maximal allowed quantity of minerals to be applied per hectare of arable land in The Netherlands (the amount of N depends on the soil type).

Heavy metals	Maximal allowed quantity (g/ha)	Nutrients	Maximal allowed quantity (kg/ha)
Arsenic	30	Nitrogen	265
Cadmium	2.5	Phosphate (P_2O_5) or	85
Chromium	150	Phosphorus (P)	37
Copper	150	Potassium (K_2O) or	200
Mercury	1.5	Potassium (K)	166
Lead	200		
Nickel	60		
Zinc	600		

Table 4. Load of Cu and Zn in utilised agricultural area in The Netherlands (g/ha).

	Copper		Zinc	
	1980	2004	1980	2004
Animal manure	525	208	900	600
Inorganic fertilisers	75	17	75	23
Wet and dry deposition	40	10	230	30
Other sources	60	10	85	80
Total input	680	245	1200	733
Output via crops	70	50	350	285
Net load, excl. leaching	610	195	850	448

3. Estimation of excretion of copper and zinc by pigs in the European Union

Some years ago, a study was undertaken to estimate the excretion and potential soil accumulation of Cu and Zn due to pig production only in the EU (Kemme *et al.*, 2000). These values were calculated on the basis of recent Eurostat data and performance characteristics of pigs in the countries of the EU, and if applicable, in several regions of these countries. Constant parameters were chosen for retention in the body of pigs (2 and 1 mg Cu/kg at a supply above

30 and below 30 mg/kg diet, respectively, and 16 mg/kg for Zn), crop uptake (45 and 220 g Cu and Zn/ha, respectively), and atmospheric deposition (20 and 130 g Cu and Zn/ha, respectively). Leaching of Cu and Zn was not taken into account because it largely depends on the precipitation surplus and the type of the soil (clay, sand, peat) and pH of the soil. We chose a fixed tillage depth of 20 cm. It has to be remarked that the input of Cu and Zn by agriculture to soils is only partly related to pig farming (in The Netherlands about 58%; Van Eerdt *et al.,* 1999). Several scenarios were calculated for Cu and Zn using the following options with regard to dietary concentrations (Table 5).

The first scenario is according to the maximally allowed concentrations in the diets until January 2004. The second one is for Zn according to EU legislation from 2004 onwards, but the levels for Cu deviate slightly from this legislation. In the third scenario the Cu and Zn levels should be sufficient for all categories of pigs (Jongbloed *et al.,* 1998). The fourth scenario for Cu and Zn comprises the restriction to the physiological requirement of 12 and 75 mg/kg, respectively.

Accumulation of Cu and Zn in the soil was expressed in the number of years that are necessary to obtain an increase of 1 mg/kg soil, in which leaching was not taken into account. For several countries and regions this was estimated and the results of the worst ones are presented in Table 6.

Table 6 shows very little differences in Cu and Zn accumulation of the soil due to pig production among the various countries and regions. The soils in The

Table 5. Concentrations of Cu and Zn in diets (mg/kg) for piglets, growing-finishing pigs and productive sows at different scenarios.

Scenarios	Piglets (weaning - 25 kg)		Starter pigs (25 – 40 kg)		Finisher pigs (> 45 kg)		Productive sows	
	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
1. Max. allowed <2004	175	250	175	250	100	250	35	250
2. Cu/Zn restricted to xx/150	100	150	100	150	35	150	20	150
3. Cu/Zn restricted	20	120	20	120	20	120	15	120
4. Cu/Zn restriction to physiol. req.	12	75	12	75	12	75	12	75

Table 6. Number of years to obtain an increase in the soil of 1 mg/kg at the different scenarios from pig husbandry only.

Scenarios	NL		Denmark		Belgium		Nordrhein (Germany)		Brittany (France)		Cataluna (Spain)	
	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
1. Max. allowed <2004	8	4	10	5	10	4	12	5	8	4	8	4
2. Cu/Zn restricted to xx/150	27	8	28	9	27	8	33	10	21	7	21	6
3. Cu/Zn restricted	90	11	107	13	90	11	120	14	65	9	65	9
4. Cu/Zn restriction to physiol. requirement	279	23	414	28	279	23	590	32	167	18	163	17

Netherlands, Belgium and Denmark accumulate Cu and Zn, irrespective of the dietary scenario. On a countrywide scale, Germany, France, and Spain do not face environmental problems that cannot be overcome. However, the situation is completely different if we focus on certain regions within these countries. This is the case in the region of Nordrhein-Westfalia (Germany), Brittany (France), Cataluna (Spain), Lombardia (Italy), Murcia (Spain), Niedersachsen (Germany) and Lisboa et Valo de Tejo (Portugal).

The accumulation of Zn is more severe than that of Cu, even at maximal levels of 75 mg Zn/kg of diet. A substantial reduction of accumulation of Cu and Zn in the soil of countries or regions with intensive pig production can only be achieved by banning pharmacological levels of these minerals in the pig diets.

4. Actual excretion of nitrogen and minerals by pigs

Excretion of nitrogen and minerals by livestock can be calculated as the difference between dietary intake and the amounts retained in the body of the animal or in the product designated for human consumption. However, large differences can exist in the amount excreted due to factors such as: animal, feed, and environment. A more detailed description of this matter has recently been described by Jongbloed (2006), hence only Table 7 is presented showing how

Table 7. Number of growing-finishing pigs or sows allowed per hectare of land when complying constraints in Table 3.

	N	P	Cu			Zn		
			EU< 2004	EU≥ 2004	15 mg/kg	EU< 2004	EU≥ 2004	80 mg/kg
Growing-finishing pigs (26-114 kg)	102	59	11	19	43	10	18	35
Breeding sows + piglets to 26 kg	12.6	5.9	0.9	1.0	5.0	1.2	2.0	3.8

many growing pigs or breeding sows are allowed per hectare of land in The Netherlands using the constraints as presented in Table 3. For growing-finishing pigs it is estimated for the live weight range of 26 to 114 kg. Average growth rate in that period is 762 g/d and the feed conversion ratio is 2.67. Concentrations of N and P are those currently used in practice in The Netherlands. Those for Cu and Zn are those according to EU legislation before and after 26th of January 2004 or at further reduced levels. Calculations for breeding sows include a sow and her piglets up to 26 kg.

Table 7 shows clearly that with regard to the number of growing-finishing pigs or sows allowed per ha of land, and with the current EU legislation, Cu and Zn are the most limiting minerals for applying manure and not N or P. Now only the manure of 19 growing-finishing pigs is allowed per ha of land to comply with the (intended) Dutch legislation. The number of sows allowed per ha of land is only one or two at the current EU and Dutch legislation. In some countries, 1500 to 3000 mg Zn/kg of feed is used because of its positive effect on the performance of piglets. If only during 14 days post-weaning 3000 ppm of Zn is provided to the piglets, the excretion of Zn per sow per year is increased from 302 (EU≥ 2004) to 748 g.

5. Estimation and comparison of the nutritive value of mineral sources

It is very important to accurately express the nutritive value of minerals. Estimation of the nutritive value of minerals from various sources for animals should be closely linked with those biological parameters, that are accurate, distinguishable, easy to execute and cheap. They should also lead to tabulated values that can easily be applied in practice, or fit in an existing evaluation system. In judgement of the nutritive value of minerals it is important to know which method and criterion have been used. Especially for micro-minerals, there are a large variety of methods and criteria used, sometimes leading to large differences even within the same experiment.

5.1. How to estimate and express nutritive value of minerals

In the literature, different terms are used to determine nutritive values of minerals for pigs, for example, digestibility, absorbability or (bio-)availability (Partridge, 1980). The digestibility and absorbability refer to the gastrointestinal tract (feed - faeces). The term (bio-)availability, however, is used with different meanings, and can therefore, be misleading. With regard to P in pig feeding, it has widely been accepted to express the nutritive value of P in terms of apparent digestibility, while in some literature also true digestibility of P is proposed. Some countries still use total P or non-phytate P content in the diet as a criterion.

For micro-minerals like Cu and Zn the situation is less clear. In principle, one should also choose for (apparent or true) absorbability to express the nutritive value of a mineral compound. However, no evaluation system is yet existing that meets the conditions described for estimation of the nutritive value. Therefore, the micro-mineral under investigation is often compared with a reference mineral, which availability is set to 100% (NRC, 1998). This is often called the relative bioavailability (RBV). When defining availability in the latter situation, various response parameters not directly associated with absorption are used. These response parameters can be:

1. Animal performance (average daily gain, feed intake, feed conversion ratio, reproduction characteristics).
2. Digestion/absorption coefficients.
3. Concentrations of minerals in several tissues (bone and organs, like liver, kidneys, muscle, spleen).
4. Total mineral content in the animal's body.
5. Morphological characteristics in specific tissues.
6. Blood parameters (concentrations of the minerals, enzyme activities, hormone levels).
7. Concentrations in secretory fluids (bile, pancreatic fluid).
8. Concentrations in urine.

Some remarks can be made on these response parameters, which are given below.

5.1.1. Animal performance

Performance as a criterion for assessing the nutritive value of minerals is for several minerals probably the least sensitive response parameter. An effect on performance can only be expected if the animal is fed below its physiological requirement unless a pharmacological effect can be expected (e.g. for Cu). Differences in performance can only be noted at large differences in nutritive value or large differences in mineral supply. Broilers are often more sensitive in their performance to differences in mineral supply than pigs, because they have hardly any storage of minerals, in contrast to pigs or calves when born.

5.1.2. Digestion/absorption coefficients

Assessing the nutritive value of mineral sources by means of digestion and absorption studies seems to be one of the best direct methods. This is especially the case for macro-minerals but less for micro-minerals. The latter is predominantly due to the low inclusion levels, the low absorption coefficients and the relatively high endogenous secretion of the specific mineral. Under specific defined conditions, the potential value of products can be measured accurately. However, the problem is that the methods, although they look quite similar, may differ among each other. One large difference may be the basal diet: a more or less practical diet or a synthetic diet, because interactions among minerals may play an important role, e.g. complexing food components like phytic acid and oxalic acid (Harland, 1989). Hence, altered digestibility coefficients may be measured e.g., by a lower faecal endogenous excretion. A prerequisite for a better harmonisation is that the basal diets become more similar among research centres. Methods that are used are the balance technique and the slope ratio technique. Radio-labelled or stable isotopes for micro-minerals studies are sometimes used.

5.1.3. Concentrations in several tissues

In general, bone parameters are the most frequently used parameters for assessing the nutritive value of calcium, phosphorus, manganese and zinc in mineral sources. A large variety of bone parameters can be used such as, fat-free bone weight, bone ash weight, calcium, phosphorus, manganese or zinc content in bone ash, etc. Several bones can be chosen such as, femur, tibia, metatarsals

(3^{rd} and 4^{th}), metacarpals (3^{rd} and 4^{th}), tail vertebrae, and toes. Because there is a rather large between-animal-variation, quite a large number of observations are necessary. Furthermore, it is an indirect parameter so that it has to be converted to a direct (tabulated) value. This is one of the disadvantages of using bone parameters, as well as the price for sacrificing the animals. Moreover, the pre-preparation of the bones is very laborious.

Some micro-minerals may accumulate in specific organs like copper and zinc in the liver, kidney, spleen, or muscle. Therefore, for evaluation of particular micro-minerals some of these target organs are chosen. For large animals, biopsies can be taken from some organs and tissues. In human studies, hair or nails are used as indicators for the supply of certain minerals, *i.e.* selenium and copper, but this is not common for livestock, because this represents more long-term effects.

5.1.4. Total amount of minerals in the animal body

It seems obvious that the total amount of a mineral that is retained in the animal body is one of the best response parameters. However, this holds true only if the animals are fed below their mineral requirement. When fed above their mineral requirement, the surplus of the mineral is excreted with the faeces and urine and is, therefore, not retained in the body. This leads to an underestimation of the nutritional value of the mineral source, although there are some exceptions such as for copper (accretion in the liver) and zinc (accretion in the bones). There are several disadvantages of this method. Sample preparation from a whole body is not an easy task. Furthermore, the amount of the mineral present in the animal body should be doubled at least to obtain a reasonably accurate estimation of the value of minerals, when using pigs.

5.1.5. Blood parameters

Blood parameters such as the concentration of minerals and the activity of specific enzymes may also be used as criteria for the evaluation of the nutritive value of mineral sources. One should realise, however, that there is hormonal regulation to control homeostasis in the extracellular fluid. Therefore, differences in blood levels only occur when the regulatory mechanism is not able any more to maintain the extracellular content of the mineral within the narrow physiological range (Van der Velde *et al.*, 1986). This means that serum mineral levels can only be used when large differences in nutritive value of the mineral sources are under investigation. Also, diurnal variation in serum mineral content or enzyme activity may influence the results. For copper, criteria may be blood or serum copper content, superoxide dismutase, cytochrome c oxidase or ceruloplasmin content in the liver.

5.1.6. Concentrations in secretory fluids

In some cases concentrations of minerals in secretory fluids can be used as a criterion for the supply. This is the case for the content of copper in bile or the zinc content in pancreatic fluid.

5.2. How to compare results within or between different experiments on Cu and Zn

Literature shows that in most experiments several of the above mentioned response parameters have been used to judge the effect of supplying a certain amount of Cu or Zn of a specific source on the animal's mineral status. As already indicated, when comparing different sources of Cu or Zn, bioavailability has to be related to a reference mineral source. This source is defined to have a relative bioavailability of 100%. For Cu, the reference source is mostly $CuSO_4•5H_2O$ (reagent grade); for Zn, the reference source is mostly $ZnSO_4•1H_2O$ (reagent grade) or $ZnSO_4•7H_2O$ (reagent grade). Although several response criteria are used, not all criteria are equally important. Therefore, criteria have to be ranked in order of their importance. This order may be different between the specific animal species or even animal categories. Furthermore, it is important to note that the order of importance of the criteria may depend on the level of supply (below or above recommended requirements). Criteria and weighting factors for Cu and Zn are presented in Table 8. The higher the ranking the more important is the criterion for judging the mineral status of the pig.

For Cu, liver Cu concentration is the most important criterion, while many are less or not suitable. For Zn, mainly bone Zn and plasma Zn can be used. A review of these response parameters has been given by Delves (1985).

The main interest has been in comparing bioavailability from different mineral sources, which was recently reviewed (Jongbloed *et al.,* 2001). For Cu, sources were grouped as $CuSO_4•5H_2O$ and other inorganic sources, and compared with organic Cu complexes. For Zn, $ZnSO_4•xH_2O$, $ZnCO_3$, ZnO, Zn methionine and Zn lysine were compared. Response criteria and their importance of ranking, as has been described, have been applied. A problem in the interpretation of the data on Cu and Zn sources is that these sources are not always well defined with regard to their origin and their chemical and physical properties. Therefore,

Table 8. Ranking of criteria to judge the effects of a certain supply of Cu or Zn on pig mineral status.

Criterion	Ranking of importance (weighting factors)	
	Supply below requirements	Supply above requirements
Cu		
Apparent Cu absorption	3	1
Hepatic Cu content	4	3
Superoxide dismutase activity	1	1
Hepatic ceruloplasmin content	1	1
Animal performance	1	no
Cytochrome oxidase activity	no	no
Serum/plasma Cu concentration	no	no
Bile Cu concentration	no	no
Zn		
Apparent Zn absorption	3	1
True Zn absorption	3	3
Tibia/toe/metatarsal Zn concentration	5	5
Pancreatic Zn concentration	3	3
Animal performance	3	no
Serum/plasma Zn concentration	4	no
Liver metalloproteins	no	no
Urinary Zn	no	no
Hair Zn	no	no
Erythrocyte Zn	no	no
Hair condition	no	no
Zn balance	no	no

within the same mineral source, large differences in bioavailability in relation to the reference source can be obtained, although this will depend upon the basal diet used. Also, a better description of the mineral source is required. Furthermore, large differences exist in the response criteria used and often levels are supplied that substantially exceed the physiological requirement of the animals.

In almost all experiments, $CuSO_4 \bullet 5H_2O$ or $ZnSO_4 \bullet xH_2O$ have been used as a reference source for Cu and Zn, respectively, and their bioavailability was assumed to be 100%. The results of Cu bioavailability trials published in pigs are summarised in Table 9.

Bioavailability data are reported for $CuSO_4$, $CuCO_3$, CuS, tribasic Cu chloride, (in)organic chelated Cu, Cu citrate, Cu methionine (CuMet) and Cu lysine (CuLys), and were published in the period 1961 - 1998. The results of Zn bioavailability trials published in pigs are summarised in Table 10.

6. Reduction of the excretion of P, Cu and Zn by altering nutrition and feeding

In this chapter, only some general aspects of altering nutrition will be discussed because details have been described elsewhere (e.g. Jongbloed and Lenis, 1998). Apart from N, nutritional research in relation to environmental pollution has focused mainly on reducing the dietary input of P, Cu and Zn, and for P on its more efficient utilisation. To achieve this, it is important to supply dietary minerals in close accordance with the animals' requirement. This requires adequate knowledge about the digestibility (absorbability) of minerals in the feed used, and on the animal requirements for these nutrients. It has been recognised that the nutritional requirements for minerals in different countries

Table 9. Summarised results of bioavailability trials with different Cu sources for pigs.

Reference	Category	Sources used	Bioavailability
Bunch *et al.*, 1965	Piglets	$CuSO_4$, $CuCO_3$, CuMet	$CuSO_4$ = $CuCO_3$ = CuMet
Apgar *et al.*, 1995	Piglets	$CuSO_4$, CuLys	$CuSO_4$ = CuLys
Allen *et al.*, 1961	G-F pigs	$CuSO_4$, Cu carbonate	$CuSO_4$ > Cu carbonate
Apgar and Kornegay, 1996	Finisher pigs	$CuSO_4$, CuLys	$CuSO_4$ > CuLys
Coffey *et al.*, 1994	Piglets	$CuSO_4$, CuLys	$CuSO_4$ = CuLys
Cromwell *et al.*, 1998	Piglets	$CuSO_4$, tribasic Cu chloride	$CuSO_4$ = tribasic Cu chloride
Armstrong *et al.*, 1998	Piglets	$CuSO_4$, Cu citrate	$CuSO_4$ <= Cu citrate
Barber *et al.*, 1961	Growing pigs	$CuSO_4$, CuS	$CuSO_4$ > CuS
Cromwell *et al.*, 1978	Piglets	$CuSO_4$, CuS	$CuSO_4$ > CuS
Buescher *et al.*, 1961	Growing pigs	$CuSO_4$, Cu carbonate	$CuSO_4$ = Cu carbonate

Table 10. Summarised results of bioavailability trials with different Zn sources for pigs.

Reference	Category	Sources used	Bioavailability
Schell and Kornegay, 1996	Piglets	$ZnSO_4$, ZnO	$ZnSO_4$ > ZnO
Wedekind *et al.,* 1994	Piglets	$ZnSO_4$, ZnMet, ZnO, ZnLys	$ZnSO_4$ > ZnMet > ZnO > ZnLys
Swinkels *et al.,* 1996	Piglets	$ZnSO_4$, ZnAAC	$ZnSO_4$ = ZnAAC
Miller *et al.,* 1981	Piglets	Zn dust, ZnO	Zn dust > ZnO
Hill *et al.,* 1986	Pigs from 8 – 96 kg	$ZnSO_4$, ZnMet	$ZnSO_4$ = ZnMet
Hap and Zeman, 1994	Piglets	$ZnSO_4$, ZnO, $ZnCO_3$	ZnO > $ZnSO_4$= $ZnCO_3$
Cheng *et al.,* 1998	Piglets	$ZnSO_4$, ZnLys	$ZnSO_4$ = ZnLys
Rupic *et al.,* 1997	Pigs from 16 - 90 kg	$ZnSO_4$, ZnMet	$ZnSO_4$ = ZnMet

may vary because of differences in housing conditions, genotype of the animals, level of feeding, major ingredients used in the diets and response criteria. Furthermore, it is possible to enhance the digestibility of P, Cu and Zn in feeds by using extrinsic enzymes. Also, by improved performance (genetical improvement of pigs) reduction of the excretion of minerals can be achieved. In this respect also optimal management with regard to housing and health status of the pigs and feeding strategy (e.g. multiphase feeding), which may improve feed conversion ratio, will be beneficial for the environment. Some of these aspects will be further outlined below.

6.1. Reduction of the P, Cu and Zn excretion by pigs

6.1.1. Supply dietary minerals in close accordance with the animals' requirement

Results regarding apparent faecal P digestibility show that there are large differences among feedstuffs of plant origin. There are also substantial differences among those from animals and feed phosphates. The large variation among and within a feedstuff is attributed to differences in phytate P content, phytase activity, and processing (Jongbloed and Kemme, 1990). Raw materials with lowered concentrations of phytate P, like low-phytate corn and soybean meal indeed show higher P digestibilities than the regular types of seeds (Spencer *et al.,* 2000; Bohlke *et al.,* 2005; Dilger and Adeola, 2006).

The requirements are also expressed in terms of digestible P. Piglets and growing pigs deposit P in lean tissue, organs and bones. In order to estimate the P requirement for growth, an allometric function was developed by Jongbloed *et al.* (2003), and the amount of P deposited at a certain empty body weight is presented in Figure 1. When compared with data before 1985, there is no decline at higher body weights, as is indicated by the P retention per kg growth. This is possibly due to the higher lean production of the modern pigs. In this study it was also shown that modern growing-finishing pigs contain more phosphorus compared with pigs from experiments published before 1985.

The requirements of pigs for Ca and digestible P are summarised in Table 11. The content of digestible P in terms of g/EW (1 EW equals 8.79 MJ NE or 12.55 MJ ME) decreases gradually from 2.4 at 25 kg live weight to 1.8 at 110 kg LW for a good type of gilt with a high feed intake capacity. It is obvious that the required amounts of digestible P are different at other growth rates.

Nutritional requirements for Cu and Zn are to a large extent based on research at lower animal production levels than those of modern genotypes. Maybe, like for P, modern pigs have a higher requirement for Cu and Zn than previous genotypes. Therefore, to get a better insight into the actual nutritional requirements, we made a survey of the literature concerning requirements for Cu and Zn of pigs (Jongbloed *et al.*, 2001; 2004b). In the latter survey we

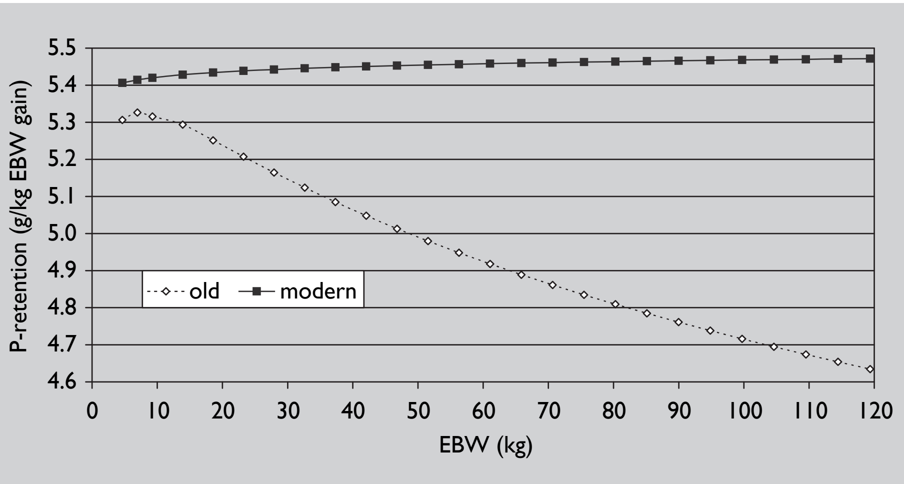

Figure 1. Course of P retention in growing pigs in relation to empty body weight (EBW) and genotype (old – before 1985 and modern pigs – later than 1984).

Table 11. Requirements of pigs for Ca and digestible P (g/12.55 MJ ME).

Animal category	Calcium	Digestible P
Piglets		
0 to 2 weeks post-weaning	8.0	3.2
2 weeks post-weaning to 25 kg	9.5	3.4
Growing-finishing pigs		
25-35 kg	6.9	2.4
35-70 kg	6.4	2.2
>70 kg	5.7	1.9
Breeding sows		
<70 days of pregnancy	5.0	1.5
70 – 98 days of pregnancy	6.6	2.0
>98 days of pregnancy	7.3	2.2
lactating	7.7	2.9

critically evaluated the background of the recommendations for growing-finishing pigs.

In various cases, information is lacking as to whether recommendations are "true" minimum requirements or include a safety margin. If a safety margin is included, the size of this margin is not given. Judgement of the recommendations is, therefore, difficult. The Cu and Zn needs may depend on the nature of the diet (other compounds interfering with absorption and utilisation of Cu or Zn), but this is difficult to quantify. We also discriminated diets into (semi)synthetic, maize-soybean meal diets and other types of diets.

Table 12 summarises the recommendations regarding requirements of Cu and Zn in different countries for specific categories of pigs and those obtained in our study. In some countries no discrimination is given between requirements according to physiological status of the animal. This means for example, that the same requirement is given for growing and lactating animals, which is indicated in Table 12.

Table 12 shows that the recommended requirements vary substantially among the different countries. The recommendations of Cu for growing-finishing pigs are in rather good agreement with our results. An addition of 4 mg/kg Cu to a complete diet (88% DM) seems to be sufficient. The recommendations for

Table 12. Summarised inventory of requirements of Cu and Zn for piglets and growing-finishing pigs (concentrations as mg/kg fresh diet) in different countries and the results of our study (Jongbloed et al.*, 2001; 2004b).*

	Requirement of Cu		Requirement of Zn	
Country		Our study		Our study
BSAS, 2003 (UK)	6 (added)	4 added to a diet	60 – 100 (added)	67
NRC, 1998 (USA)	3 – 6		50 – 100	
Pallauf, 1996 (DK)	4 – 5		45 – 90	
Anon., 1999 (Fr)	10[a]		100[a]	

[a]same for all categories of the specific animal species.

Zn in different countries for growing-finishing pigs are intermediate with our results. Based on maize-soybean meal diets we concluded that 57 mg Zn/kg seems to be sufficient. The assessed requirement, however, should be adapted to the current improved feed conversion ratios. Therefore, a concentration of 67 mg Zn/kg is recommended as was obtained for pigs receiving diets other than maize-soybean meal. No definitive answer could be obtained if, and how much the requirements should be enhanced at higher animal performance levels than documented in the literature.

6.2. Enhancement of digestibility of P, Cu and Zn by microbial phytase

Plant ingredients used to formulate pig diets may contain from 0.7 to 3.5% of phytates (Cosgrove, 1980). They are of very limited digestibility for pigs. Therefore, feed manufacturers and farmers have to add inorganic P from feed phosphates to their pig diets. To enable dephosphorylation of the dietary phytates, intrinsic or extrinsic (microbial) phytases can be used. Since 1990, several experiments with exogenous microbial phytases were reported to quantify their effect on the apparent digestibility of P. A survey of a large part of these studies has been presented by Jongbloed *et al.* (2000). Most studies show an exponential dose-response curve (Figure 2).

When 500 to 1000 units of *Aspergillus niger* phytase are added per kg of feed, the increase in the amount of digestible P is almost 50% of the requirement for digestible P of a growing pig. The efficacy of microbial phytase depends,

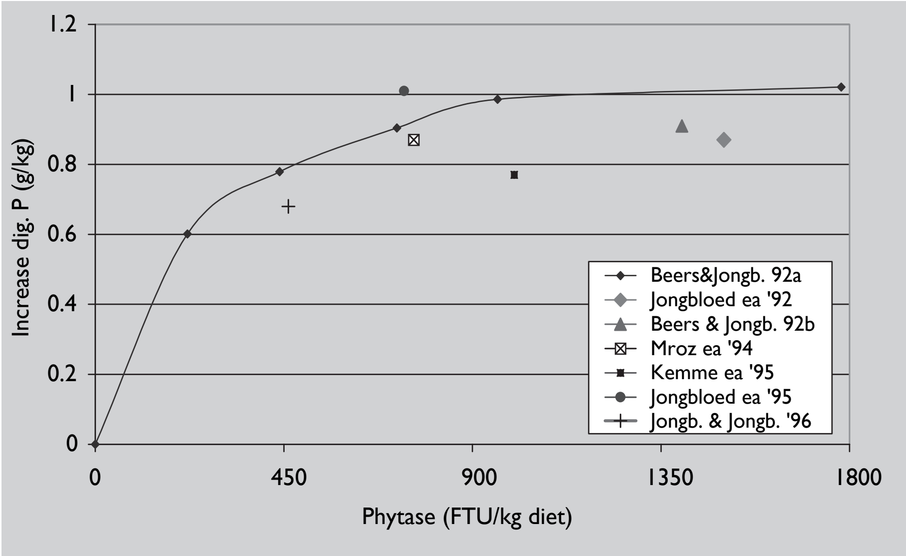

Figure 2. Dose-response effect of 3-phytase and of several other experiments by ASG on the amount of digestible P generated of diets containing more than 50% maize and soybean meal (Jongbloed et al.*, 2000).*

apart from its origin, also on animal related factors like physiological status and housing conditions (Kemme *et al.,* 1997a; b). It has also been demonstrated that microbial phytase is effective in breeding sows (Jongbloed *et al.,* 2004a).

In addition to the positive effect on the digestibility of P, microbial phytase also increases one of the other mono- and divalent cations (Kies *et al.,* 2006). Jongbloed *et al.* (1998) concluded that 500 FTU/kg of diet may replace an addition level of 10-20 mg ZnSO4/kg diet, while an inconsistent effect on Cu availability was noted. Revy *et al.* (2004) showed that using 1200 U phytase in the basal diet largely exceeded the effect of adding 20 mg Zn/kg, while also Cu availability was increased from 9 to 18%. Revy *et al.* (2005) further stated that using 700 U phytase could replace even 35 ppm Zn addition, but had no effect on Cu utilisation.

Performance of pigs fed microbial phytase is better as compared with a non-supplemented diet or with a positive control diet (Jongbloed *et al.,* 2000). The improvement in FCR can be attributed to increased digestibility of protein/ amino acids and a slight increase in energy digestibility. The magnitute of the effect also depends on the dietary phytate content.

Several types of microbial phytase have been found to enhance P digestibility substantially. Phytase-supplemented feeds for growing-finishing pigs and pregnant sows may need little or no supplementary feed phosphate, thereby reducing total dietary P content and excretion of P. Microbial phytase has been incorporated in more than 80% of pig feeds in The Netherlands.

The environmental impact of microbial phytase is substantial. It is generally accepted that by using 500 FTU/kg of feed, about 0.8 g digestible P/kg is generated which is equivalent to 1.0 g P from monocalcium phosphate or to 1.23 g P from dicalcium phosphate.

6.3. Changes in dietary composition

The wide variety of feedstuffs available for pig diets shows a considerable variation not only in P content but also in P digestibility. Therefore, in order to decrease further the excretion of P, feedstuffs should be chosen in which P is present in a highly digestible form. Because feed phosphates are only used to supply P, one can easily choose those feed phosphates in which P is highly digestible. In The Netherlands, this has already led to an almost total shift to monocalcium phosphates (digestibility = 83%) at the expense of dicalcium phosphates (P digestibility = 67%).

In addition to the changes mentioned before there is also the possibility to increase the energy concentration in the feeds. As a result mostly raw materials are chosen that have a higher digestibility, consequently leading to a lower excretion of minerals via faeces.

6.4. (Multi)phase feeding

For P, the concentration of digestible P per kilogram feed can decrease as the live weight of the pig increases from 30 to 110 kg. Therefore, the introduction of a two-, three- or multi-phase feeding will help balance digestible P in the diet to the requirements of the animals. Phase feeding leads to less P excretion, in the case of one additional feed up to 6% according to Lenis (1989). A slightly larger reduction in P excretion by growing pigs can be achieved by mixing a feed rich in protein and minerals (feed A) with a feed having a low concentration of protein and minerals (feed B) in a changing ratio during the fattening period (multi-phase feeding). This mixing system can be achieved with a computerised mechanical feeding system. A feeding strategy can be developed with a good fit of energy, protein and mineral supply based on pig potential, stage of production, production objective and environmental constraints. Using a multi-phase feeding system, Beers *et al.* (1991) reported a 22% lower P excretion in growing-finishing pigs.

Required concentrations of digestible P per kg feed for breeding sows are much lower during pregnancy than during lactation. The use of separate diets for pregnancy and lactation compared with one diet for both reduced the excretion of P by 20% (Everts and Dekker, 1994).

For Cu and Zn lower requirements are suggested for the finishing phase compared with the starter or grower phase. This is mostly taken into account when formulating feeds in practice when phase feeding is applied.

6.5. Effect of feed conversion ratio

A powerful tool to decrease the excretion of N and P is to aim at improving the feed conversion ratio of pigs. One and the same diet is offered to pigs that have large differences in their potential for growth, and consequently in their feed conversion ratio. This means also a large range in utilisation and thus excretion of P, Cu and Zn by a growing-finishing pig. Table 13 shows the effect of different feed conversion ratios (average, best and worst 20% of the farms in The Netherlands in 2005) on the excretion of P and Zn by a growing-finishing pig from 25 to 110 kg LW. A feed conversion ratio that is obtained on the worst 20% of the pig farms as compared with the best 20% results in almost 0.18 kg more P and 5 g Zn excreted per pig.

Table 13. Effect of different feed conversion ratios on P and Zn excretion by growing-finishing pigs.

Feed conversion ratio	FCR average 2.64		FCR worst 20% 2.85		FCR best 20% 2.41	
	P	Zn	P	Zn	P	Zn
Intake (kg)	1.05	0.034	1.14	0.036	0.96	0.031
Excretion (kg)	0.60	0.032	0.68	0.035	0.50	0.029
Excretion (relative to average = 100)	100	100	113	108	83	91

6.6. Course of P and Cu excretion in The Netherlands

Table 14 summarises the course of P and Cu excretion by growing-finishing pigs in practice in The Netherlands. From 1973 to 2005 the total P content in diets for growing-finishing pigs has decreased by more than 2.5 g/kg. Meanwhile, the feed conversion ratio has improved substantially, whilst the health of the pigs has not been compromised. From 1991 to 2000 is predominantly the phytase effect. Phosphorus excretion in the period 1973 to 2005 decreased by more than 1.00 kg per pig, which is almost two-thirds! With regard to Cu excretion a significant decrease can be noted: in 2005 only 10% of the amount excreted in 1973. This is mainly due to legislation on maximal allowed concentrations in pig diets.

Table 14. Mean excretion of P and Cu of growing-finishing pigs from 25 to 110 kg in The Netherlands (kg or g/pig).

Year	In diet (g/kg)	In diet (mg/kg)	Feed conversion	Excretion (kg)	Excretion (g)
	P	Cu		P	Cu
1973	7.4	250	3.37	1.66	71
1983	6.2	175/125	3.08	1.18	33
1988	6.0/5.0[a]	175/35	2.96	0.89	16
1992	5.5/4.9	175/35	2.87	0.76	14
1996	5.3/4.6	175/35	2.71	0.64	14
2001	5.3/4.6	175/35	2.57	0.57	12
2005	4.7/4.7	25/25	2.64	0.60	6

[a]6.0/5.0 means 6.0 g/kg in the starter diet and 5.0 g/kg in the grower-finisher diet

7. Discussion and applications for practice

At the interface of sustainable agriculture and pig production, Honeyman (1996) indicates four levels of issues, specifically the farm, the rural community, the society or consuming public and the ecosystem or environment. It could be speculated that in the future pig production will have to deal with more constraints that are imposed from society, much more than in the past. This may relate to animal well-being and health, quality of the animal product and production system, utilisation of nutrients, and last but not least from an environmental viewpoint.

In The Netherlands, it has been shown that despite early warnings of scientists that the mineral balance on a farm was disturbed, 15 years passed before it became politically interesting. Therefore, a lot of precious time was lost and expansion of large operations without sufficient agricultural area took place. Because measurements for reduction of excretion increase in general production costs as well, farmers wanted to delay implementation of environmental legislation. This was partly correct, because we did not have adequate knowledge and technologies available. If environmental constraints can be anticipated at an early stage, money may be saved in the long term.

First of all, it should be noted that minerals in animal manure have been, and still are used, to maintain and improve soil fertility to produce crops for human and animal consumption. Application of nutrients via manure and/or chemical fertilisers on the fields should be in close balance with the uptake by the crop, with minor losses via leaching or volatilisation/evaporation. This is part of our goal to achieve a sustainable agriculture. The problem is when there is an imbalance in the supply of, and the demand for certain nutrients, not only for crops but also in relation to livestock production. Manure legislation can help to achieve a better balance in nutrient input and output. Also, a regional approach can be recommended.

Nutrition management can substantially contribute to reductions in P, Cu and Zn excretion by pigs. Adequate knowledge is required concerning the digestibility of P in the feed used, but for Cu and Zn no adequate data are available yet. This is also true for the requirement of these nutrients at any stage and type of production. New technologies are required to increase the digestibility of Cu and Zn substantially. Supplementary microbial phytase can enhance the digestibility of P by 20 % or more so that feeds for growing-finishing pigs and for pregnant sows may need little or no supplementary feed phosphate. Also, digestibility of at least Zn is increased by microbial phytase. Phosphorus excretion can be lowered by 20 to 30% by using microbial phytase. A favourable feed conversion ratio also contributes to a lower excretion of minerals per pig. In The Netherlands, the nutritional approach by reduction of excretion of minerals was most successful and effective compared to distribution and application of manure or manure processing.

It is known that ruminants and pigs consume a lot of by-products and also (wet) waste products. These by- and waste products may originate from several food-processing industries, slaughter houses, etc. In this respect, ruminants and pigs are used to utilise products that are not or can not be used for modern human consumption, as has been the case in past centuries (De Boer, 1980). Therefore, ruminants and pigs substantially contribute to reducing industrial wastes. Because part of these products has lower digestibility and utilisation of N and P compared with common feedstuffs, they seem to become less attractive for environmental reasons. As a consequence, part of these waste products may be transported directly to the refuse dump, which is even worse. Apart from the higher costs for the producer of these waste products, and possibly the higher price for the food to be paid by the consumer, this should worsen the national or regional mineral balance. In this respect, it can also be mentioned, that ruminants are able to convert roughages of a low biological value into animal products of a high biological value. Home-grown feeds can also contribute to a better regional mineral balance.

Today, high safety demands are set for raw materials used in livestock nutrition. This means that several local by- and waste products are not allowed anymore, and consequently more raw materials have to be imported. This leads to a higher surplus of minerals at national level. An alternative can be using the local by- and waste products for biogas production. One should be aware that the minerals in the residue are still present and should be disposed as well. Also the ban on using animal products in the diets of pigs leads to a higher environmental load due to imports of protein-rich raw materials and feed phosphates.

Current knowledge concerning the possible reduction of the manure surplus has to be integrated into future feed strategies. A further integration of the nutrition research with other disciplines is necessary. In this respect, both the genetic potential of the animals and hygienic conditions should be evaluated. An approach more at system level should be emphasised.

8. Conclusions

Soil fertility and quality of the surface and groundwater determine to a large extent the amount of manure that can be applied per hectare. Nowadays on most intensive livestock farms the input of P, Cu and Zn by means of feeds and inorganic fertilisers often exceeds the output in meat, milk or eggs. Therefore, new legislations have been enforced, that limit the use of animal manure per hectare of land or put limits on maximal allowed contents of minerals in diets. However, animal manure is still a valuable commodity to maintain or improve soil fertility.

Accumulation in the soil is more severe for Zn than for Cu in the EU, but it is more a regional than a countrywide problem. Alleviation of this accumulation is only possible when growth-promoting levels in pig diets are banned, and Cu and Zn sources enter the market which are much more absorbable.

Nutrition management can substantially contribute to reduction in P excretion. Adequate knowledge is required on the availability/digestibility of P in the feeds used and on the requirement of P at any stage and type of production. The digestibility of P can be enhanced by using microbial phytase, resulting in a lowered P excretion of 20 to 30%. Also the availability of Zn is increased by microbial phytase. In the future more tailored nutrition and feeding strategies will be applied to obtain a further reduction of P, Cu and Zn excretion.

Differences in bioavailability between the several inorganic and organic Cu sources for pigs are small. Furthermore, the bioavailabilities of commonly used (in)organic Zn sources for pigs seem to be almost similar. All the same, knowledge on Cu and Zn availability is rather diverse and needs more attention. Perhaps harmonisation in research methods can bring us a big step further. Recommended requirements of Cu and Zn for growing-finishing pigs vary substantially between different countries. No definitive answer could be obtained if and how much the requirements should be enhanced at higher animal performance levels than documented in the literature.

By means of legislation on P in The Netherlands excretion of P in manure of pigs has already decreased considerably. New technologies to supply the market compounds with a high availability for Cu and Zn look promising, and are necessary to comply with environmental and consumers' demands.

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Trace mineral nutrition for the modern genotype

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1. Introduction

Advances in modern genetics and production systems have resulted in significant changes to pig productivity levels. Fremaut (2003) has estimated that over the past 15 years feed conversion in grow-finishers has improved from 3.5:1 to 2.7:1. However, typical diet formulations over the same time period have changed very little with regard to trace mineral specifications (NRC, 1998). This improvement in feed efficiency has actually resulted in a reduction of trace mineral intake by some 23%. Due to their vital role in metabolism (Mateos *et al.,* 2005), the trace minerals copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) and selenium (Se) must be supplied in the diet of all pig categories to prevent mineral deficiencies and maintain metabolic homeostasis (NRC, 1998). While a reduction in trace mineral intake is positive from an excretion perspective (Creech *et al.,* 2004), it is important to ask 'what are the consequences of such a dramatic reduction in trace mineral intake on performance, reproduction, metabolism and overall health of the modern pig?'

Research concerning trace mineral nutrition and supplementation for pigs, in many cases, was carried out more than 30 years ago in order to develop trace mineral requirements. Table 1 illustrates the year that the research data used in defining the NRC, (1998) trace mineral requirements for various categories of swine was published. However, recent heightened interest concerning the impact of trace mineral supplementation with regards to improving performance (Carlson, 2005) together with new approaches to supplementation have been explored (Acda and Chae 2002; Jondreville and Revy, 2003; Mullan and D'Souza, 2005). Moreover, high levels of trace minerals in livestock effluent, especially Zn and Cu (Ferket *et al.,* 2002), and the subsequent impact on the environment has begun to be investigated in more detail (Leeson, 2003; Burkett *et al.,* 2006). Therefore, the purpose of this paper is to review the importance of trace mineral nutrition in today's modern pig genotypes with particular reference being made to new advances in supplementation sources, levels, and the potential for a reduction in the environmental impact of trace minerals in intensive livestock production.

Table 1. Year (19__) of research used in estimate of trace mineral requirements[1].

Trace Mineral	Year research published
Copper	1979, 1981, 1983
Iron	1960, 1964, 1967, 1974
Manganese	1944, 1962, 1975, 1989
Zinc	1956, 1962, 1968, 1970, 1976, 1981, 1984
Selenium	1971, 1973, 1974, 1976, 1977, 1979, 1981, 1984

[1]Adapted from NRC (1998).

2. Trace mineral overview and function in modern pig genotypes

Requirements for trace minerals in pig diets vary depending on region, country, institution, regulatory body or breeding stock supplier. Table 2 illustrates the recommended trace mineral levels for grower finisher pigs from various jurisdictions. It is noteworthy that while the ratios between minerals are of approximately the same magnitude, the range in absolute ppm is quiet broad. Additionally, all are significantly higher than the levels recommended by NRC (1998). In light of environmental pressures to reduce heavy metals in effluent (Ferket *et al.*, 2002), the higher levels recommended may be contributing unnecessarily to pollution. Recently released research findings are also indicating that excessive levels of inorganic trace mineral supplementation, above NRC, may even be detrimental to performance (Mahan and Peters, 2006). As a result, optimising nutritional programs to better meet the needs of specific genotypes is a focus of researchers and nutritionists alike. More specifically, consideration of the absolute level and source of trace mineral supplementation has been a focal point of current research initiatives. Furthermore, interactions between trace minerals has also been considered and is outlined below.

2.1. Zinc

The minimum NRC (1998) recommendation for zinc (Zn) supplementation of swine diets is shown in Table 3. Zinc is an essential element in a number of metalloenzymes, DNA and RNA synthetases and tranferases, digestive enzymes, and is required for bone development and hormone systems (Mateos *et al.*, 2005; NRC, 1998). Zinc is therefore a key component in energy, protein and lipid metabolism (NRC, 1998). Deficiency symptoms include growth

Table 2. Recommended trace mineral levels for growing pigs[1].

	INRA	KSU	NRC	Hypor	NSU	BSAS	Canada[2]		EU[3]
	1989	1995 [a]	1998 [b]	1999	2000 [b,c]	2003 [d]	Min	Max	Max
Fe	80	150	60	60	70-150	80	40	750	750
Cu	10	15	4	10	4-15	6	6	125	25
Zn	100	150	60	60	70-150	100	100	500	150
Mn	40	36	2	30	3-30	30	10	200	150
Se	0.1	0.09	0.15	0.2	0.3	0.2	NRS[4]	0.3	

[1]Adapted from Mateos *et al.* (2005), all levels in mg/kg of complete feed.
[2]CFIA Table 4 (1983).
[3]Commission Regulation (EC) No 1334/2003.
[4]No requirement specified.
[a]Kansas State University.
[b]20 to 50 kg BW.
[c]Nebraska and South Dakota State University.
[d]30 to 60 kg BW.

Table 3. Trace mineral recommendations for swine[1].

	Body weight (kg)					
	3-10	10-20	20-50	50-80	80-120	Sows[2]
Fe	100	80	60	50	40	80
Cu	6	5	4	3.5	3	5
Zn	100	80	60	50	50	50
Mn	4	3	2	2	2	20
Se	0.3	0.25	0.15	0.15	0.15	0.15

[1]Adapted from NRC, 1998, all values are mg/kg of complete feed.
[2]Lactation and gestation sows.

retardation, parakeratosis and reproductive dysfunction in both males and females (Mateos *et.al.*, 2005). Considerable research has been focused on Zn supplementation at pharmacological levels to enhance growth and reduce the incidence of non-specific post-weaning scours (Carlson, 2005). Levels in the range of 2,500-3,000 ppm Zn from Zinc Oxide (ZnO) have traditionally been fed, however, excretion of Zn in faecal material is extremely high due to the low bioavailability of ZnO (Ammerman *et al.,* 1995; Meyer *et al.,* 2002; Mullan, 2004; Carlson *et al.,* 2004). The growth promoting effects of pharmacological levels of ZnO were recently investigated by Xilong *et al.* (2006) who reported that, in addition to enhancing performance, 3,000 ppm zinc from ZnO resulted in increased villus height and increased IGF-1 and IGF-1R expression in the small intestinal mucosa.

In sow diets, very little research has been conducted evaluating zinc levels and production parameters. Two recent reports indicate that elevated levels of zinc in sow diets had either no effect (Payne *et al.,* 2006) or a detrimental effect (Mahan and Peters, 2006) on sow performance. During the grow-finish period even less research is available examining the effects of zinc supplementation on performance. One interesting study examined the impact of reducing dietary trace mineral levels on live animal and carcass performance as well as nutrients excreted in the faeces (Burkett *et al.,* 2006). These researchers found that reducing trace mineral levels to below NRC (1998) levels resulted in equal performance, both live animal and carcass, when zinc was fed in either the inorganic or organic form (inorganic zinc at 81% NRC, 1998, organic zinc at 45% NRC, 1998). These findings parallel those of Leeson (2003) in broilers. Further research is required in order to elucidate the exact mechanism by which Zn improves growth in the weanling pig and techniques to reduce levels in sow and grower finisher rations while maintaining performance, cost and reducing excretion.

2.2. Copper

The minimum NRC, (1998) recommendation for copper (Cu) supplementation of pig diets is shown in Table 3. Copper is essential for proper bone growth and development and is also required in various enzymes involved in Fe transport and metabolism, collagen formation, melanin production and integrity of the central nervous system (Mateos *et al.*, 2005). Deficiency symptoms include poor Fe absorption, abnormal blood cell formation, poor keratinisation and synthesis of collagen, elastin and myelin. Signs of Cu deficiency include anaemia, bowing of the legs, spontaneous fractures, cardiac and vascular disorders and depigmentation (NRC, 1998). While low levels of Cu are actually required to prevent deficiency symptoms, research efforts have been largely focused on the nursery phase of production and supplementing Cu at pharmacological levels of 100-250 ppm (Mateos *et al.,* 2005). Feeding pharmacological levels of trace minerals may lead to reduced absorption of other minerals, since interactions are known to exist between minerals in the diet (Figure 1). Elevated levels of Cu (as $CuSO_4$) have been shown to reduce Zn and Fe metabolism but not when Cu was fed as a Cu proteinate (Bioplex™, Alltech Inc.; Veum *et al.,* 2004; Wu *et al.,* 2001; Hemken *et al.,* 1996). Furthermore, significant reductions in Cu excretion were reported by feeding the Cu proteinate (Veum *et al.,* 2004). In sows, very little research is available investigating Cu levels in diets on performance. Mahan and Peters (2006) reported that inclusions of trace minerals, fed in inorganic form, at higher than NRC 1998 levels reduced reproductive performance. However, this investigation included all trace minerals and did not focus on Cu alone. In the growing and finishing pig it has been common practice to add pharmacological levels of Cu to that diet to improve growth performance (Hill and Spears, 2001). Davis *et al.* (2002) reported pharmacological levels of Cu, as $CuSO_4$, improved gain and feed efficiency in growing and finishing pigs, while Meyer *et al.* (1992) reported no improvement with the addition of 250 ppm Cu from $CuSO_4$ on performance. Zhou *et al.* (1994) reported that the growth promoting effect of Cu was independent of the antimicrobial effects of dietary Cu. However, these pharmacological additions may pose a threat to the environment (Kornegay and Verstegen, 2001; Ferket *et al.,* 2002), with the result that this practice is

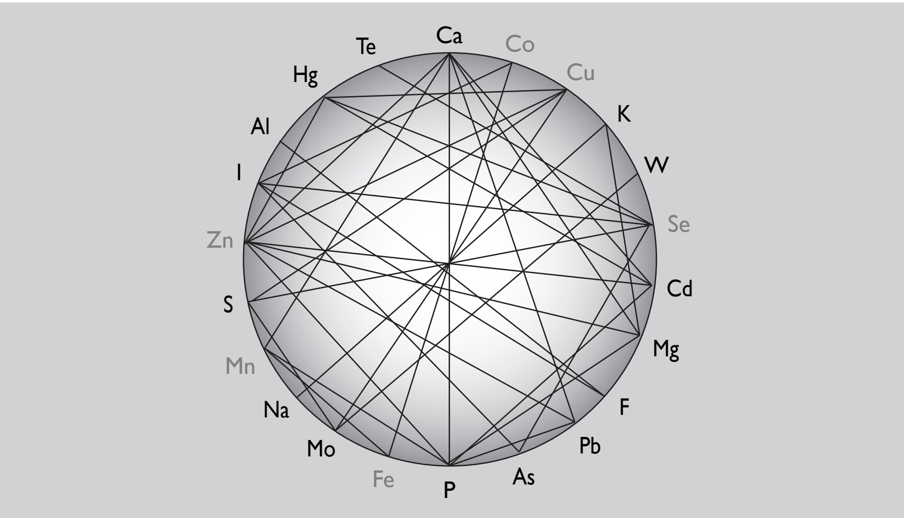

Figure 1. Mineral interactions illustrated in the mineral wheel (Adapted from Miller et al.*, 1979).*

now outlawed in some parts of the world, for example, the European Union. In an attempt to reduce Cu excretion, while still maintaining performance, Pierce *et al.* (2001) reported that feeding 50 ppm Cu from Bioplex™ Cu (Alltech Inc.) maintained performance yet significantly reduced Cu excretion compared to 160 ppm Cu from $CuSO_4$. As with Zn, further research is required to define the optimal level and source of Cu supplementation to reduce excretion (Ferkett *et al.*, 2002) while maintaining performance and costs of production. Recently, Hernandez *et al.* (2005) demonstrated that the addition of lower levels (25 ppm Cu & 40 ppm Zn) of organic (Bioplex™ Alltech Inc.) minerals to grow-finish pig diets maintained performance and feed efficiency, but significantly reduced faecal Cu and Zn levels (P<0.001) when compared with higher sulphate diets (Figures 2 and 3).

2.3. Manganese

The minimum NRC (1998) recommendation for Manganese (Mn) supplementation of pig diets is shown in Table 3. Manganese is essential in several key enzyme systems in carbohydrate, lipid and protein metabolism as well for the synthesis of chondroitin sulfate, a component of mucopolysaccharides in the organic matrix of bone (NRC, 1998). Manganese is also required for the

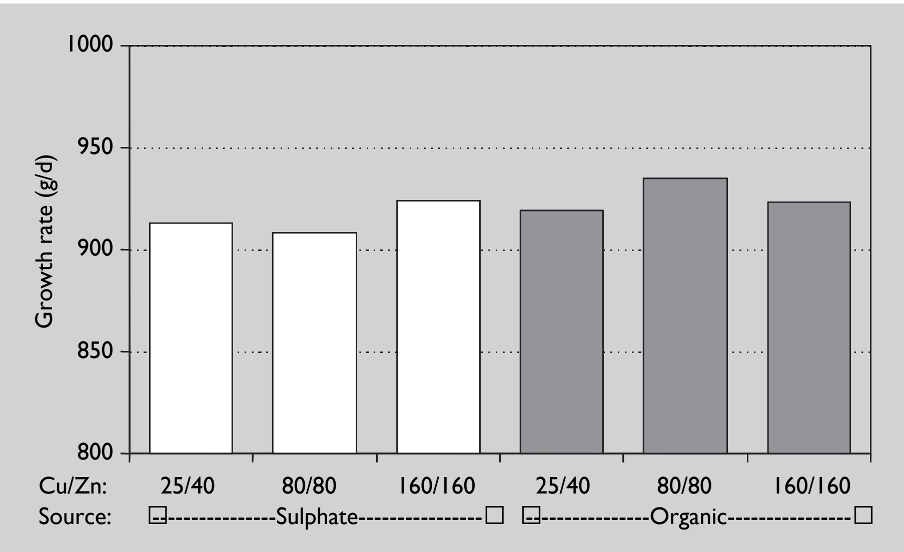

Figure 2: Growth rate of pigs from 16 to 107kg liveweight when fed different levels and sources (organic and inorganic) of Zn and Cu (Hernandez et al.*, 2005).*

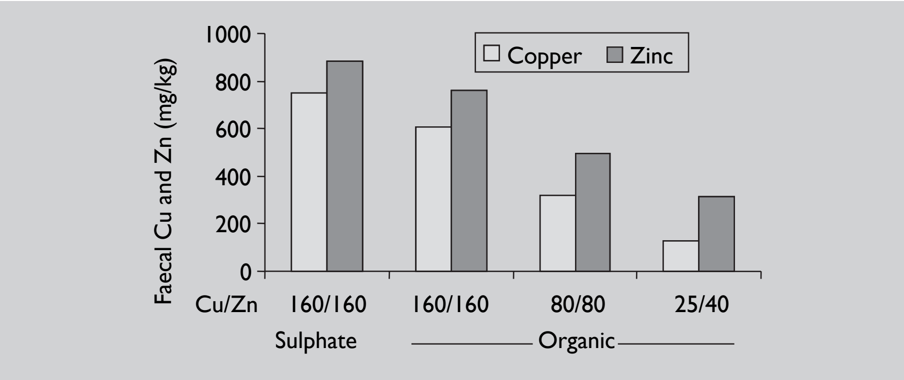

Figure 3: Faecal concentrations of Zn and Cu in grower pigs according to level and source of Cu and Zn (Hernandez et al.*, 2005).*

proper reproductive function in both males and females and for immunological function (Mateos *et al.*, 2005). In nursery and grow-finish pigs deficiency symptoms are not observed in practical diets for pigs (Mateos *et al.*, 2005). Apple *et al.* (2004) conducted a trial investigating the impact of elevated Mn levels on growth and carcass characteristics in grow-finish pigs and reported that pigs fed diets supplemented with 320 ppm Mn supplied as an amino acid-Mn complex exhibited improved efficiency and carcass composition. However, the economics of this level of Mn addition in grow-finish diets must be evaluated. In sows, Mn concentration in diets has received very little attention in the past 15 years. Mahan and Peters (2006), supplemented either organic or inorganic forms of trace minerals and found that increasing inorganic mineral content of the diets, above NRC 1998 levels, reduced performance. However, this trial included all trace mineral so no conclusion can be made on Mn levels or source of Mn supplementation. Further research is required to optimise supplemental Mn levels, over that found in standard ration formulations.

2.4. Iron

The minimum NRC (1998) recommendation for iron (Fe) supplementation of pig diets is shown in Table 3. Iron is an essential component of several key enzymes and is found as haemoglobin in red blood cells, myoglobin in muscle tissue, transferrin in serum, uteroferrin in the placenta, lactoferrin in milk and ferritin and hemosiderin in the liver (NRC, 1998). Most plant and mineral ingredients used in common diet formulation contain adequate levels of Fe to meet the pigs requirement, thus many trials conducted to investigate the effect of additional Fe supplementation have shown little performance improvement (Close 1999; Mateos *et al.,* 2005). However, young piglets are born with a limited amount of Fe. Since milk is low in Fe content, exogenous supplementation in newborn piglets is required to prevent anaemia (NRC, 1998). Rincker *et al.* (2004) reported that Fe contribution from feed ingredients alone were not sufficient to prevent reductions in hepatic Fe concentrations in 35-day old piglets, and to maintain these concentrations required 100 ppm of Fe from a highly available Fe source. In sows, Close (1999) reported that 90 ppm of supplemental Fe, as Bioplex™ Fe (Alltech Inc.), reduced pre-wean mortality (-15%), improved weaning weights (+0.3 kg) and reduced the variability of piglet bodyweights. In grow-finish pigs, the only recent data investigating Fe is that of Burkett *et al.* (2006) and Creech *et al.* (2004) but these trials investigated all trace minerals in inorganic or organic forms, at various inclusion levels. They found that by reducing dietary concentrations of trace minerals, when fed in the organic form, performance was maintained and trace mineral excretion reduced. Klasing and Humphrey (2003) indicated in mammals that Fe is the "first limiting" nutrient for pathogen microbial growth so mechanisms to optimise Fe supplementation in pig diets warrants further research.

2.5. Selenium

The minimum NRC (1998) recommendation for selenium (Se) supplementation of swine diets is shown in Table 3. Selenium is an essential component of the enzyme glutathione peroxidase (GSH; NRC, 1998), thioredoxin, methionine sulfoxide reductases as well as a multitude of selenoproteins involved in antioxidant defense (Surai, 2006). Selenium's role in animal nutrition has evolved from Se being considered a toxic element, therefore tightly regulated, to being an essential nutrient (Mateos *et al.*, 2005). Deficiency symptoms include hepatic necrosis, tissue oedema, white muscle disease, mulberry heart disease, impaired reproduction, reduced milk production, impaired immune response and sudden death (NRC, 1998). The maximum Se supplementation level in many countries is 0.3 ppm. Selenium research in starter pigs has been somewhat limited. Lampe *et al.* (2005) reported a commercial evaluation utilising either inorganic or organic Se (Sel-Plex®; Alltech Inc.) on nursery performance, and found that organic Se reduced mortality and morbidity by 50% in the nursery. In sows the vast majority of research has been conducted comparing inorganic *vs.* organic sources of Se on reproductive performance. Mahan (2004) reviewed the current research findings of organic and inorganic Se in reproducing sows and reported that over time, especially in hyperprolific sows, Se is depleted thus reducing the transfer of selenium to the foetus, colostrum and milk. The feeding of organic Se as Sel-Plex®, while equal at maintaining GSH activity at 0.15 ppm, was superior in the transfer of Se to foetal tissues, colostrum and milk. Fortier and Matte (2005) reported that in reproductive sows, Sel-Plex® appeared to be the only source of selenium able to cope with the oxidative pressure and to maximise the quality of ovulation and the subsequent development of embryos. In grow-finish pigs virtually all diets are supplemented to the maximum allowable concentration of 0.3 ppm (EU, 0.5 ppm). Mahan and Parrett (1996) reported that maximal GSH levels were reached with 0.1 ppm inorganic Se in grow-finish diets but that excretion was reduced when organic Se (as Sel-Plex®) was fed. New areas of research surrounding Se have focused on the interaction of Se and viral infections (Beck *et al.,* 2003) and this could prove to be a very exciting avenue to explore in order to enhance of pig health and productivity.

3. Impact of excessive supplementation

The role of trace mineral supplementation is to prevent deficiency symptoms and to optimise animal performance. Due to advanced genetics and increased productivity, it is important to ask 'is adding more trace minerals to the diet always better or justifiable?' Additionally, excessive trace mineral supplementation has proven to have positive, negative and no effects on animal performance. Pharmacological levels of trace mineral supplementation increase effluent trace mineral levels (Mullan, 2004; Meyer *et al.,* 2002; Ferket *et al.,* 2002). Mahan and Peters (2006) discovered that increasing dietary concentrations of trace minerals to sows over a 6 parity period reduced reproductive performance, when the trace minerals were supplied in the inorganic form. However, supplying these trace minerals in the organic form (Bioplex™ and Sel-Plex®) resulted in improved performance with one extra piglet born alive per litter. Furthermore, Mullan (2004) reported that replacing 3,000 ppm Zn from zinc oxide with 250 ppm Zn from Bioplex™ Zn, improved nursery performance whilst reducing faecal Zn concentrations. With these results in mind, it is important to ask "is the absolute level of trace mineral supplementation critical or the form in which it is delivered?"

Key productive indicators, such as the cost of growth, feed efficiency, immunocompotence and reproductive performance will drive the implementation of new technologies. Reproductive performance and longevity are the key drivers in sow productivity. The importance of individual trace minerals on sow reproduction is summarised in Figure 4. In nursery production, efficient average daily gain, feed efficiency and cost per unit gain are the key indicators. Considering environmental concerns, a number of strategies exist in

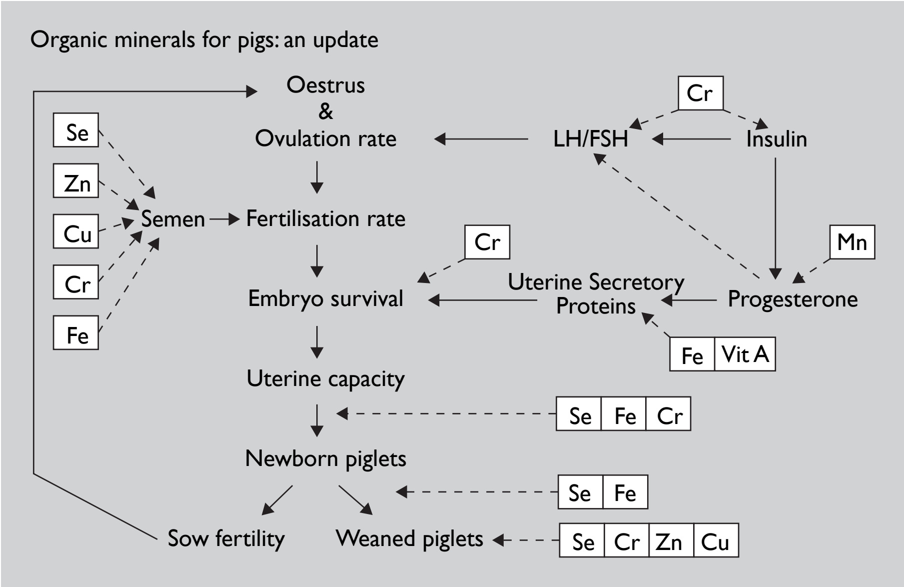

Figure 4. Potential role of trace minerals in sow production (Adapted from Close, 1999).

order to enhance or maintain animal performance while significantly reducing mineral excretion levels (Figure 5; Carlson *et al.*, 2004; Mullan, 2004; Burkett *et al.*, 2006; Meyer *et al.*, 2002). Veum *et al.* (2004) reported similar findings by replacing 250 ppm $CuSO_4$ with 50-100 ppm Bioplex™ Cu and maintaining performance (ADG & feed efficiency). Additionally, the organic (Bioplex™) Cu did not interfere with Zn or Fe metabolism. The impact of excessive trace minerals in pig effluent has been reported by Lopez *et al.* (2000). These investigators concluded that a direct correlation existed between hepatic Cu levels in calves and the density of young pigs in the area. Current research indicates that by reducing the trace mineral concentration of grow-finish diets by using organic trace minerals, such as Bioplex™ trace minerals, live animal and carcass characteristics remain the same as with the higher levels of inorganic mineral supplementation (Burkett *et al.*, 2006; Taylor-Pickard, 2005). Utilising this approach also significantly reduces the trace mineral concentration in effluent, thus reducing the levels applied to soils (Leeson, 2003).

Environmental pressures will continually tighten and the focus on reducing effluent emissions from livestock production and will be an ongoing concern (Ferket *et al.*, 2002). Regulatory mechanisms are in place to minimise the impact

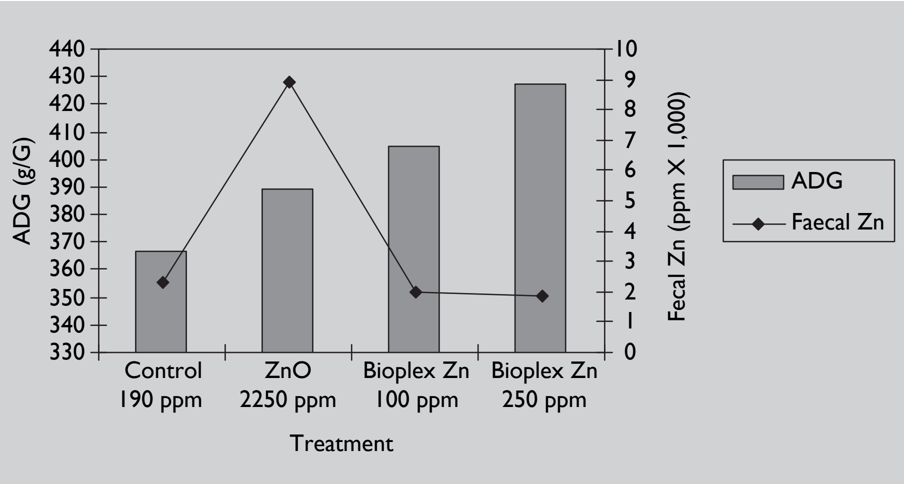

Figure 5. ADG and faecal Zn concentration of pigs fed Zinc Oxide or Bioplex™ Zinc (Adapted from Mullan, 2004).

of excessive trace mineral supplementation in pig diets (Table 2), and continue to be stringently enforced. On-going advances concerning the mechanism of absorption of organic trace minerals will continue to shed increasing light on their bioavailability (Power, 2006). Enhanced bioavailability will lead to lower trace mineral additions, allowing for more environmentally-friendly and cost-effective swine rations.

Consideration of recent advances in trace mineral nutrition, from a deeper understanding of the intestinal microclimate to re-defining trace mineral levels for pigs, provides enormous scope for future research and practical application of trace mineral nutrition in pigs. Although swine trace mineral nutrition has been somewhat neglected over the past few decades, new technologies have allowed advances in products that can perform several extremely important functions. Supplementation of diets with lower levels of organic trace minerals in piglet and grow-finish diets has thus far proven to enhance or maintain performance, compared to inorganic trace minerals, reduce mineral excretion in effluent and do so in a cost effective manner. Overall, this improves efficiency of production, is more environmentally-friendly and provides economic stability to the industry.

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Managing meat production and efficiency: the key to competitiveness in the pig industry

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1. Introduction

Globally, pork production has become an extremely competitive industry. Consumers continue to demand safe, high quality pork products at competitive prices compared to other high protein food alternatives. To ensure sustainability of the pig industry, pork producers must continue to seek new technologies to improve production efficiency whilst lowering the cost of production and producing a quality product.

To correctly formulate diets for finishing pigs it is very important to understand the rate and composition of gain in the pig. This means the total tissue accretion curve of a pig from 7 kg to finishing (100-120 kg), and the rate and composition of the weight gain changes as the pig increases in body weight. Viscera gain decreases while lean and fat gain increases. The amount and ratio of lean to fat gain is very dependent on the genetic potential of the pig for lean growth. This paper will review some of the key nutritional, feeding management strategies that pig producers are using in grower and finisher pigs to improve production efficiency and profitability.

2. Nutrition-genetic interactions

Genetic differences in the pig can affect their response to increased levels of amino acids and energy in the diet. Figure 1 illustrates the response of two genotypes to increasing ME (metabolisable energy) level (via added fat) in the diet. Line 1 corresponds to fat addition while line 2 does not. Also note that the response in line 1 is greater in the grower phase compared with the finisher phase. It is important to understand the nutrition-genetic interaction when designing finisher feeding programs.

It is necessary to identify the nutrient requirements of the genotype for maximum genetic potential by varying the nutrient density of the test diets. There are large differences between genotypes for key amino acids and energy.

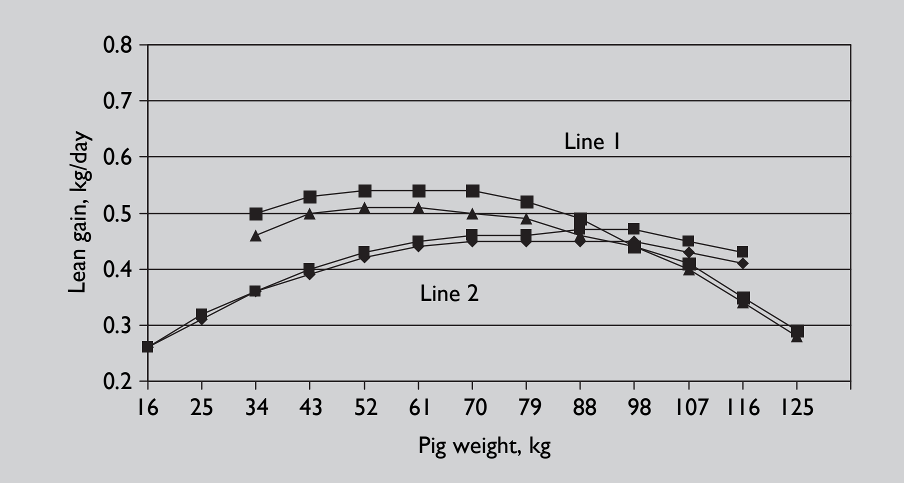

Figure 1. Effect of genetic line and ME level on lean gain (Bryant et al.*, 2006).*

In fact each genotype has an ideal amino acid to energy ratio at which, gain, feed efficiency and carcass quality are maximised.

Recently, Bryant *et al.* (2006) validated this lysine:calorie concept in two high lean genotypes marketed in the US. Gilts were fed one of four diet regimes (4 phases) varying in lysine to calorie ratios. Overall performance data for the two genotypes (across all four treatments) are illustrated in Figures 2 - 4. Line 2 gilts gained 0.916 kg/day compared with 0.866 kg for Line 3 gilts. Average daily feed intake was almost identical at 2.15 kg/day. The improved gain for Line 2 gilts at the same feed intake resulted in improved feed efficiency for Line 2 gilts. The biggest differences in feed to gain ratio occurred after 60 kg liveweight. The overall data (by line) was then used to predict the optimal lysine calorie ratio needed to optimise daily gain. We determined that Line 2 gilts require a higher lysine to calorie ratio (1.3 g lysine/kg) compared to Line 3 gilts (Figure 5). Having this valuable information allows the nutritionist to develop feeding programs for different genotypes more accurately.

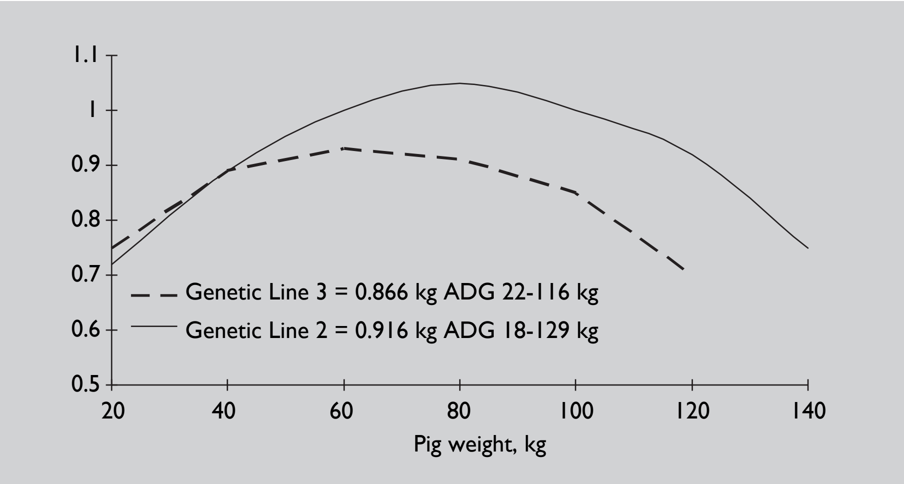

Figure 2. Daily gain (kg) for genetic Line 2 and 3 gilts (Bryant et al.*, 2006).*

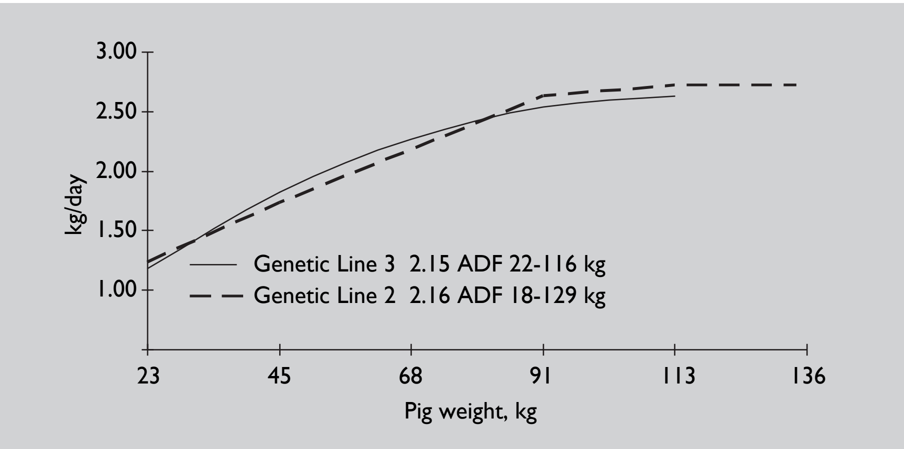

Figure 3. Daily feed intake (kg) for genetic Line 2 and 3 gilts (Bryant et al.*, 2006).*

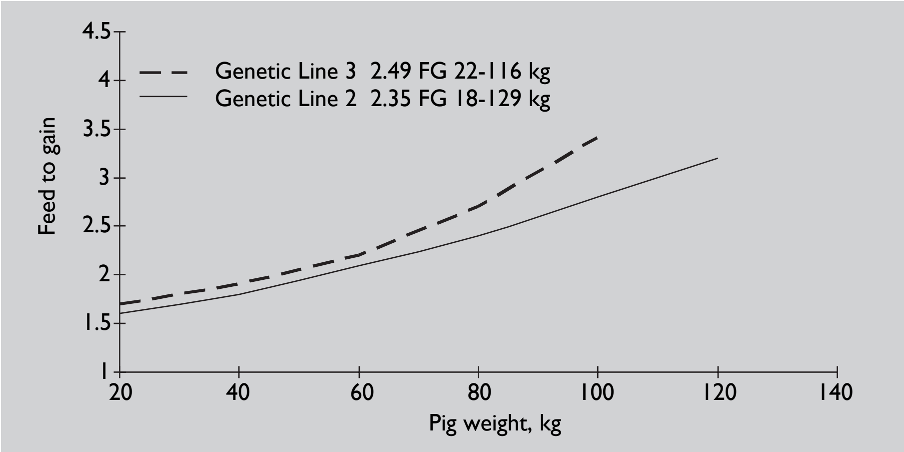

Figure 4. Feed to gain ratio for genetic Line 2 and 3 gilts (Bryant et al.*, 2006).*

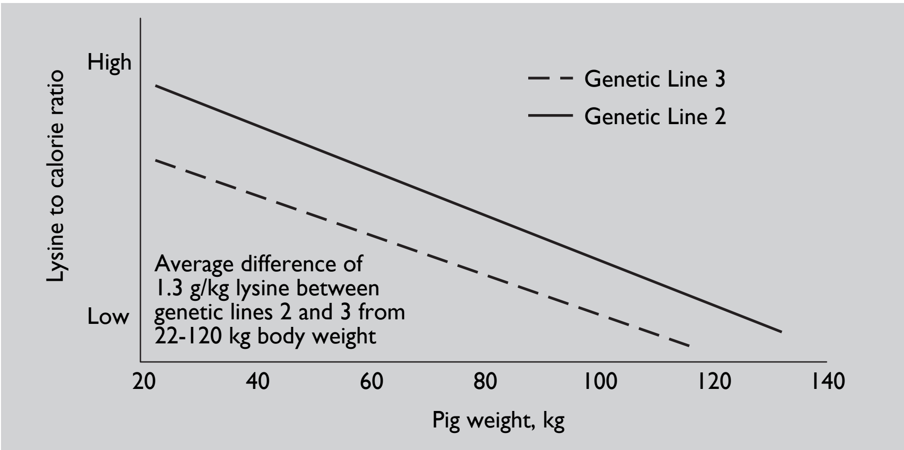

Figure 5. Lysine to calorie ratio to optimise daily gain in genetic Line 2 vs. 3 gilts (Bryant et al.*, 2006).*

3. Amino acid issues and considerations

Following an evaluation of published research, some key considerations to apply amino acid nutrition determining optimum dietary levels, and formulating best-cost diets include: multiple and differing "optimum" dietary amino acid ratios; different ileal amino acid digestibility values for ingredients; variable levels of amino acids in any given ingredient; and genotypic variation among pigs for muscle accretion, efficiency of amino acid utilisation and their dietary requirements. Obviously, fluctuating cost of ingredients supplying amino acids, including crystalline amino acids, is also a critical consideration.

As a result of these many variables, research discrepancies, changes in genotype, etc., there is difficulty applying or "extrapolating" the supposedly required amino acid levels or ratios for pigs from various sources of research. Although other variables or factors (*i.e.* health status) which differ among production systems undoubtedly affect the optimum dietary amino acid level and ratios at any given time, genotypic differences and variability exert a large influence on requirements. In general, most modern commercial genotypes have dramatically increased the lean accretion potential during recent years. Important differences, however, still exist among genotypes for lean gain potential, fat deposition rates, maturity rate and body composition. In addition, differences in efficiency of gain (feed conversion), feed intake, rate of gain potential, and lean and fat deposition rate between gilts and castrates appear to have narrowed considerably within some genotypes. However, these differences between the sexes vary across different genotypes. An example in growth responses of different modern genetic lines and estimates of optimal dietary lysine levels are shown below (Figure 6). This type of information from feeding trials can estimate optimal lysine: calorie ratios for efficiency of gain and rate of gain. Then, it really does not matter which source of nutrient values should be used or which are more precise, etc.

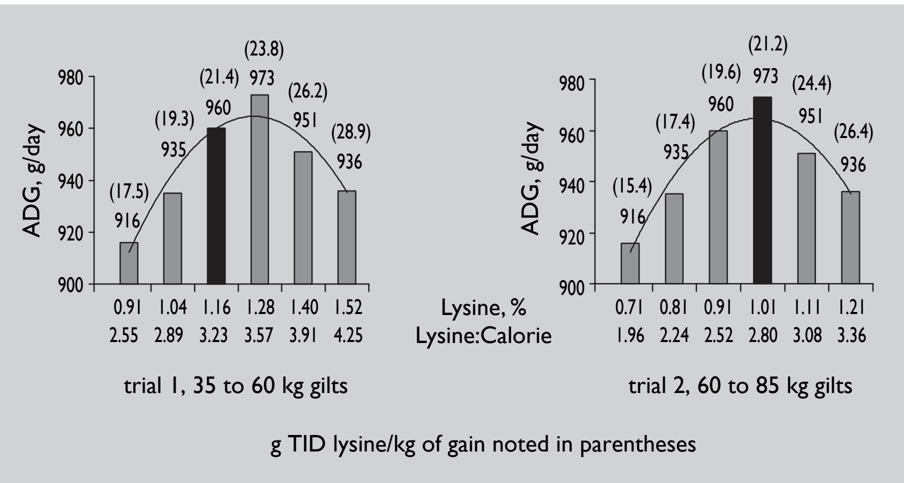

Figure 6. Lysine requirement in grams per kg of gain on average daily gain. Gram TID lysine/kg of gain are noted in parenthesis. From Tokach et al. *(2003).*

The large amount of varying or inconsistent research reflects diverse and varying ingredients used, amino acid values and digestibilities of ingredients, energy levels utilised, genotypes, etc. It is apparent that both the required or optimal dietary lysine and amino acid ratios (to lysine) still need to be determined with feeding trials specific to individual genotypes. This not only allows for the determination of optimal levels for a given genotype of pig, but results will be based on whatever digestible amino acid levels for ingredients are used and to whatever ingredient energy values are used. This can be conducted either in a rather controlled set of conditions to determine optimum levels for relatively unlimited growth potential and (or) under more typical "field" or commercial circumstances.

Tokach *et al.* (2003), demonstrated that between 20 to 120 kg live-weight, the lysine requirement is around 19 to 20 grams true ileal digestible lysine per kg of gain, for average daily gain, feed efficiency, and lean percentage (Figure 6). This information agrees with the data shown in the Brazilian tables for poultry and swine (Rostagno *et al.*, 2005); in the phase 30 to 125 kg the requirement for true ileal digestible lysine is around 20 grams per kg of gain (Table 1). With knowledge of the average daily gain and daily feed intake for each phase, it is possible to more accurately predict the lysine requirement.

Since there is a minimum or necessary amount of threonine, methionine, and tryptophan, etc. needed relative to the lysine level in a diet (*i.e.* amino acid to lysine ratios), diets are formulated with these ratios specified. In the past, only crystalline L-lysine (and sometimes crystalline DL-methionine) was used routinely for grower and finisher pigs. Recently, L-threonine became readily

Table 1. Lysine requirement in grams per kg of gain on average daily gain (Rostagno et al.*, 2005).*

Weight, kg	15 - 30	30 – 60	60 – 95	95 – 125
Average wt, kg.	22.5	45	77.5	110
Feed intake, g/day	1100	1954	2800	3057
Dig. lysine intake, g/day	12.43	20.62	25.20	21.40
Maintenance lysine, g/day	0.372	0.625	0.940	1.223
Dig. lysine for gain, g/day	12.058	19.995	24.914	20.673
Average daily gain, kg/day	0.748	0.997	1.160	0.976
Dig. lysine g/kg gain weight	16.131	20.061	20.914	20.673

available and has allowed formulations with a larger maximum quantity of L-lysine in diets (*i.e.* 0.30% to 0.35% *vs.* 0.15% inclusions). Diets with this high level of crystalline lysine would need to include crystalline threonine and crystalline methionine to meet the necessary threonine:lysine and methionine: lysine ratios. Depending upon the amount of crystalline lysine allowed in the diets, L-tryptophan may or may not need to be added. Crude protein levels in such diets can also be reduced. Trials conducted by Cera (2003) demonstrated that both performance and carcass results can be similar with higher crystalline amino acid levels and reduced crude protein diets.

When reducing any excess crude protein (and nitrogen) it is important to still meet the optimal essential amino acid levels for the "net" energy of the diet. Substituting more crystalline amino acid for soybean meal will improve slightly the energy available for productive purposes.

As crystalline threonine is needed in diets, large amounts of L-lysine is also necessary to meet the required threonine:lysine ratios during the finishing period. Determination of this minimum ratio is critical not only for maximising growth and feed efficiency but, also for minimising feed cost. Excessive dietary threonine would only detract from the least-cost formulation advantage. Over the last decade, there have been many published reports and recommendations covering the optimum threonine:lysine and methionine:lysine ratios for finishing pigs.

Dietary specifications are based on a threonine:lysine ratio (ileal digestible ratios), thus if the dietary lysine minimum specification is above the pig`s requirement, excessive crystalline threonine will be used. So, not formulating to excessive dietary lysine levels is important to prevent artificially elevated L-threonine and to minimise feed costs.

Timely results from genotype-specific feeding trials, ongoing monitoring of pig performance within a specific production system, knowledge of responses or results of other systems with the same genotype, and close monitoring of the carcass data provide the best information to determine optimal feeding programs. Properly addressing and managing the concepts and concerns described above are necessary to achieve excellent growth and carcass performance at least cost.

4. Dietary energy density

Dietary energy typically constitutes 80% of the grower and finisher pig diets. Therefore, evaluation of dietary energy density and alternative ingredients is important. Furthermore, many multi-site pig production systems are operated on an all-in-all-out basis by house or site. Therefore, evaluation of dietary energy density and its impact on average daily gain is important for maximising throughput and economics in these systems.

From a practical perspective within the field, the first factor that dictates dietary energy density is the selection of ingredients available at the feed mill. For example, a swine producer that grows sorghum and does not possess the capability of adding fat to the diet will have the energy density of the diet dictated by whatever level will be provided by a sorghum-soybean meal-based diet. In contrast, a producer that has access to low cost alternative ingredients and a variety of added fat sources will require a detailed economic analysis of the dietary energy sources available.

An initial evaluation of the ingredients available and feeding system capabilities can readily reduce the practical number of ingredients that need to be further evaluated. The remaining ingredients available can then be evaluated on a feeding value per unit of energy basis. We typically evaluate cost per unit of metabolisable energy (ME) for this evaluation. Use of net energy (NE) should in theory provide a more precise prediction of the feeding value (Noblet, 2007). However, reliable net energy values are simply not available for many ingredients. Nonetheless, it appears that ingredients containing higher amounts of fiber or crude protein appear to have a ME estimate that is overestimated compared to the NE value. Thus, in general when considering the use of alternative ingredients that contain high amounts of fiber as an energy source for growing pigs we tend not to use the ingredients if only a slight saving is projected. The magnitude of the amount of projected saving before using the alternative ingredient is usually left up to the owner or production manager.

The next step in the process includes the impact that using the ingredient will have on average daily gain. In some farms, the value of throughput will lead to increasing the nutrient density to levels that are higher than those in diets that yields the lowest cost per unit of energy. In these circumstances, the producer's production goal must be established. The question to ask is whether the goal is to minimise production costs per kg of gain or to maximise profit over feed cost. Due to the importance of energy intake in driving average daily gain and market weight, high energy diets can often increase margin over feed cost and, thus, net profit, while not being the lowest in feed cost per kg of gain. This is particularly applicable to young pigs, up to about 60 kg body weight, but may also apply to finishing pigs that are managed under practical conditions, e.g. that are crowded or that are under mild heat stress. Therefore, it is important to understand the impact that dietary energy density has on growth rate. It is also important to recognise that the feed intake for pigs up to about 60 kg does not change over a wide range of dietary energy densities. This is termed the energy-dependant phase of growth. Thus, for pigs consuming the same amount of an increased energy density diet they consume more total calories than are available for growth. This is illustrated by the data of De La Llata *et al.* (2001) where there was no impact on feed intake of increasing energy density of a corn-soybean meal based diet by adding fat from 0 to 6% (3,345 to 3,614 kcal ME/kg of diet; Figure 7). However, there was a linear improvement in growth rate through the highest level of added fat. Thus, if the production goal is to maximise average daily gain, the energy density of the diet fed for this phase would be constrained by the amount of added fat that could be provided in the diet without compromising feed flowability.

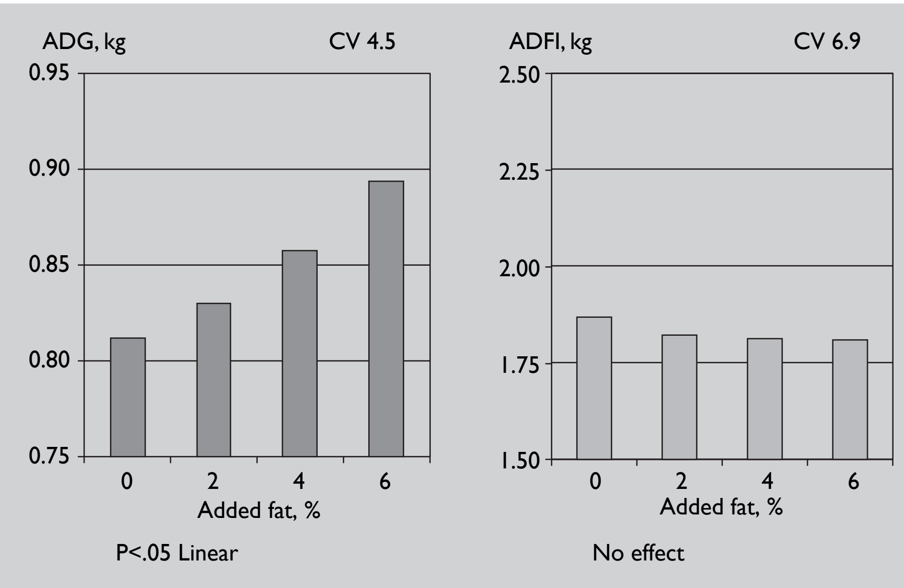

Figure 7. Influence of level of added dietary fat on pig performance (36 to 64 kg). 0% added fat corn soy = 3,345 kcal ME/kg; 6% added fat = 3,614 kcal ME/kg. From De La Llata et al. *(2001).*

This data is in contrast to pigs in the latter stages of growth where increasing energy density results in decreased feed intake and in similar amounts of calories consumed per day with no impact on growth rate across a range of energy densities (Figure 8).

Data from Stein *et al.* (1996; Figure 9) further illustrates that at a certain point the pig is unable to alter its feed intake sufficiently to compensate for the decreased energy density. Thus, a lower number of calories are consumed and growth rate is decreased. It is important to note that as dietary energy density was increased above 3,100 kcal ME/kg, further significant improvements in growth rate were not observed. However, below this point average daily gain was decreased. This indicates that the pigs were not able to increase their feed intake enough to consume an equivalent amount of calories as the pigs consuming the diets with greater than 3,100 kcal ME/kg.

The transition from the energy-dependant to non-energy-dependant phase of growth is dependant on environmental constraints placed on feed intake. In a recent review, Dritz *et al.* (2003) performed a retrospective analysis of 26 energy density experiments to compare those conducted in University swine research centers to those conducted under field conditions (Figure 10). It is noteworthy that feed intake is up to 30% lower in field conditions compared to

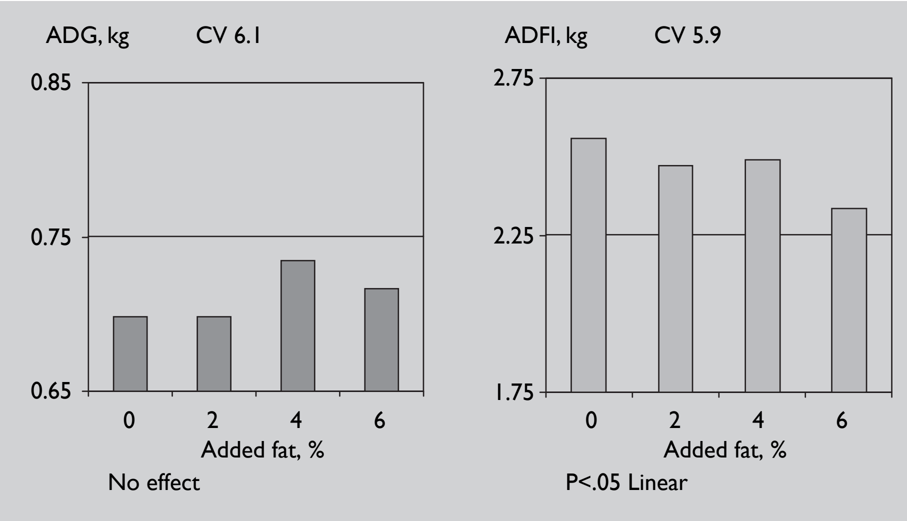

Figure 8. Influence of level of added dietary fat on pig performance (95 to 120 kg). From De La Llata et al. *(2001).*

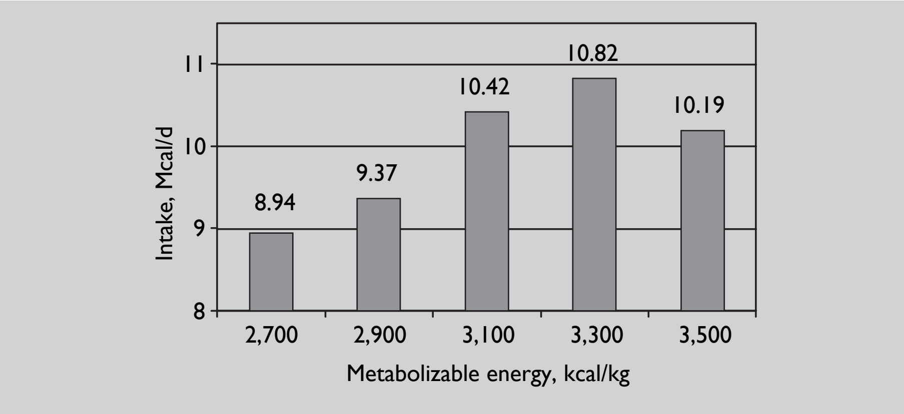

Figure 9. Influence of dietary energy level on finishing pig performance (Stein et al.*, 1996).*

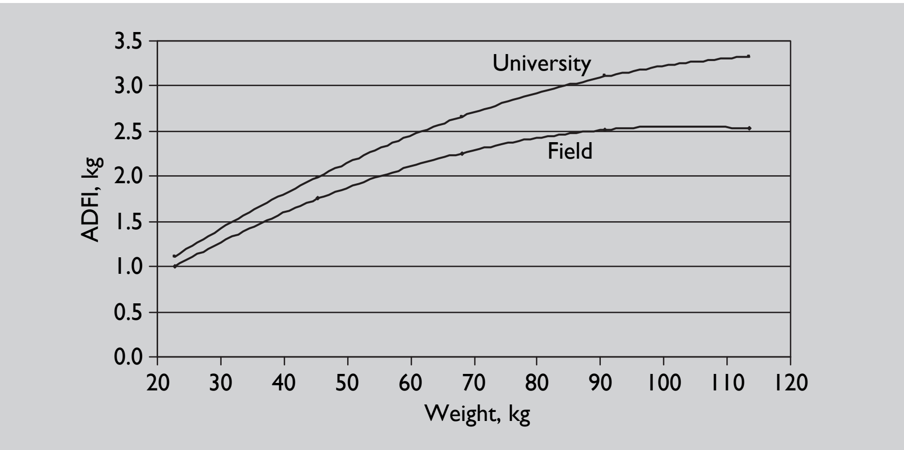

Figure 10. Influence of location on ADFI (Dritz et al.*, 2003).*

the University research trials. Also, note that feed intake plateaus at about 90 kg under field conditions whilst continuing to increase in the University trials.

This indicates that in the University trials, as pigs grow larger they transition to a less energy-dependant phase of growth at a lighter weight compared to those in the field. Therefore, the improvement in growth rate to increased dietary energy from adding fat decreases with increasing body weight under University conditions. However, in the data from the field where feed intake does not increase as rapidly with the increase in body weight, this decrease in response is at a lower rate. Also, note that under field conditions, the response is relatively similar regardless of the dietary energy density or added fat level. However, under University conditions, the response is greater for the first 2.5% added fat than when adding 5% fat. This suggests that the response per percentage added fat is much less from 2.5 to 5% compared to the first 2.5% of added fat. The practical implications of this data is that for farms with high levels of feed intake, the value of increasing average daily gain with dietary energy density is less and the transition away from the energy-dependant phase of growth will occur at a lighter body weight (Figure 11).

Using the response described above for field conditions, Kansas State University have modelled the impact of dietary energy density on net return and feed cost using actual prices paid for corn, soybean meal, and fat by one commercial Midwestern production system over the last 5 years. Note that the net return to added fat is almost always positive in the lighter weight pig (Figure 12). However, the return fluctuates for the heavier weight pig (Figure 13). Furthermore, for the heavier weight pig, adding fat increased the feed cost per unit of gain in most scenarios. This would tend to indicate that using higher energy diets for lighter weight pigs are cost-effective and increase profitability in the majority of circumstances. However, energy density of the later finishing diets will be variable depending on the economic conditions at the time.

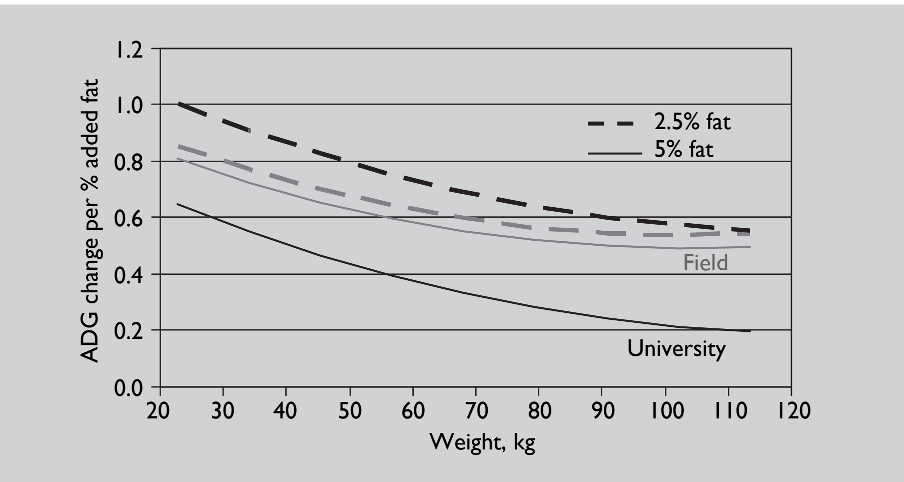

Figure 11. Influence of location and pig weight on change in ADG due to adding fat (Dritz et al.*, 2003).*

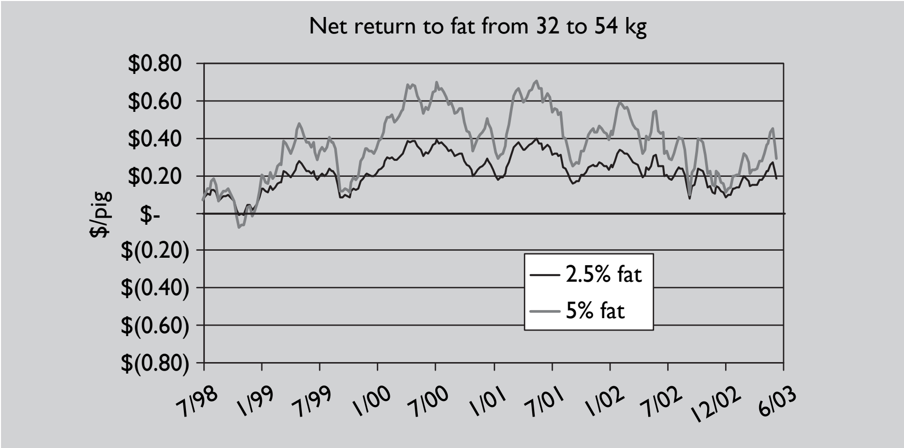

Figure 12. Economics of energy decision for Midwest U.S. production system: Net return to fat from 32 to 54 kg (Dritz et al.*, 2003).*

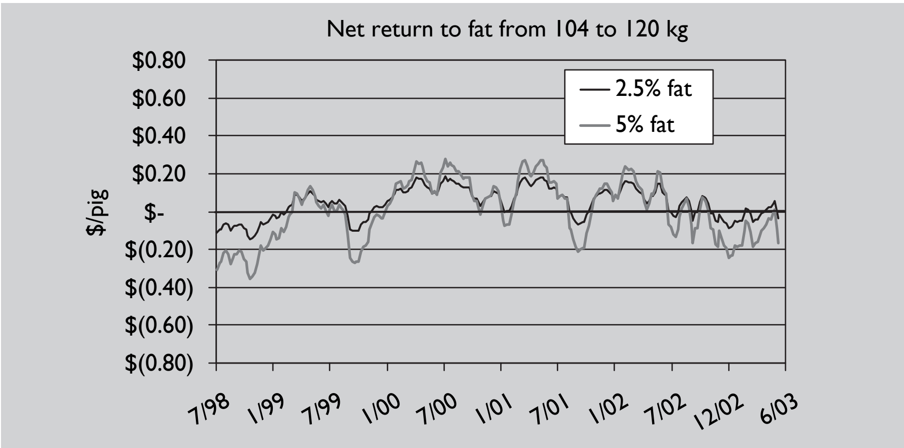

Figure 13. Economics of energy decision for Midwest U.S. production system: Net return to fat from 104 to 120 kg (Dritz et al.*, 2003).*

5. Phase feeding: determining the number of diet phases to feed

The maximum number of diets that can be successfully utilised within a pig production enterprise is limited by feed manufacturing, feed delivery, and feed management constraints. The number of phases must be able to be efficiently administered under existing capabilities for the following:

- feed manufacturing;

- feed inventorying (at the manufacturing site and at animal facilities);
- scheduling and coordination of feed deliveries.

These systems often impose a minimum quantity of each individual diet that can be handled in a cost and time efficient manner. This minimum batch size is influenced by the feed mixer capacity, the size of storage bins in the feed manufacturing facility and at animal facilities, and by the compartment sizes of feed delivery trucks.

Table 2 lists the projected theoretical savings per pig due to increasing the number of diet phases. The actual dollar value of feed savings due to an increased number of phases is determined primarily by the price of soybean meal. This is true since the major effect of increasing the number of diet phases is to reduce the overfeeding of lysine (*i.e.* soybean meal) in the latter portion of each diet phase. For the sake of comparison, if 44% soybean meal were priced at $200/ton instead of $130, the feed savings per pig due to diet phasing would be approximately double those listed in Table 2. These calculations demonstrate that the greatest benefit of multi-phase feeding occurs as the number of grow-finish phases is increased from two to six. It is clear to see that there is only a minimal incremental benefit when adding greater than six diet phases. Furthermore, one should bear in mind that these calculations represent the

Table 2. Impact of number of diet phases on feed cost per pig (Koehler, 1999).

Number of grow-finisher diet phases	Diet cost per pig marketed US$	Savings compared to a two phase G-F program US$	Incremental savings per additional diet phase US$
2	28.75		
3	28.27	0.48	0.48
4	28.10	0.65	0.17
5	27.96	0.79	0.14
6	27.86	0.89	0.10
9	27.72	1.03	0.04
12	27.64	1.11	0.03

Note: These calculations are based on the following assumptions:
- Corn cost of $1.75/bushel; 44% soybean meal cost of $130/ton (July 1999 prices).
- Equal pig performance across all programs (same amount of feed consumed per pig).

maximum theoretical savings. In actual practice, these full incremental benefits are not likely to be attained because group average performance is reduced by more frequent dietary changes due to differences in the actual nutrient needs of individual pigs.

Figure 14 illustrates the range of actual nutrient needs that may be present within a group of market pigs. Periods of overfeeding and underfeeding of nutrients based on the average requirement level of a group of pigs are also indicated. The purpose of changing diets on a frequent basis is to keep actual dietary nutrients as close as possible to the cumulative needs of the group of pigs. However, this also ensures that the pigs within the group that have the highest nutrient needs (upper line) will spend a greater proportion of their lifetime consuming diets containing insufficient nutrient concentrations to support their maximal levels of performance. In general, the smaller, poorer performing pigs that are less able to compete for feed require the greatest nutrient density.

If more than four diets were to be fed, the situation illustrated in the figure would be exacerbated. Overly aggressive staging of diets progressively handicaps the

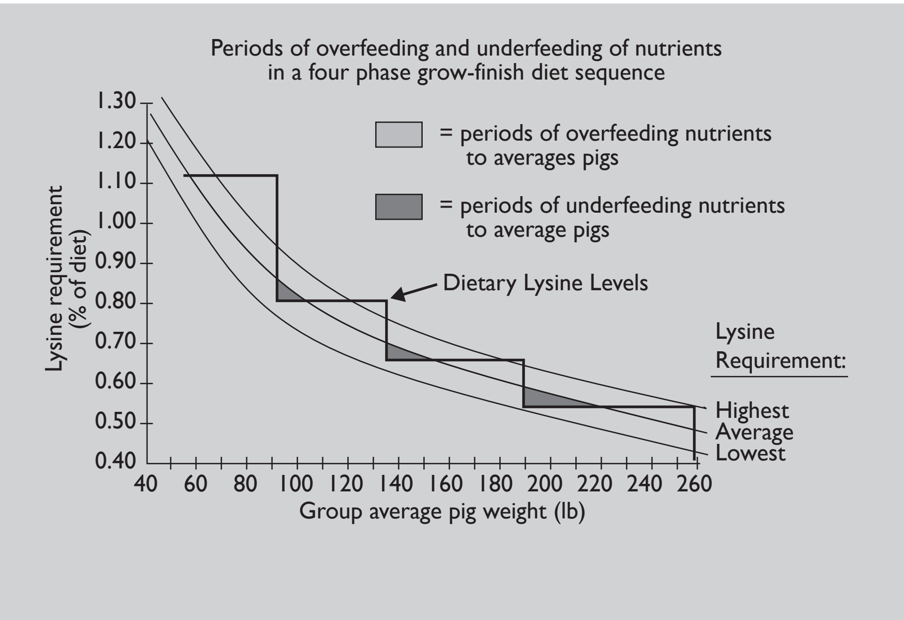

Figure 14. Periods of overfeeding and underfeeding of nutrients in a four phase grow-finish diet sequence (Koehler, 1999).

smallest pigs and leaves them farther and farther behind the rest of the group. In fact, if the variability of individual pig live-weights are high at the time that a group is formed, the smallest pigs within the group may almost never receive their optimal level of nutrition. As a result, pig flow and sort loss problems are amplified.

6. Impact of biological variation on nutrition management (fill time)

The more uniform that the pig group is initially in terms of age and size, the greater the number of diet phases that can be utilised without fear of artificially increasing the weight distribution at marketing time. With frequent phasing of diets, there is a danger that a significant number of pigs may spend a high proportion of time consuming diets that do not meet their nutrient needs. Therefore, using more than four or five grow-finish diet phases is generally not justified unless pigs are placed into feeding groups with a "fill time" of approximately one week or less, and are very uniform in size and health status.

7. Feed budgeting and feed tracking

The final step in the implementation of farm-specific nutrition programs is the on-going use of feed budgets based on farm performance data. Feed budgets and growth curves should be tracked for each group of pigs so that aberrations from expected performance parameters can be detected. In many cases, non-conforming data can be directly attributed to readily identifiable health challenges within a pig group. However, it is important to monitor changes over time because changes in overall performance can indicate alterations in overall herd health status, environmental conditions, feedstuff variation/palatability concerns, or changes in pig phenotype. These changes should serve as warning beacons for potential production problems or indicate that more intensive efforts should be made to re-define nutrient needs for the herd based on real changes in overall biological performance profiles.

8. Enzymes used

The practical use of enzymes in diets was first outlined by Charlton *et al.* (1996), suggesting ways of using enzyme complexes:

- *Simple addition to the diet:* Enzymes added on top of the standard diet (without reformulation) improves digestibility of soybean meal and, consequently, improves growing pig performance. Therefore, its use was suggested in pre-starter and starter diets for pigs.

- *As another raw material in the diet:* Using the improvements observed in energy, crude protein and amino acid digestibility of soybean meal, enzymes can be added to the formulation matrix and used in least-cost diet formulation.

8.1. Grow-finish diets: Reformulation to reduce diet cost

For the growing and finishing stages of pig production the purpose of exogenous enzyme supplementation is also to release otherwise unusable nutrients and improve digestibility; however, improved sanitary/environmental conditions are also an important response. Reduced intestinal non-starch polysaccharides (NSP) means less substrate is available for unwanted gut bacterial growth, there is reduced loss of nutrients via excretion and consequently less potential for pollution.

The increased nutrient digestibility with enzyme addition to grow-finish diets must be considered during diet formulation in order to maximise benefits in terms of reduced diet cost. Xavier *et al.* (2005), reported under different production systems in Brazil, reductions of diet costs between 0.5 and 1.8% along with similar or even better performance being obtained with the supplementation of enzymes (VegPro; Alltech Inc.) in reformulated diets. Other benefits included reduced excretion of N (and other nutrients) and a better utilisation of protein sources.

Lindemann *et al.* (1997) worked with growing-finishing pigs (average initial and final weight of 26 and 109 kg, respectively) to study the effects of VegPro on performance. Pigs were fed either a high density corn/soybean meal diet, or a lower density, corn/soybean meal/wheat middlings diet with or without VegPro supplementation. Growing pigs (between 26 and 63 kg) fed the corn/soybean meal diet with VegPro had higher daily weight gain ($P<0.06$) and better feed conversion ($P<0.10$) than pigs fed the same diet without the enzyme complex. Daily weight gain was unaffected in grower pigs fed the corn/soy/wheat middlings diet although pigs supplemented with VegPro had numerically better feed conversion. Similar responses were noted in finishing pigs (between 63 and 109 kg), although of a smaller magnitude in comparison to the grower period. Overall, pigs fed the corn/soy diet supplemented with VegPro had higher daily weight gain ($P<0.05$). They also had a numerically better feed conversion efficiency. There were no significant differences in performance between pigs fed corn/soybean meal/wheat middlings with or without VegPro (Table 3).

Table 3. Effect of VegPro addition to diets on performance of growing-finishing pigs. Adapted from Lindemann et al. *(1997).*

	Corn/soy		Corn/soy/midds	
	Control	VegPro	Control	VegPro
26 – 63 kg				
Daily gain, g	770	840	720	710
Daily feed intake, kg	1.98	1.92	2.10	1.96
Feed: gain	2.57	2.29	2.91	2.76
63 – 109 kg				
Daily gain, g	820	880	790	780
Daily feed intake, kg	2.70	2.77	3.08	3.03
Feed: gain	3.28	3.16	3.91	3.90
Total period (26 – 109 kg)				
Daily gain, g	800	860	770	750
Daily feed intake, kg	2.37	2.36	2.68	2.55
Feed: gain	2.96	2.75	3.48	3.41

In another trial, Pluske (1998), reported an average increase of 6.4% in energy digestibility, 5.5% in organic matter digestibility, and 2.7% in crude protein digestibility of soybean meal with VegPro supplementation in comparison to a control diet without the enzyme. Other research has shown an increase in digestibility of threonine + 3.00; tyrosine + 0.80; valine + 1.80; phenylalanine + 2.18; methionine + 6.90; histidine + 0.75; isoleucine + 1.87; lysine + 0.34 and leucine + 2.56; of soybean meal with the addition of exogenous enzymes to the diets.

The utilisation of enzymes in pig diets in Brazil is growing steadily each year. According to Pupa *et al.* (2005), the use of enzymes is roughly 25% in pre-starter diets and approximately 50% in growing and finishing diets.

8.1. Effects on amino acid digestibility

Soybean meal is the major protein source for swine diets around the world, corresponding to 15 to 35% of the total. As previously stated, although this ingredient is considered highly digestible, the presence of anti-nutritional factors and NSP impair swine digestive processes and nutrient utilisation. The addition of enzymes to swine diets improves nutrient digestibility and reduces the impact of anti-nutritional factors.

Working with growing pigs in Brazil, Costa *et al.* (2005), determined the true ileal amino acid digestibility of soybean meal with and without enzymes. Enzyme hydrolysed casein was used to determine amino acid endogenous losses. Though a high coefficient of variation associated with the analysis precluded statistical separation of the means apart from histidine digestibility, numerical increases for the majority of amino acids were noted in response to Enzymes (VegPro) (Table 4).

Table 4. True digestibility coefficients of protein and amino acids of soybean meal and soybean meal plus VegPro for swine (Costa et al.*, 2005).*

Nutrient	Soybean meal	Soybean meal plus VegPro	Improvement in absolute values (%)
Crude protein, %	86.24	85.24	
Amino acids, %			
Alanine	70.84	77.30	+6.46
Arginine	96.69	98.07	+1.38
Asparticacid	89.31	90.57	+1.26
Cystine	89.91	92.03	+2.12
Glutamicacid	87.41	89.42	+2.01
Glycine	78.60	86.48	+7.88
Histidine	99.03	93.96	
Isoleucine	82.40	83.44	+1.04
Leucine	80.79	84.12	+3.33
Lysine	87.67	89.74	+2.07
Methionine	92.94	91.62	
Phenylalanine	86.08	89.29	+3.21
Proline	79.08	85.06	+5.98
Serine	85.84	88.11	+2.27
Threonine	73.99	80.79	+6.80
Tryptophan	87.13	83.20	
Tyrosine	93.03	87.99	
Valine	79.39	82.08	+2.69

9. Conclusions

A thorough understanding of nutrition-genotype interactions will enable the correct formulation of diets for grow-finish pigs. Furthermore, the use of optimal ratios and levels of amino acids and energy-dense diets will not only allow the pigs to achieve their potential for growth, but also in an efficient and cost-effective manner. Phase feeding also has an important role to play in meeting the pigs' needs. However, in group housing conditions, the maximum theoretical savings associated with phase feeding are not achieved since the group average performance is reduced due to differences in actual nutrient needs of individual pigs. This further highlights the importance of grouping pigs with uniform age, size and health status. Finally, feed budgets and performance recording systems are critical in ensuring optimal performance and also for tackling any production problems or health issues in order to achieve maximum profitability.

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Protein and amino acid nutrition in poultry: impacts on performance and the environment

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1. Introduction

Public concerns with air quality from livestock and poultry operations have dramatically increased in recent years. Part of the issue at hand, is the paucity of data on emissions from different livestock and poultry operations. An emission is the product of the concentration of the pollutant in question multiplied by a flow rate. Each of those factors has a unique set of measurement challenges with precision, especially with naturally-ventilated buildings, outdoor manure storage structures, or with animals that are not reared in confinement.

Development of environmental regulations, however, is quite complex. Simply put, any environmental regulation has to ultimately achieve a particular performance or outcome standard. Achieving that standard, however, becomes relatively difficult when having to address:
1. who is regulated;
2. what threshold of operation is selected (is this arbitrary or to encompass a certain proportion of regulated industry(ies));
3. does picking a threshold shift land base or operational ownership without achieving the performance standard;
4. economic burdens of compliance;
5. current technology for achieving the performance standard;
6. process-based regulation that shifts the site of environmental impact.

Moreover, regulations that are enacted and enforced separately can have non-synergistic impacts on environmental performance standards. A good example of this could be the application of separate water and air regulations in the USA to livestock and poultry operations. According to Aillery *et al.* (2005), separate air and water policy largely will encompass different proportions of the industry and possibly cause geographical shifts in livestock and poultry operations. For example, if a 10% reduction in atmospheric ammonia (NH_3) regulation were put in place with the current water regulation for confined livestock, the industry would bear additional storage, handling, treatment, hauling, and application costs of $208M USD (water regulation alone = $534.5M USD; 10% atmospheric NH_3 reduction alone = $42.2M USD; combined = $742.4M USD). Environmental benefits would be estimated at a reduction in NH_3 emissions by 10%, but at the cost of an additional 2 to 3% of field nitrogen (N) runoff. Therefore, Aillery *et al.* (2005) surmised uncoordinated policies could ultimately increase discharge of N into surface and ground water.

2. Diet modification

Diet modification is an approach to the air emissions issue that has been studied and shown to have promise. The good news is we do have a relatively good literature base for reducing compounds and nutrients within manure. The bad news is that these reductions do not always correspond to reduced emission factors (which we have an insufficient literature base at present), and the extent of improvements made may not be sufficient to meet compliance needs. Generally, there are two general types of diet modification, nutrient input mass reduction and nutrient form modification.

The first**,** nutrient input mass reduction, changes the concentrations of the nutrient being fed such as decreasing the protein content of the diet while supplying the amino acid needs for animal performance using purified amino acids. The second, nutrient form modification, changes the chemical form of the nutrients being excreted through diet manipulation (*i.e.* diet acidification, dietary inclusion of additives such as urease inhibitors, or feedstuff selection to shift the site of nitrogen (N) excretion). Those strategies that reduce nutrient input mass must, by mass balance definition, decrease nutrient mass output, yet those that only change the form may only initially reduce nutrient emissions to air because they "trap" nutrients in chemical forms that are not volatilised. The important question that needs answering is - for how long are these nutrients trapped in a solid form? Thus, the extent to which any reductions observed in the animal housing area through dietary strategies that change the excretion form are preserved during manure/litter storage is currently unknown and must be defined before successful implementation can occur and before mass flow models can be established.

To reduce nutrient input mass through dietary changes two approaches can be used. The first is to reduce dietary nutrient concentrations to more closely meet the need of the animal. In the case of nitrogen (N), one way this can be done is to reduce the concentration of protein and thus N in the diet, but meet amino acid requirements by supplementing the diet with purified amino acids. Most of the research conducted to date on reducing nitrogenous air emissions through dietary nutrient input mass reduction has relied on this strategy. Within this approach, it is imperative that the changing nutrient needs of the animal are considered as well as strategies that allow for more frequent feed changes. If not, we may have periods of time with sufficient over feeding of a nutrient (for example, with lysine as exemplified in Figure 1).

A novel strategy that has the potential to further reduce air emissions is the second approach. This approach focuses on dietary modifications that shift the chemical form of nutrients being excreted thereby reducing the amount of nutrient volatilised. Because these two approaches work through different mechanisms they could successfully be coupled resulting in much greater reductions in the mass input and thus mass output of nutrients. Although dietary studies focusing on crude protein (CP) reductions have demonstrated reductions in N excreted, little work has also looked at what will be volatilised under specific storage conditions and what form N will be in once excreted (NH_3, NO_x, N_2O, N_2).

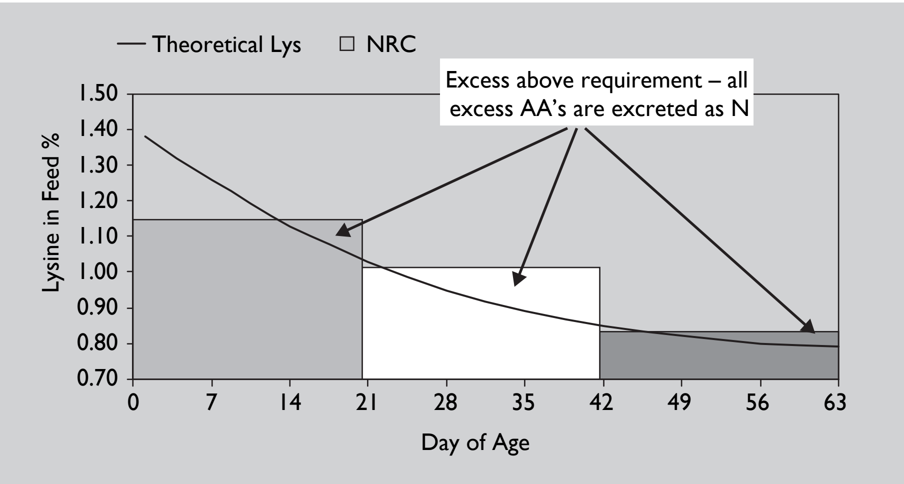

Figure 1. Example of how phase feeding to changing nutrient needs of the animal is important to prevent excessive nutrient excretion. NRC (1994) requirement for broilers versus calculated needs from recent literature.

3. Variation in nutrient utilisation by poultry

Present commercial poultry breeds/strains are more efficient in utilising nutrients and the present commercial feeds are better formulated to meet the requirements of the rapidly growing animal (Havenstein *et al.*, 1994). For example, N and phosphorus (P) excretion per kg live weight was 55 and 69% less, respectively from a 1991 commercial broiler strain versus a 1957 commercial broiler strain when fed the same diet. Considerable variation exists within the literature, however, for utilisation of different nutrients. Much of the variation can be attributed to feeding of different ingredients, ages, or health status. Nutrient retention values for N, P, and dry matter (DM) as summarised from 84 peer-reviewed articles from 1985 to 2003 are presented in Table 1 (Applegate *et al.*, 2003). Notably, substantial variation existed within and

Table 1. Profile of peer-reviewed publications (1985-2003) summarised for nitrogen (N), phosphorus (P), and dry matter (DM) retention (Applegate et al.*, 2003).*

Specie	Average % N retention	Minimum	Maximum	Number of reports
Broiler	60.2	44.0	73.5	11
Turkey	56.8	47.8	75	8
Duck	65.7	54.6	78.1	4
Laying hen	45.6	30	75.0	5
	Average % P retention			
Broiler, < 32 days	49.3	34	64.1	22
Broiler, > 32 days	41.0	36	51.0	5
Turkey	48.0	33.9	56	9
Duck	46.4	-	-	1
Laying hen	29.1	13.6	44	20
	Average % DM retention			
Broiler	68.6	52.2	74.5	10
Turkey	74.8	67.1	82.5	2
Duck	69.4	53.7	87	5
Laying hen	79.3	74.6	84	2

between species. For example, for the broiler, N and P retention each had a range of 30% and DM by 20%.

4. Process uncertainty and feeding safety margins

Knowledge of N reduction strategies by the industry is imperative, but often difficult to implement. For example, process variation in sampling, creating diets, ingredient N content as well as N utilisation by the animal still limits reductions by the industry in order that they guarantee their animals never become deficient. To illustrate this, process uncertainty can be calculated for feed formulation for broiler chickens (square root of the sum of squared coefficients of variations; Funk *et al.,* 2003) from the variation listed for these processes (Table 2). Even if the lesser of the variation is assumed, the overall process uncertainty is 17.4% (or 22.3% at the worst). Even if exact ingredient analysis is known, due to bird utilisation and diet manufacturing limitations, the process uncertainty could be no better than 15.8 to 18.0%. The industry, however, has been feeding at considerably lower safety margins than at these levels of uncertainty. Processes that reduce variation in individual nutrient retention, greatly improve N digestibility, or consistent nutrients within ingredients may hold the most promise in reducing the N excretion by all livestock and poultry.

Table 2. Summary of variation in processes associated with feeding of crude protein to broiler chickens.

Process variation	Coefficient of variation (%)
Sampling variation	5-10
Analytical variation[1]	5
Mixer variation[2]	5-10
Bird utilisation (Table 1)	15
Ingredient variation (corn and SBM)[3]	1-7

[1]Variation was assumed to be better for feedstuffs than that for manure (10-119%) as reported by Funk *et al.* (2003) in referencing Floren (2002).
[2]Wicker and Poole (1991).
[3]P. Dorr – ConAgra (personal communication).

5. Reduced dietary protein

Minimising N excreted is the most obvious method to curb NH_3 emissions. By reducing the available substrate, less NH_3 will be formed and volatilised. Unfortunately, there is a wide-spread belief that whenever CP concentrations are lowered, performance would be negatively affected. Burnham (2005) speculates this belief stems from researchers (Neto *et al.,* 2002; Bregendhahl *et al.,* 2002) who have lowered crude protein concentrations beyond practical formulation and then did not supplement back with sufficient amounts of limiting amino acids other than Met and Lys. Reductions in the non-essential amino acid pool, coupled with supplying a more “ideal” amino acid profile in the diet can substantially increase the efficacy of overall N retention by the bird. On a practical basis, however, bird performance can be hindered by excessive lowering of CP in diets due to a number of factors. According to Waldroup (2000), these factors can include: reduced potassium levels, altered ionic balance, lack of non-essential amino acids, imbalances among certain amino acids (e.g. branched chain amino acids), and/or potential toxic concentrations of certain amino acids.

5.1. Broilers

Reducing CP content of broiler diets by less than 2 percentage units resulted in decreased litter N content but no significant differences in NH_3 concentration in the house (Ferguson *et al.*, 1998). The 13.3% decrease in N intake did correspond to 18.2% reduction in litter N content. Elwinger and Svensson (1996) fed broilers diets containing 18%, 20% or 22% CP and measured NH_3 emissions from the litter bed. Total N losses in the houses averaged 18% to 20% of total N input.

Angel *et al.* (2006) also studied the possibility of reducing dietary N intake in broilers to 42 days of age. In their studies, an industry control 4-phase feeding program (corn-SBM based) with synthetic Met and Lys were compared with a 6-phase feeding program with synthetic Lys, Met, Ile, Thr, Val, Trp, and Arg. Birds were reared on the same litter for 5 consecutive flocks. Feed conversion was similar between groups after 5 flocks, but live body weight was 77 g lighter in birds fed on the 6-phase program. In a sampling of 40 birds per diet, however, dressing or breast yield (%) were not affected by diet in the third or fourth flocks. Consumption of N with the 6-phase feeding program was 8.3% lower than those on the 4-phase feeding program (7.04 versus 7.68 g/bird) resulting in a 20% reduction in N excretion (2.3 versus 2.9 g/bird). The 6-phase feeding program resulted in a 15.4% reduction in daily NH_3 emission (1,407 versus 1,663 mg/d per 50 birds) over the first three flocks (Powers *et al.,* 2006).

5.2. Turkeys

Reducing CP content (particularly by formulating to essential amino acid needs rather than setting of a CP minimum) of turkey diets can have considerable economic benefits. For the strains of turkeys when the studies were conducted, several researchers have noted that when essential amino acid requirements are met, NRC (1994) CP recommendations are not warranted (Sell and Jeffrey, 1994; Waibel *et al.,* 1995; Boling and Firman, 1997; Kidd *et al.,* 1997; Waldroup *et al.,* 1997). Depending on phase feeding programs, these studies indicate that 100 to 107% of NRC (1994) recommendations for essential amino acids were needed to maximise growth and breast meat yield. Little if any work has been done with turkeys, however, with consideration to loss of N to the environment.

In the case of turkeys, phase feeding also can have a dramatic impact on overall N consumption. For example, Waldroup *et al.* (1997) reported that when turkeys

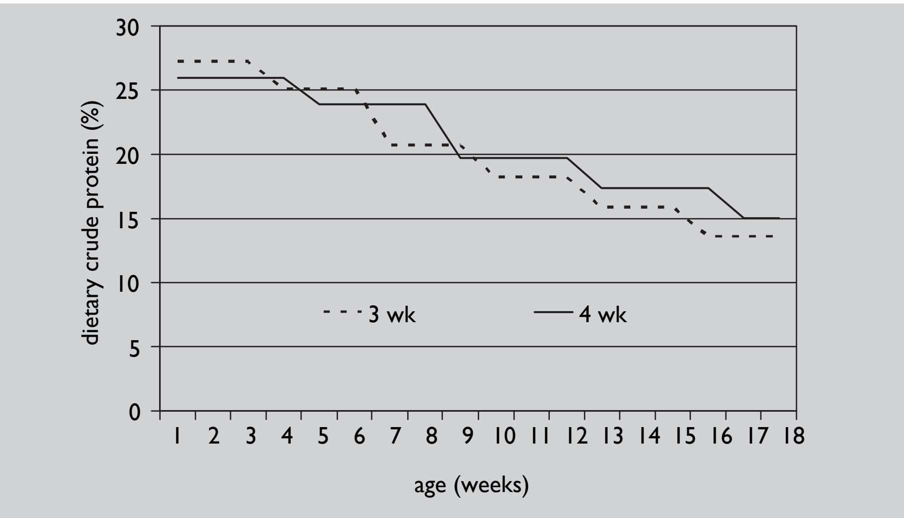

Figure 2. Formulated crude protein diet phases for male turkeys, as adapted from Waldroup et al. *(1997). Diets were fed in either 3 or 4 week phases. Concentrations indicated maximised growth and meat yield when fed at 105% of NRC (1994) recommended amino acid concentrations for 3-wk phases and 100% of NRC (1994) recommended amino acid concentrations for 4-wk phases.*

were fed 105% NRC (1994), recommended amino acid formulation, they maximised performance and breast yield when fed in 3 week phases (Figure 2). When diets were fed in 4 week phases, only 100% of NRC (1994) recommended concentrations of amino acids were needed. Using the Nicholas 700 predicted intake, one is able to translate those formulations into actual N fed (Figure 3). Due to the timing of when the 3-week phases were fed, however, the turkeys fed 105% of NRC (1994) amino acid concentrations in 3-week phases consumed 8% less N over the life of the flock (Figure 3). Given Spring 2006 US pricing for corn, SBM, poultry oil, Lys, Met, and Thr the feed cost would be $0.142 USD cheaper per marketed tom for the life of the flock for the 3-week versus 4-week phases (assumed pricing was $0.079, 0.20, 0.35, 1.56, and 2.75 USD per kg for corn, SBM, fat, Lys, and Met, respectively).

5.3. Laying hens

In the case of laying hens, CP and amino acid formulations are largely over formulated with the hopes of getting a return in either egg size or egg number. Unpublished research from our laboratory, however, suggests that 15.3 g of CP (858 mg Lys, 450 mg Met, 585 mg Thr, and 638 mg Ile) is sufficient to maximise egg weight and production from 25 to 45 weeks of age versus birds fed corn/SBM diets containing 16.15 g of CP (874 mg Lys, 409 mg Met, 627 mg Thr, and 684 mg Ile). Although this 5.6% reduction in N intake doesn't appear like much

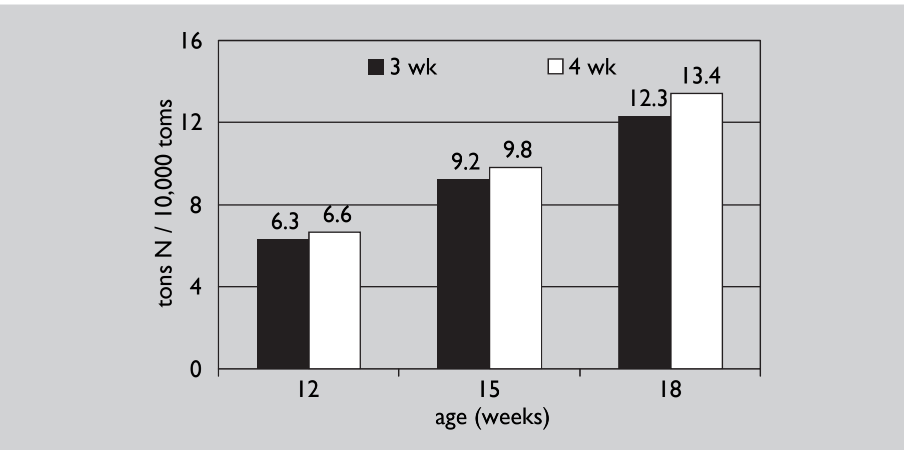

Figure 3. Cumulative N intake of turkey toms as adapted from Waldroup et al. *(1997) for maximising body weight and breast yield. Feed intakes were predicted using optimum of Nicholas 700.*

when the lower CP diet is fed, it results in a $1024 USD/100,000 hens difference in daily feed cost (ingredient pricing similar to turkey example) and a 13.6 kg reduction in daily N intake per 100,000 hens.

Generally, as a guide, for each 1% reduction in dietary CP estimated NH_3 losses are reduced by 10% in swine and poultry (Sutton *et al.*, 1997; Kay and Lee, 1997; Blair *et al.*, 1995; Jacob *et al.*, 1994; Aarnink *et al.*, 1993). As animals are fed closer to true N requirements, further reductions in dietary CP may result in less pronounced reductions in N excretion and NH_3 losses.

5.4. Ingredient selection

Selection of feedstuffs with relatively high digestibility can largely help with overall reductions in amino acid formulation. Table 3 presents data for protein sources and their respective true and apparent digestibility. Notably, sources such as feather-meal are not typically considered due to their amino acid profile, but rather their digestibility. Similarly, formulation for emission reduction should also consider the protein quality as exemplified in the range of apparent digestibility, where processing temperatures could cause Maillard reactions as well as other conditions that would reduce amino acid availability.

Table 3. Standardised and apparent digestible lysine (Lys) from chickens for different feedstuffs.

	Standardised digestible Lys, %[1]		
Feedstuff	Mean	Range	Apparent digestible Lys, %[2]
SBM	90	85-93	86
Canola	80	64-84	72
Sunflower	84	-	-
Cottonseed	67	-	55
DDGS	67	35-84	-
Fish-meal	88	-	83
Blood-meal	87	50-91	-
Poultry byproduct-meal	80	68-90	-
Meat and bone meal	80	45-90	58
Feather-meal	65	34-80	54

[1]Parsons, 2005 utilising cecectomised roosters.
[2]Ravindran *et al.,* 1998. Apparent ileal digestible Lys.

Formulation on a digestible amino acid basis will also (1) reduce the total amount of CP fed, and (2) limit the excessive amount of non-essential amino acids fed – particularly if higher digestible CP feedstuffs are available.

5.5. Formulation on a digestible amino acid basis

Digestible amino acid values are considered by many to be the best measure of the amino acid value of ingredients. Long-term, reductions in protein formulation together with adoption of the digestible amino acid concept should greatly reduce feed cost and N emissions. Further benefits of formulating on a digestible amino acid basis include decreasing safety margins, increasing the accuracy of predicting performance, and increasing the uniformity of product after processing. Unfortunately, knowledge of what the causes of variation in amino acid digestibility within and between ingredients is not sufficient. Additionally, inconsistent methodologies make it difficult to make the switch to using digestible amino acid values, especially for non-traditional feed ingredients. Notably, most of the grow-out poultry studies focusing on the use of digestible amino acid formulations have only focused on performance and economic considerations and not necessarily on N excretion or emission reduction (Fernandez *et al.*, 1995; Rostagno *et al.*, 1995; Dari *et al.*, 2005). Formulation on a digestible basis can have large economical and environmental benefits, particularly when formulating with ingredients known to have lower digestibility. For example, unpublished data by Rostagno (University of Viscosa, Brasil) suggest considerable differences in BW and feed/gain of birds fed either 6 or 12% cottonseed meal or sorghum when formulated on a total versus a digestible basis. Similarly, Pertilla *et al.* (2002) noted significant reductions in performance and yield when diets were formulated with lower digestible ingredients (rapeseed meals or meat and bone meal) when compared with those formulated on a total lysine basis versus a digestible lysine basis.

Lemme *et al.* (2004) provides an excellent review and commentary on application of the ileal digestibility concept and its application into broiler diet formulation. Notably, standardisation of amino acid digestibilities from ingredients is needed to account for endogenous amino acid losses. This standardisation accounts for factors such as amino acid concentration in the diet. For example, results from our laboratory suggest that the difference between apparent and standardised amino acid digestibility coefficients for SBM may differ by 1 to 3% whereas that for corn can differ up to 14% (Adedokun *et al.*, personal communication).

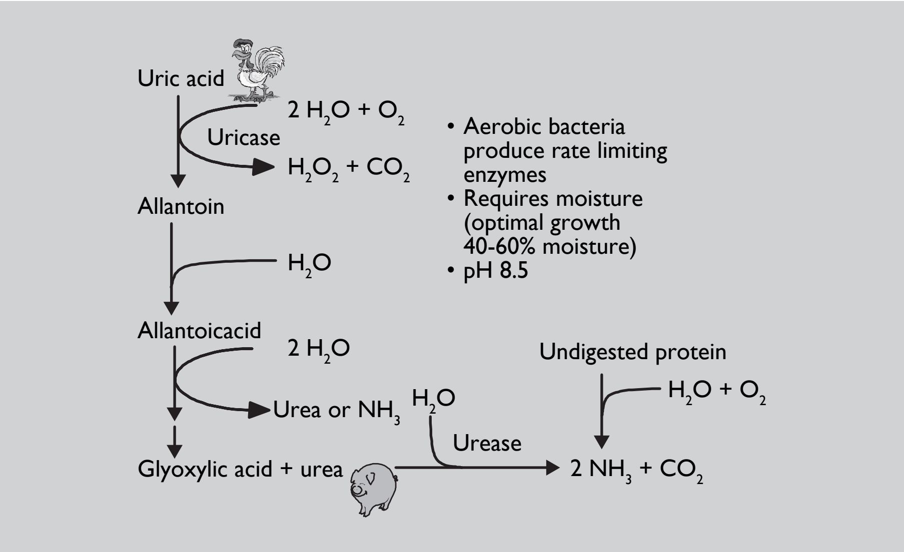

Figure 4. Conversion of uric acid and urea to ammonia (NH_3) is an aerobic process requiring moisture, optimal pH, and temperatures for proper microbial growth and production of the rate-limiting enzymes uricase and urease.

6. pH manipulation of diet

Ammonia is a primary by-product of uric acid (poultry) and urea (swine) degradation as well as microbial degradation of undigested protein (Figure 4). Although uric acid contains two additional metabolic steps for conversion, both uric acid and urea are very quickly converted to NH_3. This conversion for uric acid occurs via the primary uricolytic bacteria, *Bacillus pasterii* (Schefferle, 1965) which has an optimal growth pH of 8.5 (Elliott and Collins, 1982). Therefore, the primary factors driving growth and NH_3 conversion in poultry manure/litter would be temperature (24 °C), moisture (40 to 60 percent), and pH (<7.0; *i.e.* higher pH increases NH_3/ammonium ratio) (Groot Koerkamp, 1994). This conversion also is reliant upon two enzymes: uricase (uric acid conversion to allantoin) and urease (urea to NH_3). Once NH_3 is formed, it can either be volatilised, or remain in the non-volatile state as ammonium (NH_4^+). In order to stay in the non-volatile state, NH_3 must be protonated, which essentially means litter pH must be 7.0 or less. Several researchers have investigated how this can be accomplished through post-excretion amendments, but the more efficient conversion would ultimately be through dietary manipulation.

6.1. Pigs

Sutton *et al.* (1997) observed a reduction in swine manure pH when 5% cellulose was added to the diet. Canh *et al.* (1997) observed reduced NH_3 emissions of 26% to 53% by including Ca-salts up to dietary Ca levels of 7 g/kg to 10 g/kg resulting in reductions in urinary pH ranging from 1.6 to 1.8 units. Hendricks *et al.* (1997) observed a 37% reduction in NH_3 emissions following feeding calcium benzoate to grow-finishing pigs. Kim *et al.* (2000) observed a 30% reduction in NH_3 emissions associated with growing pig diets containing a combination of phosphoric acid and calcium sulfate and a lesser reduction in emission (17%) when diets contained a combination of monocalcium phosphate, calcium sulfate, and calcium chloride. Relative to the control diets, no NH_3 emission reductions were observed when diets contained a combination of monocalcium phosphate and calcium sulfate despite significantly reduced urinary pH in these animals. This may relate to the buffering capacity in animals fed these diets. In all of these studies, measures were made after less than 24 h post-excretion. Long-term impacts, however, remain in question.

6.2. Laying hens

Little research with laying hens has been reported with the strategy of trying to reduce litter/excreta pH with dietary manipulation. The primary strategy attempted to date, includes that of replacing a portion of limestone with calcium sulfate (gypsum; up to one third can be replaced without affecting bird performance or shell characteristics; Keshavarz, 1991). Hale (2005) noted that the replacement of 45 percent of dietary limestone with calcium sulfate resulted in a 17 percent reduction in NH_3 emissions over a 7-day manure incubation. Reductions of up to 95 percent were obtained when 35 percent dietary limestone was replaced with calcium sulfate, in combination with a 0.3 percentage unit reduction in dietary CP and 1.25 % added zeolite into the diet. Data by Wu *et al.* (2007) suggest that this combination will reduce NH_3 emissions by 30-40 percent, but at the expense of increased H_2S emissions.

Another strategy that has been studied has been to supplement the diet with a fermentable fiber source such that N excretion from urine would be shifted to microbial protein, a more stable form of N. Notably, NH_3 release from manure stored over 7 days was considerably less when Hy-Line W36 hens were fed diets containing either soy hulls, wheat midds or dry-distillers' grains with solubles versus a corn-SBM control diet (Roberts *et al.,* 2006).

7. Conclusion

Taken alone, each of the following strategies for N emission reduction: (1) dietary CP reductions, (2) manure acidulation, and (3) NH_3 binding, have demonstrated measurable reductions in NH_3 emissions. Arguably, these reductions (when considered alone) may not be to the extent, nor duration needed for practical implementation by the swine and poultry industries. Therefore, studies encompassing combinations of these strategies are imperative such that the industry will have documented magnitudes of reduction for future regulations.

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Producing enzymes on feed ingredients: the solid state fermentation story

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1. Introduction

For over twenty years feed enzymes have been available for use in poultry diets, where they have been shown to improve performance and production efficiency. The use of in-feed enzymes not only improves production levels, but also reduces variability in broiler chicken and laying hen performance and allows lower quality (in terms of nutritional value) or local raw materials to be included in the diet. Increased phosphorous pollution concerns have resulted in the use of certain key enzymes, such as phytases, to become mandatory in many countries. Consequentially, the vast majority of poultry diets globally are supplemented with enzymes (Leeson and Summers, 2001).

2. Commercial enzyme production

Typically feed enzymes consist of one or more catalytic components, derived from either bacterial or fungal origin. Bacterial strains used to produce enzymes are often genetically modified, allowing over-expression of the desired enzyme and making it more cost effective for use in animal feed. In-feed enzyme products typically consist of mixtures of single enzymes tailored to the raw materials used in the ration formulation, each raw material having different enzyme requirements for appropriate digestion. For example, xylanase predominates in enzyme products destined for use in wheat-based diets, whereas β-glucanase is used for barley, and protease for soybean meal (Leeson and Summers, 2001).

Certain enzyme products, such as the Allzyme® series (Alltech Inc., USA), are derived from non-genetically modified fungi. This natural production process is well suited to address consumer concerns regarding genetic engineering and to maximise production and efficiency of modern poultry genotypes.

Over 90% of commercial enzymes are produced by batch fermentation in large holding tanks (Filer, 2001), where specific nutrients to encourage single enzyme production are included in a liquid 'broth'. The finished material is purified through a series of procedures, resulting in a product that predominates in one enzyme activity, which is then applied to a carrier to generate a dry form of suitable density for in-feed mixing. Overall, this method of production can be costly and involves the removal of liquid waste products of bacterial origin, a practice that is increasingly regulated in many parts of the world.

3. Solid state fermentation technology

Recently, a 4,000 year-old method of enzyme production called 'solid-state fermentation' (SSF) has been resurrected by Alltech (Martin, 2003). Many foodstuffs that are still in use today are derived from solid-state fermentation such as sauerkraut, soy sauce or kimchi. In agriculture, solid-state fermentation is used in silage production.

The process for feed enzyme production involves growing the enzyme-producing fungus *Aspergillus niger* directly on a feed raw material substrate. Once initiated, the fungus produces enzyme specifically tailored for digestion of the substrate available, allowing it to grow. Fungal organisms have exogenous digestive systems, secreting enzymes onto the substrate on which they are grown. This digestive process facilitates the production of nutrients in a suitable form for translocation across the cell wall, where they can be incorporated into the fungus. The enzyme remains within the substrate.

Suitable fungal strains are screened for their usefulness in producing in-feed enzymes. Selection criteria include high enzymatic activity, enzyme profile, genetic stability, sporulation index, growth rate and the capacity to reproduce on an industrial scale. Additionally, the cereal-based growing media is carefully selected based on consistency in both quality and supply. Before fermentation begins, the substrate is sterilised carefully to ensure preservation of certain compounds that provide the stimulus for enzyme production. Fungal inoculum is combined with the sterilised substrate to produce a mixture known as Koji (a Japanese word meaning 'bloom of mould'). The koji is then placed on trays and incubated in fermentation chambers under controlled temperature, humidity and atmospheric (oxygen) conditions, in order to optimise the fermentation process. The substrate composition provides certain stimuli for enzyme production, resulting in a wide range of enzyme activities, which work in synergy to break down the available nutrients. Once the required level of enzymatic activity is reached, the koji is removed from the fermentation chambers, dried and granulated to form the final product, Allzyme® SSF.

4. The solid state fermentation advantage

The final enzyme product contains a combination of enzymes specifically tailored to digest the nutrient mix found in the raw material used as the substrate. In comparison with liquid batch fermentation, where enzymes have to be extracted and purified adding considerable additional production costs, the use of the whole koji as the final product makes Allzyme® SSF much more cost effective for in-feed enzyme production. In addition, by changing the growth media to reflect the cereals used in local feed formulations, it is possible to alter the final enzyme combination to match the target feed (Filer, 2001).

This means that a feed manufacturer only has to use one product to cover all of the needs of broiler or layer feed, saving storage, equipment and labour costs in the mill. The poultry farmer has the opportunity to save feed costs by reducing diet specifications or use locally available, low cost raw materials whilst maintaining performance results.

5. Efficacy of Allzyme® SSF on *in vitro* and *in vivo* nutrient digestibility

Research using a poultry digestion simulation model at Massey University, in New Zealand, compared the level of nutrients released by Allzyme® SSF versus other commercial enzyme cocktails (Wu *et al.*, 2004a). The model mimics the digestive tract of the chicken, and allows quantification of nutrient uptake (Wu *et al.*, 2004a). Allzyme® SSF showed superior digestibility characteristics compared with other commercial phytase products (produced by conventional submerged fermentation) in both corn and wheat. Allzyme® SSF had significantly ($p<0.05$) higher phosphorus, nitrogen and reducing sugar release compared to other phytase-based enzymes (Table 1; Figure 1).

Dose-response comparison revealed that the SSF enzyme gave a 2% higher nitrogen digestibility compared to the other commercial enzyme at the same dosage. Wheat grain is composed of a complex matrix of digestible and indigestible compounds, which can be difficult to break down (Leeson and Summers, 2001). In order to degrade structural non-starch polysaccharides (pentosans) that can reduce the availability of nutrients for digestion, several enzymatic activities may be required. The higher impact of Allzyme® SSF on wheat diets was thought to be related to the more suitable and complex combination of enzymes present, compared to the conventional enzyme product.

Table 1. In vitro digestibility of nutrients in a poultry simulation model comparing Allzyme SSF (Wu et al.*, 2004a).*

Enzyme (0.5 kg/t)	Phosphorus (g/kg)		Reducing sugars (g/kg)		Nitrogen (g/kg)	
	Wheat	Corn	Wheat	Corn	Wheat	Corn
Allzyme® SSF	2.04[a]	1.79[a]	44.7[a]	117.1	1.22[a]	0.67
Other phytase	1.84[b]	1.65[b]	43.4[b]	117.7	1.20[b]	0.63

[a,b]Mean values with different superscripts differ (P<0.05).

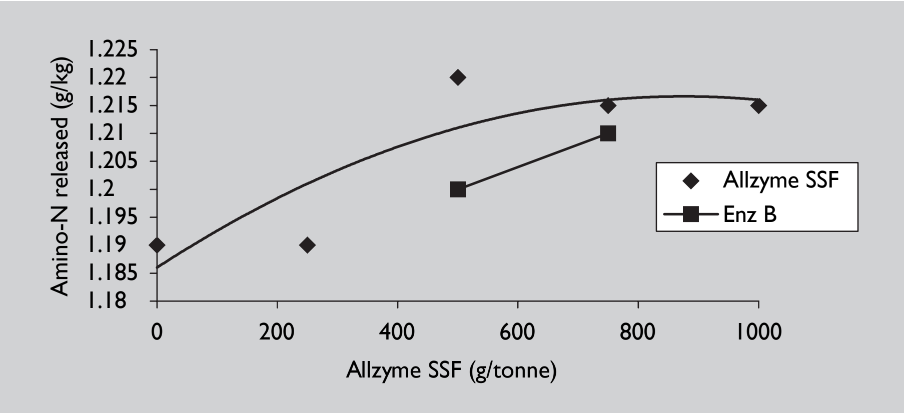

Figure 1. In vitro *amino-nitrogen release from a corn-soy diet by Allzyme® SSF compared to a commercial enzyme preparation (Wu* et al.*, 2004a).*

Nutrient digestibility and apparent metabolisable energy (AME) in layer hens was investigated in trials conducted in China (Cheng *et al.*, 2004). These studies showed that laying hens fed a down-specified diet (containing 100 kcal/kg less ME and with aP reduced from 0.35 to 0.2%) supplemented with Allzyme® SSF had significantly higher energy, protein and P digestibility (Table 2). The lower levels of excreted P and Ca is important in countries where pollution from intensive farming is a problem.

Table 2. Benefits of Allzyme® SSF on nutrient digestibility in laying hens fed down-specified corn-wheat based diets (Cheng et al.*, 2004).*

Faecal digestibility (%)	Control	Down-specified diet	Down-spec. + SSF 0.2 kg/t	SEM
Energy (AME)	87.0[a]	85.0[a]	90.0[b]	2.0
Protein	67.6[b]	61.6[a]	75.9[c]	1.77
Phosphorus	35.3[a]	34.3[a]	52.4[b]	1.99
Calcium	56.8[b]	46.3[a]	58.5[b]	3.88
Excreted nutrients (%)				
Phosphorous	1.5[b]	1.5[b]	1.2[a]	0.08
Protein	19.4	22.0	20.5	1.96
Calcium	10.2[b]	10.0[b]	7.4[a]	0.80

[a,b]Mean values with different superscripts differ ($P<0.05$).

5. Feeding studies with Allzyme® SSF

Trials investigating the impact of Allzyme® SSF on the digestibility of nutrients and energy in poultry have been conducted in many different countries, under different management and feeding conditions.

In order to confirm dose rate recommendations, the University of Guelph in Canada investigated the dose-response effects of Allzyme® SSF on broiler performance. A replicated cage trial was conducted, using 0-17 day-old broiler chicks fed corn-soy diets supplemented with increasing levels of Allzyme® SSF. Significant improvements in body weight and FCR were recorded during the trial (Table 3).

Table 3. Dose response of Allzyme® SSF enzyme on corn soy diets fed to 17 day-old broiler chickens (Leeson, 2002).

Enzyme dose (g/t)	Weight gain (kg)	FCR
0	0.463	1.25
125	0.471	1.25
250	0.456	1.21
500	0.495	1.19
1000	0.502	1.19
P-value	0.004	0.036

6. Reducing specifications in broiler diets

Results reported by Wu *et al.* (2004b) showed significant improvements in AME, ileal starch and phosphorus digestibility in diets formulated with different cereal bases (maize, wheat or barley). These improvements allow diets to be reformulated to reduce levels of certain nutrients, which the activity of the enzyme (via improved digestibility) then makes up in terms of increased availability. This can be used to reduce the costs of feed, which are typically around 70% of production costs in poultry (Leeson and Summers, 1997). Making recommendations for commercial poultry applications requires a suitable body of supporting data from relevant feeding experiments.

In addition to their initial studies, a trial was run at Massey University to examine the influence of Allzyme® SSF on available phosphorus (aP) in 35 day-old broilers. Two diets were compared, the control formulated to supply 0.65% aP and a low (0.5%) aP supplemented with 0.2 kg/t Allzyme® SSF. Birds fed the supplemented low aP diet showed a significant improvement in weight gain and FCR compared to the control (Table 4; Johnston *et al.*, 2001).

Commercial trials run in Malaysia evaluated the performance of broiler chickens fed corn-soy based diets supplemented with Allzyme® SSF. Seven thousand five hundred Cobb 500 broilers were fed one of two diets, an unsupplemented control or a diet containing Allzyme® SSF (0.2 kg/t), which was reformulated to provide 0.1% less aP and Ca, and 50 kcal/kg less metabolisable energy (ME) (Christodoulou, 2003).

Table 4. Allzyme® SSF improves performance of 35 day old broilers fed phosphorus-adequate diets (Johnston et al.*, 2001).*

Diet	Weight gain (g)	FCR
0.65% aP	1.92	1.72
0.50% aP + 0.2 kg/t Allzyme® SSF	2.00	1.66
P value	0.020	0.001

Broilers receiving the down-specified Allzyme® SSF diet showed higher weight gains, better FCR and reduced mortality in relation to the control diet flocks (Table 5). These benefits improved the economics of production by approximately US$0.055 per bird (Table 6).

Table 5. Effects of Allzyme® SSF on 42 d commercial broilers fed reduced specification diets (Christodoulou, 2003).

Diet	Body weight (kg)	FCR	Mortality %
Control	2.17	1.738	2.72
Down spec + 0.2 kg/t Allzyme® SSF	2.21	1.678	2.24

Table 6. Cost benefits of using a down-specified broiler chicken diet supplemented with Allzyme® SSF (Christodoulou, 2003).

Cost parameter (US$)	Control	Down spec + Allzyme® SSF 0.2 kg/t
Feed cost/bird sold	0.835	0.808
Total expenditure/bird	1.195	1.167
Net value live bird	1.465	1.492
Net income/t feed	71.43	87.442
Extra income per bird vs. control	-	0.055
Extra net income/t feed	-	16.014
Return on investment Allzyme® SSF	-	8.8:1

The research program at the Queensland Poultry Research & Development Centre in Australia has included trials investigating the impact of Allzyme® SSF on broilers fed either corn- or wheat-based diets. Six dietary treatments were compared in a replicated floor pen experiment, using a total of 1,600 birds housed in 40 pens containing 40 birds. Table 7 shows the reduced specifications of the dietary treatments.

The trial demonstrated that animal performance could be maintained (Table 8) despite reductions in ME of up to 75kcal/ kg in a corn based diet and 150kcal/ kg in a wheat-based diet. The implications with regard to dietary cost savings are significant.

7. Down-specification recommendations for broiler diets supplemented with Allzyme® SSF

Trials with growing broiler chickens have demonstrated that aP and ME levels can be reduced, allowing for cost savings. Current recommendations include a reduction of 75 kcal/kg ME for corn and 150 kcal/kg for wheat based diets, and 0.1 % less aP when using 0.2 kg/t Allzyme® SSF.

Table 7. Diet specifications for treatments used in a trial to examine influence of reduced energy and phosphorous and Allzyme® SSF on broiler performance (QPRDC, 2003).

Diet	Treatment	Specification
Corn Soy	Positive control	Starter 0.44% aP, 3098kcal/ kg; Finisher 0.35% aP, 3202kcal/ kg
Corn Soy	Negative control	- 0.1% aP, - 75kcal/ kg
Corn Soy	Negative control + 0.2 kg/ tonne Allzyme® SSF	- 0.1% available P, - 75kcal/ kg
Wheat Soy	Positive control	Starter 0.44% aP, 2951kcal/ kg; Finisher 0.34% aP 3126kcal/ kg
Wheat Soy	Negative control	- 150kcal/ kg
Wheat Soy	Negative control + 0.2 kg/ tonne Allzyme® SSF	- 150kcal/ kg

Table 8. Supplementing reduced energy diets with Allzyme® SSF maintains broiler performance to the same level as birds fed the full specification diet. (QPRDC, 2003, personal communication).

Treatment	Weight gain	FCR
Corn-based diets		
Positive control	2.343	1.764
Negative control	2.155	1.781
Negative control + 0.2 kg/ tonne Allzyme® SSF	2.353	1.737
Wheat based diets		
Positive control	2.278	1.848
Negative control	2.277	1.849
Negative control + 0.2 kg/ tonne Allzyme® SSF	2.339	1.844

8. Reducing specifications in layer diets

Specific laying hen studies have been conducted to determine the benefits of supplementation with Allzyme® SSF, and the levels of nutrient down-specification that the enzyme can support. It is especially important to ensure adequate mineral supply when making recommendations for reducing nutrients and using enzymes in laying hen diets, as egg quality is governed by mineral availability (Solomon, 2005).

Phosphorus and calcium availability are important in maintaining egg shell quality (Leeson and Summers, 1997), and hens fed reduced mineral diet typically show poorer eggshell quality. The use of Allzyme® SSF in rectifying this problem was investigated in a replicated trial (Cheng *et al.*, 2005; Table 9).

Hens receiving the down-specified diet supplemented with SSF enzyme did not show any losses in shell thickness, and other quality characteristics, such as Haugh units and yolk colour, were also improved. From the economic perspective, a US$0.03/kg cost benefit in egg production for the enzyme-supplemented hens was calculated using these performance figures.

Commercial trials have shown that laying hen performance and the economics of production can be improved with Allzyme® SSF. In a layer hen facility in Thailand (Bangkok Animal Research Center, 2004), commercial layers aged 28 weeks, were fed one of three diets; either a standard diet, treatment 1 (formulated

Table 9. Allzyme® SSF supplemented hens maintain laying performance when fed down-specified diets (Cheng et al.*, 2005).*

Shell parameter	Positive control	Down spec diet (-100 kcal/kg ME -0.15 Av P)	Down spec diet + Allzyme® SSF 0.2 kg/t
Haugh unit	4.21	3.91	4.35
Egg yolk colour (Roche)	6.16	5.09	5.80
Eggshell thickness (μm)	366.41	358.31	365.47
Laying cost US$/kg	0.45	0.42	0.42

with 0.1% lower P and Ca and supplemented with 0.2 kg/t Allzyme® SSF), or treatment 2 (formulated with 0.1% lower P and Ca and 75 kcal/kg less ME and supplemented with 0.2 kg/t Allzyme® SSF) (Table 10).

Supplementing both reduced specification diets with Allzyme® SSF bought performance back to the same level as the flock fed the positive control diet. It was interesting to note that both Allzyme® SSF diets tended to improve FCR compared to the control. A key finding was that feed cost per kg eggs produced was reduced by up to 3¢ (US) when diets were reformulated and Allzyme® SSF was included.

Table 10. Allzyme® SSF supplementation improves laying performance and cost benefits in 30-42 week old laying hens fed low specification diets (Bangkok Animal Research Center, 2004).

Treatment group	Positive Control	Low Ca & P + Allzyme® SSF	Low Ca, P, ME + Allzyme® SSF
Final wt. (kg)	1.93	2.16	1.91
Eggs/hen	79.29	79.72	80.17
Egg production (%)	94.39	94.91	95.44
Feed: Egg FCR	1.857	1.840	1.849
Mortality (%)	1.39	0.69	0.00
Feed cost per kg eggs (US$/kg)	0.36	0.35	0.33

These findings were supported by the commercial experience reported from Mr G Farms (Batangas, Philippines) (Gregorio *et al.*, 2005), who were feeding a corn-soy diet which had been down-specified by 75kcal/ kg and 0.1% available P and Ca, making it US$7/ tonne cheaper than the control. Over the 140 day monitoring period, laying performance averaged 93.3% for the Allzyme® SSF supplemented down-specified diet versus 92.1% for hens fed the unmodified commercial diet (Figure 2). Taking both the diet savings and production response into account, each bird resulted in an extra US$0.23 profit. Extrapolating from these figures, a layer operation with 100,000 birds could expect an extra profit of US$23,000 over the same period.

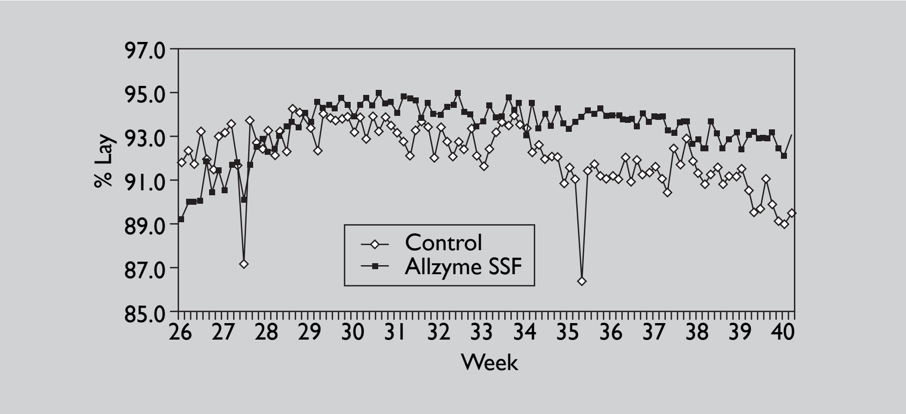

Figure 2. Effect of Allzyme® SSF diets on laying performance of hens from a Philippino commercial facility (Gregorio et al.*, 2005).*

9. Conclusions

Both *in vitro* and *in vivo* studies conducted in a range of countries have demonstrated the efficacy of solid-state fermentation enzymes in terms of both poultry performance and economic pay back. These benefits are obtained from the combination of specific enzymes generated during the fermentation process, which are designed to meet the digestion requirements for the feed substrate.

The scope for the production of different enzyme complexes using solid-state fermentation is enormous. Each change in substrate will lead to a different complex matching a different substrate, and projects are well underway to develop a complex to improve the digestibility of distillers dried grain solubles for other types of feed. As the in-feed enzyme markets become more competitive, and poultry producers demand more performance and better economic returns from using technical feed ingredients, the importance of more cost-effective products such as Allzyme® SSF will become evident.

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Research perspectives on nutritional approaches which minimise mineral excretion in turkeys

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1. Introduction

In order to assure sustainable production, the poultry industry in many parts of the world will have to evaluate and implement strategies to reduce the risk of environmental pollution associated with over-supplementing trace minerals. This paper focuses on the effect of supplementing low levels of organic trace minerals in replacement of traditionally used inorganic trace minerals in commercial turkey rations. The goal was to maintain growth performance while decreasing mineral excretion.

2. The role of trace minerals

Trace mineral supplementation is an area of nutrition that has been long overlooked. Trace mineral deficiencies are rarely seen due to the low cost of inorganic trace minerals and the ease of premix incorporation (Table 1). With the development of new regulations regarding litter application, revising trace mineral requirements may be needed to optimise animal availability while limiting environmental contamination.

Table 1. Trace mineral content of selected feed ingredients in ppm (values based on NRC, 1994).

	Zinc	Manganese	Iron	Copper
Corn	18	7	45	3
Soybean meal	55	43	170	15
Meat and bone	93	14	490	2
Ground wheat	28	24	40	7

2.1. Copper

Copper is required for a number of biological functions. In the body, copper is required for bone formation, proper cardiac function, connective tissue development (*i.e.* cardiac ruptures), myelination of the spinal cord, keratinisation, cellular respiration, tissue pigmentation and metalloenzyme systems where they play both structural and activator roles. Deficiency, while rarely observed, can be influenced by the biological copper status of poultry breeders. Embryos from copper deficient hens show haemorrhage, anaemia, bone abnormalities and retarded growth and development (Savage, 1968). Anaemia in these birds is suggested to be controlled by the effect of copper on iron transport and mobilisation (Leeson and Summers, 2001).

The importance of copper to metalloenzyme structure and function contributes to the systemic effects observed with copper deficiency. For example, lysyl oxidase, is involved in the proper cross-linking of collagen and elastin. The collagen-elastin system in turn, influences the development of both the skeletal and cardiovascular systems (Guenthner *et al.,* 1978; O'Dell *et al.,* 1961; Opsahl *et al.,* 1982).

2.2. Zinc

Zinc is a trace mineral that has multiple functions including: enzymes, hormones, growth rate, skin and wound healing, immune response, water/cation balance, relationship to Vitamin A, behaviour and learning ability, etc.

Zinc is associated with many enzymes as both a structural component and as an activator. Zinc is a stabiliser of RNA, DNA, and ribosomes (Prask and Plocke, 1971). In animals, zinc deficiency will depress activities of plasma alkaline phosphatase, liver and retina alcohol dehydrogenase, pancreatic carboxypeptidase A and liver nuclear DNA-dependent RNA-polymerase (McDowell, 1992). Zinc affects cellular function including; cellular division, growth, and repair.

Zinc's impact on the immune system is one of its most noted biological functions. A deficiency results in the rapid atrophy of the thymus, which has a deleterious effect on various T-cell functions. Zinc's influence on immunocompetence is related to thymic hormone production and activity, lymphocyte function, natural killer function, antibody dependent cell-mediated cytotoxicity, immunological ontogeny, neutrophil function, and lymphokine production (Hambidge *et al.*, 1986).

2.3. Manganese

Manganese is involved with a number of biological functions including: enzyme activity, bone growth, reproduction, lipid and carbohydrate metabolism, cell function and structure, immune function, and brain function (McDowell, 1992). Perosis is a disease state which most commonly denotes manganese deficiency. Perosis results in bone malformation characterised by: enlarged and misshapen tibiometatarsal joints, and twisting of the tibia and the tarsogastrocnemius (Achilles tendon) from their condyles (McDowell, 1992).

2.4. Sources of trace minerals

When evaluating the requirements from a number of different sources, there is a wide range of values recommended or used for feeding today's poultry (Table 2). Typically, minerals are included in the diet at levels above requirement to minimise any negative impact the diet may have on performance. Deyhim and Teeter (1993) reported that the removal of trace mineral premix (TMP) from 28 to 49 days is possible with no negative effects on performance and carcass composition. This indicates that it may be possible to remove the TMP from the finisher period of production. Concern over excess mineral excretion will force the industry to re-evaluate the way animals are fed, similar to phosphorus in the 1990s.

Table 2. Mineral requirements from several different sources (ppm).

Trace mineral	NRC, 1994[a]	Book[b]	Hybrid	Industry range
Mn	60	80	120-160	80-180
Zn	40-70	80	120-160	80-160
Fe	50-80	110	40-80	50-80
Cu	6-8	10	10-15	6-12
Se	0.2	0.15-0.3	0.3	0.3

[a]Similar to earlier NRC.
[b]Leeson and Summers (1997).

2.5. Trace minerals and phytase

The presence of the phytate molecule further complicates the issue of trace mineral supplementation. Commonly used feedstuffs (corn, SBM, wheat, etc.) contain a major portion of phosphorus as phytate, making it unavailable to the bird. In addition, the phytate molecule can bind trace minerals such as Zn, and Cu taking them out of solution. The use of phytase has been reported to increase the retention of trace minerals and may be a viable alternative to over supplementation of trace minerals. It may be possible to remove TMP during all stages of development without performance depressions using phytase.

2.6. Challenges of using inorganic trace minerals

The main issues affecting the use of inorganic trace minerals include; bioavailability, (contaminates/un-quantified trace minerals), possible interaction between other insoluble compounds that may interfere with utilisation, *i.e.* minerals in the gut, and phytate. Trace minerals enter the body as inorganic salts, but are disassociated in the low pH environment of the proventriculus and gizzard. When the mineral reaches the higher pH of the lower gut, it ionises and can bind to a number nutrients and non-nutritive components of the digesta, making it insoluble. Phytate, for example, is able to form chelates of these minerals that are very stable and highly insoluble (Leeson and Summers, 2001), insoluble minerals are excreted and increase the load of minerals in the environment. The answer may be the use of organic minerals. Organic minerals are trace minerals attached to or associated with a compound that contains carbon. Organic minerals resist disassociation in the upper GI tract and allow the presentation of either the intact compound or individual mineral to the absorptive epithelium of the small intestine (Leeson and Summers, 2001).

2.7. The ability of organic minerals to minimise mineral excretion

A 19-week trial was designed to evaluate the use of organic minerals in turkey production. Hybrid tom turkey poults (n=1,260) were placed in 35 pens for 9 replications/treatment. Treatments consisted of: positive control (POS), a typical industry trace mineral program supplementing 185 ppm Mn, 151 ppm Zn, and 10 ppm Cu; a negative control (NEG) supplemented at 10% of the POS; and two Bioplex™/Sel-Plex® (Alltech Inc., USA) treatments. The first Bioplex™/ Sel-Plex® (BPSP 1) treatment was fed at 1.5 lbs/ton (Bioplex™ Mn, 16.5 ppm; Bioplex™ Zn, 7.5 ppm; Bioplex™ Cu, 0.7 ppm; Sel-Plex® to supply 0.2 ppm of selenium / ton of feed) inclusion rate in the starter period which was reduced by 33% to 0.45 kg/ton during the grower and finisher periods. The second Bioplex™/Sel-Plex® (BPSP 2) treatment was included at 0.7 kg/ton during the starter grower and finisher periods. All diets contained 1 lb/ton copper sulfate as growth promoter. At the trial's conclusion (day 133) turkeys were evaluated for performance throughout the trial as well as carcass composition and plasma levels of IgG and IgM. Mineral content in the litter was also determined.

There was no influence of treatment on production throughout the trial (Table 3). Cold carcass composition was improved over the performance of both controls with the use of Bioplex™/Sel-Plex® (Figure 1). Whole breast and tender weights were also improved with the use of organic minerals (Figure 2). Mineral source had no influence on copper or iron content present in litter. However the presence of manganese and zinc in litter was reduced with the use of Bioplex™/Sel-Plex® (Figure 3). IgM plasma levels of the Bioplex™/Sel-Plex® group were reduced compared to the POS. This is an interesting finding given that IgM is found largely in the gut mucosa and is a primary response

Table 3. Bioplex™ / Sel-Plex® influence on turkey performance 0-19 weeks.

Treatments	Age (d)						
	1-28	28-49	49-70	70-84	84-105	105-133	1-133
Body weight (kg)							
POS	.053	1.27	3.63	7.07	9.30	12.77	16.67
NEG	.054	1.30	3.70	7.14	9.46	12.76	16.71
BPSP-1	.054	1.30	3.68	7.07	9.47	12.97	16.78
BPSP-2	.054	1.28	3.66	6.97	9.25	12.71	16.89
Feed intake (kg/period)							
POS	1.63	4.03	7.42	6.46	10.13	10.96	40.72
NEG	1.65	4.25	7.41	6.28	9.62	10.53	39.74
BPSP-1	1.76	4.35	7.24	6.28	10.38	10.27	40.27
BPSP-2	1.89	4.25	7.41	6.63	10.08	10.63	40.68
Feed conversion							
POS	1.334	1.712	2.199	2.932	2.921	2.822	2.448
NEG	1.329	1.769	2.168	2.730	2.925	2.727	2.388
BPSP-1	1.408	1.833	2.146	2.630	2.973	2.677	2.407
BPSP-2	1.379	1.783	2.260	2.940	2.922	2.595	2.415

immunoglobulin. This indicates a shift in humoral immune response with organic mineral supplementation.

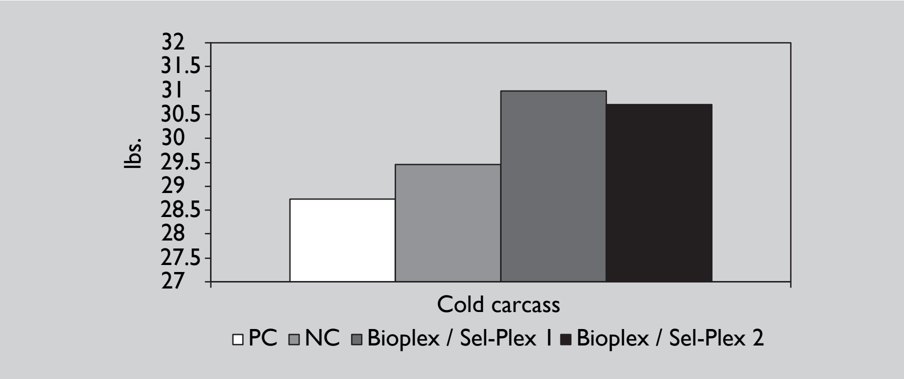

Figure 1. Cold carcass weight.

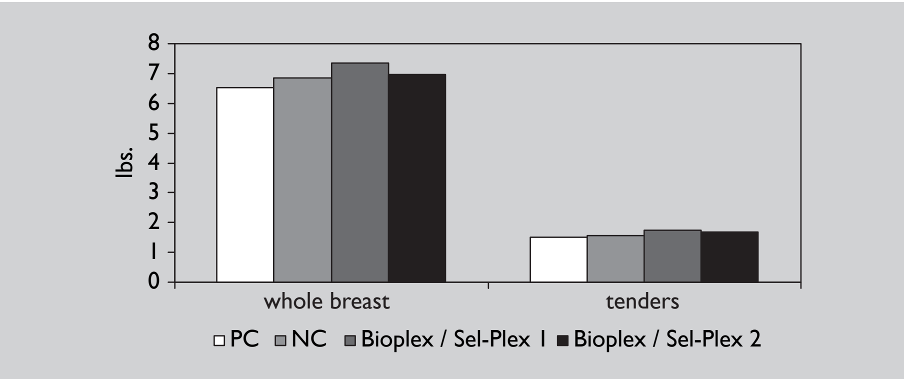

Figure 2. Breast and tender weight.

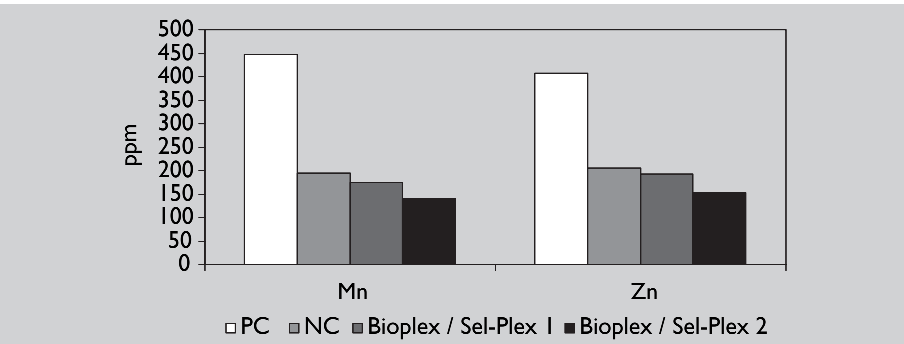

Figure 3. Litter mineral content.

To evaluate the availability of Bioplex™ minerals (organic mineral source containing: Cu, Zn and Mn), Leeson and Sefton (2003) compared the use of inorganic with equal amounts of Bioplex™ minerals. Bioplex™ minerals were also reduced in the diet from 100% inclusion (equal to the inorganic inclusion) to 20% to determine if increased availability could reduce mineral supplementation. In the caged broiler trial, it was reported that 20% Bioplex™ could be used to meet performance equal to the 100% inorganic mineral supplemented group (Table 4). With the reduction in minerals with Bioplex™, there was a subsequent significant reduction in trace mineral excretion (Table 5).

Table 4. Broiler performance with Bioplex™ (Leeson and Sefton, 2003).

		Body weight (g)		Feed : gain	
		d 17	d 42	0-17 d	0-42 d
Inorganic		489	2217	1.45	1.75
Bioplex™	100%	470	2351	1.51	1.70
	80%	472	2239	1.47	1.73
	60%	467	2285	1.53	1.72
	40%	444	2185	1.48	1.74
	20%	459	2291	1.50	1.69
	±SD	36	97	0.08	0.05
	P-value	NS	NS	NS	NS

Table 5. Calculated mineral in manure from a grow-out of 5 flocks of 100,000 male broilers / year (Leeson and Sefton, 2003).

kg minerals/year		Zinc	Manganese	Iron	Copper
Inorganic		470	273	535	19
Bioplex™	100%	318	217	523	17
	80%	294	185	491	18
	60%	309	172	494	16
	40%	299	156	487	16
	20%	292	130	446	15
	±SD	37	13	50	1.7
	P-value	<0.01	<0.01	NS	<0.05

In conclusion, the use of organic minerals seems to be a valuable source of trace minerals and could be used commercially to reduce the use of inorganic minerals while maintaining performance, improving immune function and protecting the environment by reducing the excretion of trace minerals.

3. Conclusions

The aforementioned turkey research demonstrates when challenge is minimal; feeding low levels of inorganic trace minerals (10% of commercial) was as effective as commercially supplemented levels. This may not be the case under normal industry conditions or an academically induced challenge. Research protocols are being developed to further evaluate the use and level of organic trace minerals in turkey diets and their effect on performance and immunological status under a challenge. Currently, turkey integrators are implementing the organic program with equal performance while decreasing the impact of trace minerals on the environment.

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Novel U.S. research perspectives on nutritional approaches to address necrotic enteritis

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1. Introduction

The search for novel feed additives to maximise poultry performance has been intensified over the last decade due to pressure for removing antibiotic growth promoters (AGPs) from poultry diets. In Europe all AGPs are banned. Other markets just have legislation banning the use of a limited number of products; however, the pressure for further reducing the use of AGPs is also evident in those markets. Also, non-antibiotic growth promoters such as Roxarsone (3-Nitro) an organic arsenic compound have recently come under pressure due to environmental considerations. Roxarsone has long been utilised in the industry as a growth promotant and an anti-coccidial (Kowalski and Reid, 1975). The environmental impact of arsenic, through the use of poultry litter has become a concern (Arai *et al.*, 2002; Rutherford *et al.*, 2003). Garbarino *et al.* (2003) reported that poultry litter may contain 12 to 30 mg/kg arsenic. With the widespread use of poultry litter as fertiliser, arsenic may leach into soil eventually contaminating groundwater. The use of Roxarsone also presents a food safety concern, with tissue accretion of arsenic being larger than previously recognised, 0.13 ug/g (Lasky *et al.*, 2004) versus 0.058 ug/g (Tao and Bolger, 1999) arsenic in chicken muscle tissue.

Probiotics, prebiotics, organic acids and enzymes have all been identified as potential antibiotic growth promoter (AGP) replacements or alternatives (Ceylan and Ciftci, 2003). A large body of research supports these findings, suggesting that antibiotic alternatives may maintain growth performance (Hooge *et al.*, 2003; Kumprecht and Zobac, 1997; Parks *et al.*, 2001; Spring *et al.*, 2000). An example of one such alternative are the mannan oligosaccharides (MOS) which have been shown to agglutinate type-1 fimbriae specific bacteria, for example, various strains of *E. coli* and *Salmonella*. Bacteria believed to be precursors to necrotic enteritis infection (*C. perfringens* and *Campylobacter*) are not type-1 specific. However, there is evidence that MOS may influence the capabilities of total versus type-1 microflora populations within the digestive tract (Finucane *et al.*, 1999).

Research from this laboratory at Virginia Tech, has focused on the influence of pre- and pro-biotics on gut health and growth promoter replacement, and specifically, the ability of antibiotic alternatives to minimise the impact of disease and maintain growth in place of AGPs or 3-Nitro.

2. Effect of the ANE program on performance and prevention of necrotic enteritis

Alltech Inc. has developed a program 'Alltech's Necrotic Enteritis (ANE) program' which is a combination of products each with specific roles within a drug-free programme. For example, it is well established that Bio-Mos® binds certain pathogenic bacteria, supports a more beneficial microflora and maintains a healthy intestinal lining. Competitive exclusion is provided by the lactobacilli (in Acid-Pak and All-Lac), organic acids help create the appropriate digesta pH environment for them to colonise and discourage proliferation of pathogens which favour a more alkali gut environment. Electrolytes improve water intake and reduce stress whilst the enzymes improve the nutrient absorption from feed. This programme has been found to be effective both in improving flock performance and production economics.

Sun *et al.* (2005) conducted a study which examined the effectiveness of Alltech's necrotic enteritis (ANE) program in terms of production and prevention of necrotic enteritis. Straight run Cobb broiler chicks were obtained (n=2,496) and housed at a stocking density of 0.08 m^2 / chick. Chicks were assigned to one of four dietary treatments for a total of 13 replicates /treatment over 49 days. Treatments consisted of a negative control (NC), basal diet without growth promoter or coccidiostats and a positive control (PC), basal diet + Lincomycin (2 g/ton starter and 4 g/ton grower), lincomycin was removed from feed after day 29 according to commercial procedures. The full ANE program was designated as Program 1 (PG1), basal diet + Acid Pak 4-Way (0.5 g/l of water every day for the first 5 days, then 0.5 g/l of water for only 1 day every week until processing), VegPro (0.91 kg/ton – over the top application), MTB-100 (Mycosorb in some markets; 0.45 kg/ton), Bio-Mos® (1.81 kg/ton starter, 0.91 kg/ton grower, 0.45 kg/ton finisher and withdrawal), and All-Lac XCL at hatchery. Program 2 (PG2), basal diet + Bio-Mos® (same inclusion as PG1) and All-Lac XCL (at hatchery). Lincomycin positive control and a non-medicated negative control. All-Lac XCL is a mixture of beneficial lactic acid bacteria (*Lactobacillus*, *Enterococcus*, and *Pediococcus*), and *in vitro* lactobacilli efficiently inhibit adhesion of *E. coli* and *Salmonella* on the chicken intestinal wall (Jin *et al.*, 1996), thus reducing the pathogen load in the gut. The full ANE program was designated as Program

1 which consisted of, the basal diet supplemented with All-Lac XCL, Acid-Pak 4-Way, Bio-Mos®, VegPro and MTB-100.

Performance in terms of body weight gain (BWG) and feed intake was similar across treatments for the duration of the trial. The exception being 15 to 28 d feed intake, feed consumed by the NC broilers (101.2 g/bird per d) was less than PC (104.0 g/bird per d) broilers (Table 1). Feed conversion of birds receiving the ANE programs was similar to lincomycin treated birds. All treatments; PC, PG1 and PG2 had improved feed conversion when compared to the NC (Table 1). Livability of PG1 birds was greatest compared with the other 3 dietary treatments, suggesting a positive effect of this combination of products (Table 2).

From 15 to 29 days of age (peak mortality), mortality was evaluated by avian veterinarians at the Virginia/Maryland Regional Vet School and was determined to be the result of necrotic enteritis by *C. perfringens*. Wet litter resulting from acute reaction to the coccidia vaccine may have initiated disease outbreak. When broilers were affected by *C. perfringens*, PG1 had best livability, suggesting protection. However, growth and performance as measured by BW gain and feed conversion rate in PG1 broilers were similar to other treatments. The higher stocking density of the PG1 group might have limited the positive effects. The relative stocking densities at d 49 in PG1 group were 11, 5, and 5% higher than for the NC, PC, and PG2 feeding programs, respectively.

An economic analysis of total live weight gain/100 birds started at day 0 was calculated (average BW livability· 100 at end of trial), indicating an increase ($P < 0.05$) for PG1 (259.79 kg), PG2 (256.87 kg), and PC (256.96 kg) compared with the NC group (237.47 kg). The gross income (birds sold as \$ 1.18/kg – feed cost as \$ 143.83, \$ 144.17, \$ 155.12, and \$ 146.92/ton, respectively) per 100 initial chicks was estimated as \$ 145.27, \$ 155.28, \$ 153.91, and \$ 156.44 for NC, PC, PG1, PG2, respectively. Based on the results, NC broilers had the lowest live weight gain and gross income when compared with other dietary treatments. Broilers fed PG1 had the greatest live weight gain, whereas PG2 had the numerically highest gross income due to the decrease in feed cost. Based on the data observed in the present study, Bio-Mos® in combination with All-Lac XCL can be an efficient feeding program to overcome the negative impacts of utilising drug-free diets. From our data to 49 days, there was about a 22.5 kg or 9.5% weight improvement per 100 birds started when feeding the PG1 than the NC diet and a 3.0 kg or 1.2% improvement compared with PC birds. In this trial, PG1 or PG2 seem to be appropriate programs for feeding a drug-free feed to broilers.

Table 1. Effect of drug-free feeding programs on body weight gain, feed intake and feed conversion ratio (Sun et al.*, 2005).*

Treatment	BWG (g/bird/day)				FI (g/bird/day)				FCR			
Age (d)	14	28	35	49	14	28	35	49	14	28	35	49
NC[1]	27.7	42.7	49.0	54.1	38.0	101.2[b]	151.9	162.5	1.369	1.633	1.757	1.995[a]
PC[2]	28.1	44.0	50.4	55.8	38.1	104.0[a]	151.3	165.5	1.359	1.617	1.729	1.962[b]
PG 1[3]	28.4	44.3	50.0	54.7	38.4	104.0[a]	149.9	161.9	1.357	1.612	1.739	1.980[ab]
PG 2[4]	28.4	44.5	50.3	55.3	38.5	102.9[ab]	152.1	160.5	1.358	1.590	1.729	1.953[b]
SEM (n=13)	0.4	0.6	0.4	0.5	0.4	0.9	2.3	2.3	0.0108	0.0157	0.0098	0.0097
Main effects	0.54	0.11	0.09	0.13	0.34	0.04	0.53	0.13	0.83	0.31	0.15	0.02

[a,b]Means within a column without common superscript are significantly different ($P<0.05$).
[1]NC=Basal diet (no growth promoter or coccidiostat).
[2]PC=Basal diet with lincomycin.
[3]PG1=Basal diet with Bio-Mos® associated with All-Lac XCL, VegPro, MTB-100, and Acid Pak 4-Way. [4]PG2=Basal diet with Bio-Mos® associated with All-Lac XCL.

Table 2. Effects of drug-free feeding programs on broiler mortality (%) (Sun et al.*, 2005).*

	Age (d)				
Treatment	14	28	35	49	Total
NC[1]	3.04[a]	7.58[a]	1.18	0.82	11.98[a]
PC[2]	1.94[ab]	3.13[b]	2.05	0.98	7.58[b]
PG 1[3]	1.28[b]	1.62[b]	1.08	0.93	4.63[c]
PG 2[4]	3.05[a]	2.48[b]	1.12	0.39	6.74[bc]

[a,b,c]Means within a column without common superscript are significantly different ($P < 0.05$).
[1]NC=Basal diet (no growth promoter or coccidiostat).
[2]PC=Basal diet with lincomycin.
[3]PG1=Basal diet with Bio-Mos® associated with All-Lac XCL, VegPro, MTB-100, and Acid Pak 4-way.
[4]PG2=Basal diet with Bio-Mos® associated with All-Lac XCL.

3. The ANE program revisited

A preliminary trial was conducted to both determine the ability of the ANE program to enhance performance as well as prevent a necrotic enteritis outbreak. Straight run Cobb broiler chicks were obtained (n=1,710) and were housed at a stocking density of 0.07 m^2 / chick. Chicks were assigned to one of three dietary treatments for a total of 14 replicates /treatment for treatment 3. Due to chick mortality during transport, treatments 1 and 2 had 12 replicates /treatment for the 49 d trial. The objective was evaluated using treatment 1; BMD+3-Nitro (BMD switched to Stafac at d 28). Treatment 2 consisted of the ANE program [Acid Pak 4-Way (0.5 g/l of water every day for the first 5 days, then 0.5 g/l of water for only 1 day every week until processing), VegPro (0.91 kg/ton – Matrix adjustment to Soybean meal prior to formulation to account for a 7% uplift of energy, protein and amino acids), MTB-100 (0.45 kg/ton), Bio-Mos® (1.81 kg/ton starter, 0.91kg/ton grower, 0.45 kg/ton finisher and withdrawal), and All-Lac XCL at hatchery]. Treatment 3, the negative control (NC), was established feeding the basal diet without additives. Diets formulated under the second objective were isocaloric and isonitrogenous. All chicks used were coccidia vaccinated (Cocci-Vac) at the hatchery.

4. Evaluating the ability of the ANE program to enhance performance

Body weight gain was improved during the starter (0-14 d), and finisher periods of production with the use of AGP+3-Nitro in comparison to treatments 2 and 5 (Table 3). Body weight gain was affected by treatment during the starter and finisher periods. Birds on the ANE program gained more than the AGP+3-Nitro or NC groups during the starter period. This was reversed from 28-35 days with the AGP+3-Nitro group gaining over ANE and NC birds. Feed intake was influenced by treatment during the starter and grower periods. Birds fed the ANE program had increased consumption over birds consuming diets 1 and 3 during the starter period. During the grower period, birds on AGP+3-Nitro consumed less than birds on the ANE program (Table 3). Feed conversion was increased when birds were fed the ANE program compared to the AGP+3-Nitro and NC during the grower and finisher periods (Table 3). Mortality was affected by diet during the present trial, with highest mortality occurring prior to 28 d (Table 4). Mortality increased when birds consumed the NC or ANE program versus the AGP+3-Nitro treatment.

During this trial, mortality and feed conversion were the major factors with regards to the effect of implementing a drug-free feeding program to broilers. The NC and AGP+3-Nitro treatments had lower feed conversions when

Table 3. Evaluating the ability of the ANE program to enhance performance.

	Age (d)				
Treatments	1-14	15-28	29-35	36-49	1-49
Body weight gain (kg/period)					
3-AGP+3-nitro	0.300	0.827	0.555	1.308	2.99
4-ANE program	0.326	0.833	0.500	1.315	2.974
5-Negative control	0.311	0.829	0.525	1.318	2.983
Feed intake (kg/period)					
3-AGP+3-nitro	0.411	1.252	1.003	2.745	5.411
4-ANE program	0.437	1.299	1.016	2.803	5.554
5-Negative control	0.410	1.254	0.997	2.766	5.427
Feed conversion					
3-AGP+3-nitro	1.372	1.514	1.808	2.100	1.810
4-ANE program	1.343	1.560	2.032	2.132	1.868
5-Negative control	1.322	1.513	1.904	2.100	1.820

compared to birds on the ANE program. Mortality during the grower phase was also higher for ANE and NC birds when compared to AGP+3-Nitro animals. This suggests that birds may be grown drug-free with potential for smaller economic return in both feed costs and number of birds at load out. Based on mortality, the use of the ANE program did protect the birds from negative post-coccidia vaccination effects throughout the starter period. These effects diminished thereafter, with the ANE treatment having high mortality during the grower period and having similar mortality to AGP+3-Nitro and NC during the finisher and withdrawal periods.

The differences in mortality in this trial compared to Sun *et al.* (2005) when using the ANE program are interesting. Sun *et al.* (2005) reported that the ANE program had the lowest mortality and seemed to protect the birds from the negative effects of the Coccidia vaccination. During this trial, the positive effects of the ANE program were evident to day 14, but dropped off thereafter. The ANE diet had an adjustment of 7% for energy, protein and amino acids. If the soybean quality was higher than what was formulated, the uplift may not have performed as expected. It is also possible that the birds needed more nutrients to maintain their immune response. Sun *et al.* (2005) had no adjustment, and in theory allowing more nutrients to the bird compared to the other treatments. After day 28 the drop in performance could have been due to the enzyme allowing the flow of unused nutrients to the lower gut for changes in microflora population changes.

Table 4. Effect of 3-Nitro replacement with Bio-Mos® on percent total mortality.

Treatments	% Total mortality			
	Starter (1-14 d)	Grower (15-28 d)	Finisher (29-35 d)	Withdrawal (36-49 d)
3-AGP+3-nitro	3.97	1.06	0.227	0.925
4-ANE program	4.24	9.59	0.571	0.963
5-Negative control	7.22	8.43	0.225	1.43

5. Conclusions

In regards to gut health, research is needed to further develop programs to manipulate the microflora in the gastrointestinal tract of chickens and turkeys. It will be important, as technology is developed, to better understand the relationship between the gastrointestinal microflora and the host (chicken/turkey). Both pathogenic and beneficial bacteria exist in the gut, but balancing those populations will be the key to growing poultry antibiotic or drug free in the future.

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Campylobacter control in primary poultry production

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1. Introduction

Campylobacter has become one of the most important micro-organisms involved in human foodborne diseases in the western world. Within the European Union (EU) a record of all human cases is kept, and looking at these data there was an increase of almost 20% of cases of campylobacteriosis from 2003 to 2004 in the EU-15. The majority of data on the prevalence of *Campylobacter* in food and animals originates from poultry and poultry products. This makes poultry one of the most important sources of human campylobacteriosis. However, raw milk, other animal species such as cattle, pigs, sheep, and pet animals together with surface water can also be vectors of contamination. Foreign travel also adds a substantial contribution to the incidence of campylobacteriosis (Neimann *et al.*, 2003).

Campylobacter infections seem to not only cause gastro enteritis problems (800,000 annual cases in the Netherlands), but also secondary complications may occur such as the Guillain Barré syndrome (60 cases) and reactive arthritis (1,400 cases). On top of that campylobacteriosis causes approximately 80 deaths per year in the Netherlands alone (Havelaar *et al.*, 2005). Under certain specified circumstances, the infection dose (ID) may be as low as 1-5 colony forming units (CFU) per person, but this level should be considered as exceptionally low. In poultry the ID of *Campylobacter* is relatively low (10-15 CFU) and correlates with the age of birds. When *Campylobacter* enters a broiler flock a very efficient transmission between individuals occurs, so within 2-3 days a whole flock becomes colonised. This colonisation of the gut and preferably the caeca is very efficient with CFU levels of up to 10^8-10^9 CFU per gram of caecal contents (Mead, 2002; van Gerwe *et al.*, 2005; Snelling *et al.*, 2005). In particular, thermophyllic *Campylobacters* that are responsible for the majority of human cases, are highly adapted to conditions in the avian GI tract and their optimum growth temperature of 42 °C is close to the body temperature of poultry. Flock prevalence may be as high as 70% during the summer months and much lower in winter time (10-15%). In Sweden however overall prevalence is approx. 10%. In organic and outdoor poultry production systems the summer prevalence may easily reach 100%, which is related with environmental exposure (Heuer *et al.*, 2001).

Colonisation of *Campylobacter* takes place in the mucus layer of the crypts, without physically attaching to the epithelial cell wall. Poultry normally do not show signs of clinical disease, and remain healthy carriers of *Campylobacter* until slaughter age. Preventing colonisation is not just a matter of preventing attachment to the epithelium; ingestion of *Campylobacter* has to be prevented, presence in the mucus layer has to be prohibited, or the growth should be disturbed.

2. *Campylobacter* control plans

In the Netherlands, but also in other European countries such as Denmark, Norway (Hofshagen and Kruse, 2005), Great Britain (Anon., 2003) and Sweden a nationwide Plan was developed for the control and eradication of *Campylobacter*. The initiative was taken in 1995 by the Dutch Ministry of Public Health (MPH) with the target being to reduce human gastroenteritis by 50% in five years by control measures regarding foods from animal origin. In 1997 the Product Board of Poultry and Eggs (PVE) set up an Action Plan to reduce the prevalence of *Salmonella* and *Campylobacter* in chicken meat and eggs. In 2000 the goals could not be reached, so additional plans were adopted (PVE) with targets only for *Salmonella*. Nevertheless in The Netherlands, *Campylobacter* monitoring is continued twice a year on every farm and in slaughter plants. These data show a constant prevalence level of *Campylobacter* in flocks (approx 15% as an average over the past 4 years: data PVE 2005), but on poultry meat a significant reduction was achieved: In 2000 and 2004 the prevalence was respectively 30.5% and 17.6% (Anon., 2005). MPH introduced labelling of chicken meat warning the consumer of the possible presence of pathogens and advising the consumer to prepare the food carefully. Until today, no effective interventions against *Campylobacter* are available and both the industry (PVE) and the Government agreed upon initiating further research rather than taking measures.

3. The CARMA project

In addition to other initiatives, the Dutch CARMA (*Campylobacter* Risk Management and Assessment) project started in 2001. The aim of this project was to provide advice on the effectiveness and efficiency of measures for reducing campylobacteriosis in the Dutch population. Most important questions were: (1) What are the most important routes by which the Dutch population is exposed to *Campylobacter* and can the contribution of these routes be quantified? (2) Which (sets of) measures can be taken to reduce the exposure to *Campylobacter* and what is their expected efficiency and societal support?

Key messages within the project were: (a) campylobacteriosis is a multi-source problem, chicken meat is one of the most important routes, (b) Reducing the contamination of chicken meat to low numbers is effective for public health, (c) Measures to reduce the contamination of chicken meat may be cost-effective for the society as a whole, (d) Active communication with all stakeholders during governmental decision-making and implementation of measures is paramount. Results of the project can be found on www.rivm.nl/carma.

Reducing *Campylobacter* contamination (a and b above) of poultry was considered the biggest challenge. The biggest risk may be hidden in the relatively small proportion of highly contaminated products. Products with low-level contamination do not carry a major public health risk, so the number of *Campylobacter* to which the consumer is exposed is related to the number of cases of campylobacteriosis (Figure 1).

In the CARMA project, interventions were studied and in models the following items were specified as relevant:

- At farm level:
  - improved biosecurity;
  - mono-species farms;
  - no thinning of flocks;
  - phage therapy.
- At processing plant level:
  - logistic slaughter after pre-screening;
  - reducing faecal leakage;
  - decontamination of the scalding tank;
  - decontamination of carcasses;
  - freezing infected products;
  - channelling of infected products.
- At consumer level:
  - freezing products;
  - improving hygiene awareness.

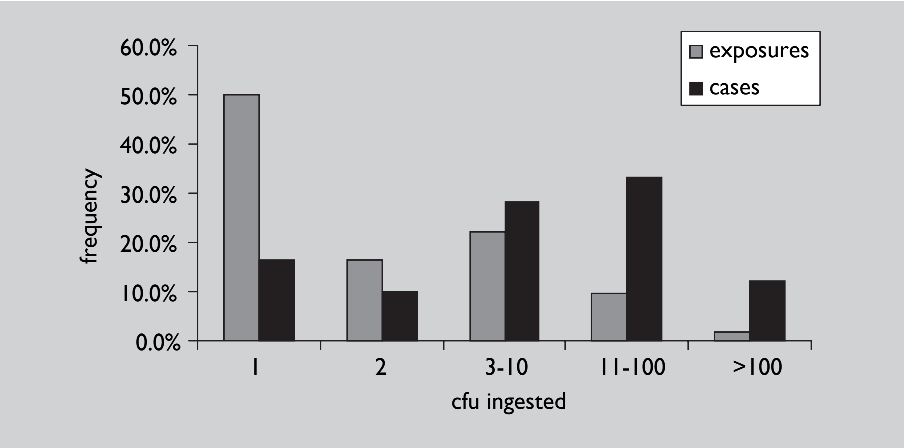

Figure 1. Relationship between the number of exposures and consequent cases of campylobacteriosis at different CFU intakes (Havelaar et al.*, 2006).*

3. Risk assessment, risk management and risk communication

Modelling of the interventions showed that risks for public health could be reduced significantly. At farm level, the effect of thinning appeared of minor importance, but biosecurity and phage therapy showed more promise. Interventions in the slaughter house such as the logistical slaughter of flocks and decontamination of the scalding tank had only minimal effects. More effective were the reductions of faecal leakage, carcass decontamination, and freezing. As no combination of the above measures is fully effective, only irradiation of meat products can guarantee *Campylobacter*-free products in the end.

An economical evaluation of the proposed interventions was included in the Carma project. Here the costs for public health that can be saved in relation with the costs and efficacy of interventions were considered. Interventions such as improved farm hygiene, crust freezing of products or heat treatment may be effective but are relatively expensive, and may downgrade the products. Alternatively, flock treatment should be applied to contaminated flocks only, so scheduling and treatment in the processing plant of flocks only tested positively is necessary. Screening of flocks requires highly sensitive test protocols to detect *Campylobacter* infected flocks and these are not (yet) available. In practice, regular pre-screening is performed at approx. 1 week before slaughter. Many flocks become *Campylobacter* positive within the last week prior to slaughter, so they appear in the processing plant as false negative flocks. Alternatively, when many flocks test *Campylobacter* positive, there may be logistical problems leading to product inefficiency which may result in a shortage in fresh meat supply in the summer period, since treated meat should be considered of "lower quality".

In order to transmit the message to poultry producers and consumers alike, active communication is needed. There is little societal support for additional measures to reduce contamination of chicken meat by chemical interventions. Farmers and processing plants are not convinced of the benefits and fear increased costs and market losses. Each poultry-producing country has to contribute to a comparable level, so measures should be taken at a European level. Consumers are not very concerned about *Campylobacter* on chicken meat. They lack information to define their opinion about many proposed measures. The chicken meat production system is very complex and there are many data gaps, and data which are available are of limited use or mainly qualitative.

Based on the results of CARMA the following recommendations were given to the Dutch authorities:

- Address multiple sources of *Campylobacter* such as poultry meat, direct contact with animals and foreign travelling.
- Reduce exposure from poultry meat by:
  - promoting a constant high hygiene level at farm level;
  - implementing scheduling programs;
  - considering carcass decontamination and reducing faecal leakage;
  - maintaining hygiene education of the consumer;
  - developing compensation mechanisms for compensating costs;
  - increasing chain transparency;
  - taking measures at European level;
  - aiming at risk based food safety and performance objectives rather than zero tolerance.

4. Interventions at the farm

The prevalenve on some farms seems to be one hundred percent, whereas other farm are always negative. No valid explanation can be given, although research indicates different causes such as water supply, level of hock burns, etc. *Campylobacter* control at farm level is closely related with identification of on site sources. There are various reviews on this subject at farm level, but most literature is available on the interventions in processing plants. Major risk factors can be characterised as:

- age of the birds;
- farm size, flock size and farm location;
- presence of other farm animals;
- season;
- ventilation systems.

Biosecurity levels appear to substantially contribute to the control of *Campylobacter*. However, when the biosecurity regime is not followed strictly, the original situation will return soon. Biosecurity is determined by several conditions where a farmer cannot interfere. The farm location, as well as the size and structure of the farm cannot easily be altered. Cleaning and disinfection however, should preferably be done in a professional manner with the appropriate protocols and chemicals. Studies show that *Campylobacter*s can be transmitted to subsequent flocks in the same house. Animals should not be stressed and visitors should wear clothing and footware from the farm. Pest control has to be adequate with regular checks. There should be no access for wild birds or rodents, and insects such as black beetles (*Alphitobius diaperinus*) should be eliminated. Medication should be applied carefully so that the development of antibiotic resistance does not occur.

From the CARMA project is not clear which one of the measures should be taken, since some are very expensive. They suggest therefore improving the hygiene status gradually over time. From experience in *Salmonella* control, it is clearly shown that interventions in farms cannot be effective when applied as an isolated action. There should be a number of actions that are taken at the same time: a hurdle principle.

Interventions at farm level aim at preventing infection rather than eradication. Modification of the gut environment in order to prevent colonisation can be achieved by vaccination, probiotic or prebiotic treatments or Competitive Exclusion (CE) floras. These therapies however, are in the early stage of research and development, and no results from the field are available. Colonisation control by commercially available CE cultures seems not very promising. Some researchers could reduce the CFU level in the caeca by approx 2 log units (100 times), but the residual level was still 10^5 CFU/g. Application of fructooligosaccharides (FOS) in chicken feed reduced colonisation of *Campylobacter*, but only limited results are available. Probiotics such as yeasts or *Lactobacilli* (Chang and Chen, 2000; Morishita *et al.*, 1997) also have an effect *in vitro*, but there is a need to confirm these findings *in vivo* experiments.

Water and feed can be treated. Although chlorination or acidification of drinking water (Chaveerah *et al.*, 2004) may not completely prevent *Campylobacter* colonisation *in vivo*, it can delay the colonisation by some days. The drinking water acts as a barrier for the transmission, by its lethal effect in the crop. Naturally-fermented poultry feed can slightly reduce colonisation of *Campylobacter* in broilers, whereas addition of lactic acid in feed had a similar effect (Heres *et al.*, 2004). There are indications from the field that medium chain organic acids (C6-C8) have potential in controlling *Campylobacter*. There are no results available from controlled studies. Phage therapy may reduce the presence of *Campylobacter* in the GI tract (Wagenaar *et al.*, 2005), but can also be applied as carcass decontaminant. Vaccination, for example with DNA vaccines resulted in a 2 log reduction of *Campylobacter* in the gut (Widders *et al.*, 1998), but further research is also needed here (Wyszynska *et al.*, 2004).

Climatic conditions such as relative humidity (RH) can influence the colonisation of *Campylobacter*. Low RH delays the transmission, so cage rearing might have a positive effect on the *Campylobacter* status of broilers (Line, 2006). Vertical transmission seems not to be an important vector for *Campylobacter*. From broiler breeders *Campylobacter*s can be isolated, even from the ovaries, but hatcheries and one day-old chicks are *Campylobacter* free, although Cox *et al.* (2002) confirmed the presence of identical DNA typed *Campylobacter*s both in breeders and in their progeny. *Campylobacter* has not been isolated from feed, nor from feed ingredients. The environment is probably the biggest threat for contamination of farm animals. In organic production systems, *Campylobacter* prevalence is generally higher than in conventional farming. The exposure to the environment appears to be an important vector and leads to a *Campylobacter* prevalence of 100% in broiler flocks. French data show that the *Campylobacter* prevalence of poultry meat from regular and "open air" production sites was 77% and 84% respectively. From this brief review it becomes clear that there is no intervention at farm level that can eradicate *Campylobacter* effectively from chickens.

5. Conclusions

A major success in the control of *Campylobacter* at the farm is not to be expected in the short term. No effective control measures or interventions are available. Interventions in the processing plant are the only effective alternatives at present, in order to reduce *Campylobacter* contamination of poultry meat.

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A fowl fear: is avian influenza (bird flu) on the leading edge of a global pandemic?

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1. Introduction

Avian influenza A (AI) H5N1, also known as Asian bird flu, is at the forefront of nearly every daily news report around the world. The reason for this intense interest in AI H5N1 is due to the growing fear that a global pandemic might occur if exchange of genetic material between H5N1 and a human influenza virus results in a virus that can be transmitted from person to person. Avian influenza A viruses pose the threat of initiating new pandemics in humans because the human population is serologically naïve to most influenza hemagglutinin (HA) and neuraminidase (NA) subtypes that partially characterise each influenza virus. Until recently, it was thought that pigs were required as an intermediate host for transmission of AI viruses to humans (Gammelin *et al.,* 1989; Yasuda *et al.,* 1991), and it was believed that AI viruses, in general, did not replicate efficiently or cause disease in humans (Beare and Webster, 1991). However, the AI H5N1 virus is the first avian influenza virus to have been documented as being capable of directly causing respiratory distress and death in humans (Yuen *et al.,* 1998). To date 83 people have died after becoming infected by an AI H5N1 virus strain. Most of those deaths have occurred in Asian countries. Ordinarily, the loss of 83 lives, spread sporadically among diverse populations and among different ages of people, would not generate such intense interest in the worldwide community, but the human mortality rate resulting from AI H5N1 infection is more than 50%, signaling to the world that AI H5N1 may be poised to cause the next human pandemic. More than 75% of those human victims of AI H5N1 infection had recently been confirmed as being exposed to live or recently dead infected chickens or other birds. In October 2005, the appearance of the Asian bird flu virus in both wild birds and domestic fowl in Romania, Croatia, Turkey and Eastern European countries far from Southeast Asian countries known to have AI H5N1 virus drove global health officials to increase planning activities to prepare for the possibility that the H5N1 virus will infect humans worldwide.

There is ample evidence to show that periodically avian influenza A viruses do mutate to novel antigenic subtypes that cause disease and high rates of mortality in humans. It is believed that the 1918 influenza A (H1N1) pandemic, which killed 40 to 50 million people worldwide, was the result of such a mutation in an avian influenza A virus (Reid *et al.,* 1999; Gamblin *et al.,* 2004; Stevens *et al.,* 2004). Similarly, emergence of human influenza A pandemics in 1957 (H2N2) and 1968 (H3N2) appeared to have had origins in avian/swine influenza A viruses (De Jong and Hien, 2006). The 1918 Spanish flu virus (H1N1) is believed to have been due to the adaptation of a purely avian strain to infect humans directly, while in 1957 (H2N2) and 1968 (H3N2) the avian influenza A viruses adapted for human infection via genetic reassortment among avian, swine, and human virus strains (Webster *et al.,* 1992; Murphy and Webster, 1996). It has been a common belief among virologists that restriction of the avian influenza A viruses to birds has precluded its potential for efficient bird-to human transmission. The only other reports of natural infections of humans by highly pathogenic AI viruses were cases of conjunctivitis associated with avian influenza H7N7 viruses, transmitted either directly from birds to humans or by seals (Lang *et al.,* 1981; Banks *et al.,* 1998). Fouchier *et al.* (2004) and Koopmans *et al.* (2004) reported that even H7N7 was also the cause of one human death.

At present, AI H5N1 remains foremost an animal health problem, and human infection by AI H5N1 is not a common occurrence even though people have become infected, which oftentimes has been lethal. Fortunately, transmission of AI H5N1 from person to person has not been a problem; and in Vietnam, healthcare workers who had direct contact with AI H5N1-infected patients in 2003 and 2004 did not seroconvert to H5N1 (Liem and Lim, 2005). In Table 1 are data reported to the World Health Organisation (WHO), which show cumulative numbers of avian influenza A H5N1 cases in humans and mortality resulting from those infections. When compared with reported outbreaks in birds (Figure 1) there appears to be a parallel between outbreaks of AI H5N1 in poultry and in humans, but these reported outbreaks are inconsistent and probably reflect a far lower than actual incidence.

Table 1. Cumulative number of confirmed human cases of avian influenza H5N1 reported to the World Health Organisation (January 16, 2006).

Onset	Cambodia		China[a]		Indonesia		Thailand		Turkey		Vietnam		Total	
	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths
2003	0	0	0	0	0	0	0	0	0	0	3	3	3	3
2004	0	0	0	0	0	0	17	12	0	0	29	20	46	32
2005	4	4	8	5	16	11	5	2	0	0	61	19	94	41
2006	0	0	0	0	3	3	0	0	12	4	0	0	15	7
Total	4	4	8	5	17	12	22	14	12	4	93	42	158	83

[a] In 1997, Hong Kong had the first outbreak of avian influenza A H5N1 human infections with 18 reported cases and six known deaths. In early 2003, H5N1 caused an additional two infections with one death in a Hong Kong family with a recent travel history to southern mainland China.

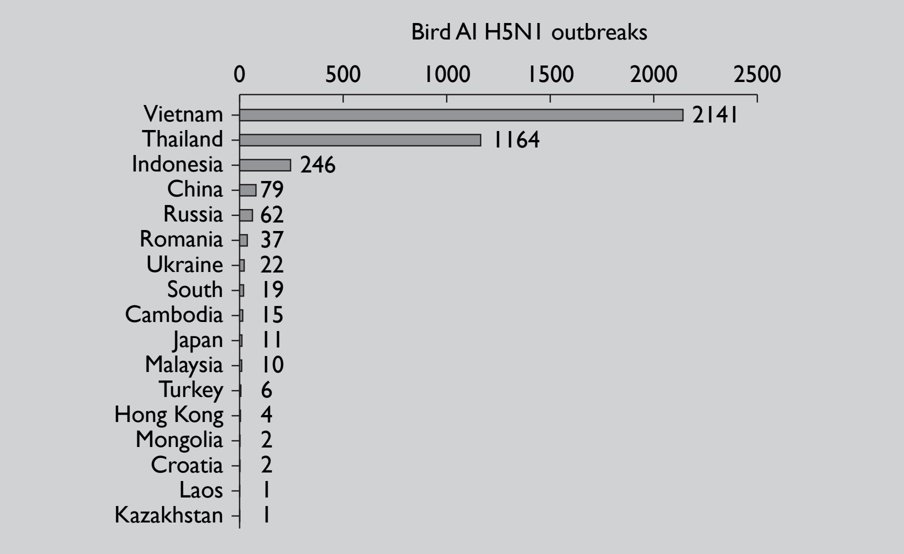

Figure 1. Avian outbreaks of AI H5N1 through 6 January 2006 (WHO, 2006).

2. Avian influenza virus infection

The causative agent for Asian bird flu, AI H5N1, is classified as a member of the family *Orthomyxoviridae* genus *Influenzavirus* A (Swayne and Halvorson, 2003; Fouchier *et al.,* 2005). Both the HA and the NA antigens on the virus contribute to its pathogenicity and are used in classifying it. There are 16 HA (H1-H16) subtypes and 9 NA (N1-N9) subtypes of surface glycoproteins that are recognised as being associated with AI viruses. The H16 subtype was discovered only recently on influenza A viruses isolated from black-headed gulls from Sweden and Norway (Fouchier *et al.,* 2005). HA is an antigenic glycoprotein found on the surface of all influenza viruses and is responsible for binding the virus to the cell that is being infected. The highly pathogenic H5N1 subtype appears to infect humans at a very low rate, but a single amino acid change in the H5N1 strain's subtype H5 antigen has been found in human patients, and is believed to alter significantly the receptor specificity of avian H5N1 viruses, providing them with an ability to bind to receptors optimal for human influenza viruses (Gambaryan *et al.,* 2006; Suzuki, 2005). This finding seems to explain how an H5N1 virus that normally does not infect humans can adapt to efficiently infect human cells. Although H1, H2, and H3 subtypes have been associated with human influenza pandemics of the past, it is possible that any of the 16 different HA antigens can be involved in human influenza outbreaks, and therefore, H5 from H5N1 is indeed a potential candidate for involvement in a new human influenza outbreak.

The HA of the H5N1 virus has been associated with the high pathogenicity of this flu virus strain, apparently due to its ease of conversion to an active form by proteolysis (Senne *et al.,* 1996; Hatta *et al.,* 2001). HA has two primary functions: (1) the recognition of target vertebrate cells, accomplished through the binding of sialic acid-containing receptors (Weis *et al.,* 1990), and (2) the fusion of host and viral endosomal membranes (White *et al.,* 1997), accomplished through the recruitment of HA molecules to the fusion site where some undergo conformational alterations to destabilise the cell membrane lipid bilayer thereby forming a fusion intermediate which anneals the two bilayers between host and virus.

NA is an antigenic glycoprotein enzyme (EC 3.2.1.18) found on the surface of influenza viruses. Nine NA subtypes are known, and many occur only in various species of duck and chicken. Subtypes N1 and N2 have been positively linked to epidemics in man. Neuraminidase has functions that aid in the efficiency of virus release from cells. Neuraminidase cleaves terminal sialic acid residues from carbohydrate moieties on the surfaces of infected cells. This promotes the release of progeny viruses from infected cells. Neuraminidase also cleaves sialic acid residues from viral proteins, preventing aggregation of viruses. Administration of chemical inhibitors of neuraminidase is a treatment that limits the severity and spread of viral infections. Neuraminidase inhibitor drugs currently in use for combating virus infections in humans are zanamivir and oseltamivir.

3. Prevalence of avian influenza (H5N1)

Countries with confirmed cases of H5N1 infections in poultry or wild birds are shown in Table 2 (CDC, 2006). The fact that AI H5N1 in domestic poultry and wild birds has been reported in Eastern Europe, throughout Asia, several unconfirmed cases in Western Europe, and in Africa suggests that there are large populations that have been exposed, but very few cases to date in humans. Research in the United States has not revealed populations of wild birds or domestic fowl with AI H5N1 infections (Hanson *et al.,* 2003, 2005), but H5, H7 and H9 avian influenza virus subtypes, which are associated with high pathogenicity in poultry, were detected in higher than expected levels (Hanson *et al.,* 2003). In an earlier review, Stallknecht and Shane (1988) demonstrated that AI viruses could be detected in 12 orders and 88 species of free living

Table 2. Countries with confirmed avian influenza A (H5N1) infections in domestic poultry, wild birds, or mammals.

Europe	Asia
Romania[b]	China[a,b]
Russia[a,b]	Mongolia[b]
Turkey[a,b]	Vietnam[a,b,c]
Croatia[b]	Kazakhstan[a,b]
Serbia[b]	Malaysia[a]
Ukraine[b]	Indonesia[a]
Bulgaria[b]	Thailand[a,b,c]
	Japan[a,b]
	South Korea[a,b]
	Cambodia[a,b]
	Laos[a,b]
	Iraq[b]

[a]Poultry.
[b]Wild birds.
[c]Mammals.

birds. Most of the isolates were from ducks, geese, swans and shore birds such as gulls and terns, which apparently serve as a reservoir for AI viruses similar to the findings of epidemiologists and virologists working on the current H5N1 problem in Asia (Murphy and Webster, 1996; Webster *et al.,* 1992, 2006).

4. Human infections with avian influenza H5N1 virus strains

Beigel *et al.* (2005) reported that most of the H5N1-infected individuals have been previously healthy children or older adults. The four who died in Turkey were also previously healthy children. In Asia, age of infected persons has varied from 1 to 60 years with median ages ranging from 9.5 in the 1997 Hong Kong outbreak to 22 in the 2005 Cambodian outbreak. There has been no indication that the gender of victims of the infection is a factor for concern. People who have developed the disease showed signs within two to eight days after exposure. Recently, incubation time has increased before showing signs of infection. Incubation times currently can range as long as eight to 17 days post exposure.

Among infected persons in the countries with an AI problem in humans, 70 to 100% had exposure to H5N1-infected live or recently dead chickens. While this observation seems compelling evidence of a direct movement of H5N1 to humans, there is the possibility of predisposing factors that might make the victims susceptible to H5N1 infections. Most infected humans had a history of direct contact with poultry, although not those who were involved in mass culling. Plucking and preparing of diseased birds; handling fighting cocks; playing with poultry, particularly asymptomatic infected ducks; and consumption of raw duck blood or possibly undercooked poultry have all been implicated in the transmission of AI H5N1 to humans. Transmission to felids has been observed by feeding raw infected chicken meat to tigers and leopards in zoos in Thailand (Keawcharoen *et al.,* 2004; Thanawongnuwech *et al.,* 2005) and to domestic cats under experimental conditions (Kuiken *et al.,* 2004). Some infections may be initiated by pharyngeal or gastrointestinal inoculation of virus. In each possible case of avian to mammal transmission of the virus, body fluids bearing the virus had to have been involved.

Among these factors, there looms the possibility of genetic susceptibility of some victims (Perdue and Swayne, 2005) as illustrated by infection in some clusters in Turkey, Vietnam, Cambodia, and Thailand. An intercurrent disease that might have been immunosuppressive allowing the virus to be more infective, consumption of uncooked H5N1-infected poultry meat with direct delivery of the virus to receptive sites in the gastrointestinal tract (Mase *et al.,* 2005a), or even nutritional deficiencies all might make the expression of the virus more pathogenically potent. It is important to note that family clusters of victims from H5N1 infections do not automatically indicate a mutation of the AI H5N1 virus making it more efficient in person-to-person transmission (Olsen *et al.,* 2005). However, conversion of the AI H5N1 virus to a virulent form or exposure to large numbers of infective organisms, *i.e.,* dose response, that can infect humans seem to be the most probable causes of human outbreaks.

Regardless of the immense media interest and coverage of the AI H5N1 problem in Asia and now Eastern Europe, Perdue and Swayne (2005) rightly emphasise that the current Asian and Eastern European AI H5N1 outbreaks are primarily animal health problems. Though human infections are relatively few and sporadic this is not meant to diminish the potential human risk associated with exposure to the AI H5N1 virus. Perdue and Swayne (2005) draw attention to the fact that there is a major human risk, albeit a low risk, associated with the potential that a seasonally recurring influenza H1N1 or H3N2 strain will infect an H5N1-infected human and a reassortant virus containing the correct combination of genes for efficient human-to-human transmission will emerge. Another issue is the unknown transmission efficiencies to other mammals and the likelihood of a co-infection of a mammal, such as a pig, with an avian and human influenza A virus strain. Currently circulating H1N2 and H3N2 swine influenza strains with genes from birds, human and swine influenza viruses can be isolated in both the United States and Asia (Olsen, 2002; Richt *et al.,* 2003; Jung and Chae, 2004).

5. Evolution of influenza viruses

The AI H5N1 viruses involved in current outbreaks apparently are still evolving (Beigel *et al.,* 2005). There have been changes in antigenicity and internal gene constellations (Horimoto *et al.,* 2004; Li *et al.,* 2005), expanded host range in avian species (Perkins and Swayne, 2002), ability to infect cats (Kuiken *et al.,* 2004; Tiensin, 2005; Rimmelzwaan *et al.,* 2006), enhanced pathogenicity in experimentally infected mice and ferrets (Zitzow *et al.,* 2002), and increased environmental stability (Beigel *et al.,* 2005). The fact that cats might be susceptible to AI H5N1 is a very important observation that provides evidence about the potential spread of the disease to and by a mammalian species within and between mammalian hosts.

Beare and Webster (1991) and, more recently, Gambaryan *et al.* (2004) state that avian influenza viruses generally do not replicate efficiently in human hosts. Gambaryan *et al.* (2004 and 2006) have reported that Asian AI H5N1 strains that infected humans in 2003 and 2004 had changed their receptor binding affinity. All but two of the isolates had preserved high affinity for Sia2-3Gal (avian-like) (3'SLN) receptors, but in 2003 those two exceptional isolates had decreased affinity to Sia2-3Gal and increased affinity to Sia2-6Gal (human-like) (6'SLN) receptors. These receptors provide a mechanism for influenza virus to bind to host cells via their hemagglutinin (HA) surface proteins to sialylglycoconjugates exposed on the cell surface. Avian viruses preferentially bind to Sia2-3Gal-terminated sugar chains while mammalian viruses prefer to bind to Sia26Gal-terminated structures (Conner *et al.,* 1994; Gambaryan *et al.,* 1997). Additionally these two exceptional AI H5N1 isolates had a unique Ser227-Asn change in the HA surface protein, which provided the AI H5N1 isolates the ability to bind to receptors that are optimal for human influenza viruses. Gambaryan *et al.* (2006) showed that the 2003-2004 Asian H5N1 isolates from both chickens and humans had increased affinity for the sulfated trisaccharide Neu5Acα2-3Galβ1-4(6-HSO_3)GlcNAcβ (Su-3'SLN) receptor differing from the 1997 Hong Kong isolates, which had increased affinity for the fucosylated Su-3'SLN receptor. American poultry H5 viruses also have increased affinity for the Su-3'SLN receptor. Gambaryan *et al.* (2006) concluded that genetic evolution of the avian influenza A H5N1 viruses is accompanied, during adaptation to poultry, by the evolution of their receptor specificity.

Virus evolution is driven by recombination of nucleic acids in the virus. Suarez *et al.* (2004) reported that a low pathogenic H7N3 AI virus had mutated in chickens to become a highly pathogenic H7N3 AI virus. That mutation was due to recombination between the hemagglutinin (HA) gene and the nucleoprotein genes. This recombination resulted in a 10 amino acid insert in the HA0 cleavage site, which made the H7N3 virus atypical among highly pathogenic viruses. Among all of the virulent influenza A viruses, one virulence factor is correlated with the HA0 cleavage site. The surface HA glycoprotein is produced as a precursor HA0 and requires posttranslational cleavage by host proteases before it becomes functional, allowing the virus to become infectious (Rott, 1992). All highly pathogenic AI viruses have multiple basic amino acids (arginine and lysine) at the HA0 cleavage site, and low pathogenic AI viruses have only two basic amino acids at the HA0 cleavage site (positions 1 and 4 for H5 viruses and positions 1 and 3 for H7 viruses) (Wood *et al.,* 1993). The difference in HA0 cleavage sites between low pathogenic AI and highly pathogenic AI signals the difference in virulence. The low pathogenic form is limited to cleavage by proteases at sites where trypsin-like enzymes are present such as in the respiratory and intestinal tracts while the highly pathogenic forms of AI with multiple cleavage sites can be cleaved by ubiquitous host proteases (Steineke *et al.,* 1992) allowing them to replicate systemically, damaging vital organs and tissues leading to more severe disease and death. Uiprasertkul *et al.* (2005) reported from a single post-mortem finding that H5N1 virus could be found in the spleen of an AI H5N1-infected person, but did not find evidence of viral replication beyond the respiratory and intestinal tracts.

The highly pathogenic AI H5N1 virus that affected people in Hong Kong appears to have been the product of recombination between two other AI viruses (Chen *et al.,* 1999; Chin *et al.,* 2002; Claas *et al.,* 1998; Peiris *et al.,* 2004; Subbarao *et al.,* 1998; Xu *et al.,* 1999). Claas reported that in May 1997, a 3-year-old boy in Hong Kong was admitted to the hospital and subsequently died from pneumonia, acute respiratory distress syndrome, Reye's syndrome, multiorgan failure, and disseminated intravascular coagulation. An influenza A H5N1 virus was isolated from a tracheal aspirate. Preceding this incident, avian influenza outbreaks of high mortality were reported from three chicken farms in Hong Kong, and the virus involved was also found to be of the H5 subtype.

An antigenic and molecular comparison of the influenza A H5N1 virus isolated from the boy with one of the viruses isolated from outbreaks of avian influenza by hemagglutination-inhibition and neuraminidase-inhibition and nucleotide sequence analysis revealed differences in the antigenic reactivity of the viruses. However, nucleotide sequence analysis of all gene segments revealed that the human virus A/Hong Kong/156/97 was genetically closely related to the avian A/chicken/Hong Kong/258/97. Although direct contact between the sick child and affected chickens could not be established, they concluded that transmission of the virus from infected chickens to the child without another intermediate mammalian host acting as a 'mixing vessel' had occurred.

In 1996, a highly pathogenic AI H5N1 influenza virus, A/goose/Guangdong/1/96 (GSGD/96) was isolated from a sick goose in Southern China, but there was little interest in that virus at that time (Chen *et al.,* 1999; Xu *et al.,* 1999). In 1997 the highly pathogenic AI H5N1 virus, which apparently had derived its HA gene from a GSGD/96 like-virus and its other seven genes from the H6N1 subtype A/teal/Hong Kong/W312/ 97-like virus, was detected and caused disease outbreaks in chickens in Hong Kong live (wet) markets (Chin *et al.,* 2002). The virus was transmitted to humans causing fatal disease (Subbarao *et al.,* 1998). Birds involved in this outbreak of H5N1 also died in large numbers, over a period of 48 hr. Even with only these two human cases resulting from this outbreak, it seemed clear that recombination among AI viruses can be a major cause of the evolution of potentially lethal viruses that can infect humans. This conclusion is supported by observations that most of the H5N1 viruses isolated before 2001 were unable to replicate in the mouse mammalian model, but viruses isolated in 2001 and 2002 replicated systemically and were highly lethal in the mouse model (Li *et al.,* 2005).

6. Signs and pathology of avian influenza H5N1 infection

6.1. In humans

Signs of AI H5N1 infection are complex, and infected persons can be asymptomatic for some signs while showing many of the other signs (Beigel *et al.,* 2005). Clinical signs tend to be somewhat variable among patients and include headache, myalgia, diarrhea, abdominal pain, vomiting, coughing, excessive sputum, sore throat, nasal drip, and shortness of breath (Beigel *et al.,* 2005; De Jong and Hien, 2006). Some of the pathological developments associated with H5N1 infection include pulmonary infiltrates, lymphopenia, thrombocytopenia, elevated aminotransferase activity, cytokine and chemokine elevation, CD4+/CD8+ ratio inversion, hemophagocytosis, hepatic lobular necrosis, renal tubular necrosis, and lymphoid depletion (De Jong and Hien, 2006). Many of the clinical signs can be related to immune-mediated pathology in the pathogenesis of the H5N1 infection (De Jong and Hien, 2006), which might lead to immunosuppression in patients. Indeed, it has been reported that humans with H5N1 infection have multiorgan failure despite the fact that viral replication is restricted to the lungs and gastrointestinal tract (Uiprasertkul *et al.,* 2005). It was hypothesised that cytokine dysregulation might promote the organ failure in the pathogenesis of severe H5N1 disease (Chan *et al.,* 2005; Cheung *et al.,* 2002).

6.2. Pathology of H5N1 infection in chickens

Swayne and Halvorson (2003) have described the pathology associated with both low and highly pathogenic forms of avian influenza in poultry species. Lesions may be absent in cases of sudden death of chickens with highly pathogenic AI H5N1 infection because the virus acts so quickly (Nakatani *et al.,* 2005). In cases where mortality was slower to develop, observations at necropsy revealed congestion of the musculature, dehydration, subcutaneous edema of the head and neck areas, nasal and oral cavity discharge, severe congestion of conjunctiva sometimes with petechiae, excessive mucous exudate in the lumen of the trachea, severe hemorrhagic tracheitis, petechiae on the inside of the sternum, petechiae on the serosa and abdominal fat, petechiae on serosal surfaces and in the body cavity, severe renal congestion often with urate deposits in the tubules, hemorrhage and degeneration of the ovary, hemorrhages on the mucosal surface of the proventriculus especially at the junction with the ventriculus, hemorrhage and/or erosion of the ventricular lining and hemorrhagic foci on the lymphoid tissues in the intestinal mucosa. Ducks shedding the highly pathogenic viruses may not show any of the clinical signs and lesions associated with highly pathogenic AI in chickens and turkeys.

7. All avian influenza virus strains are not highly pathogenic

AI H5N1 is a type of influenza virus that is hosted by birds but can infect several species of mammals. Wild waterfowl, primarily ducks, geese, swans and gulls are considered the natural reservoir of all influenza A viruses (Stallknecht and Shane, 1988; Webster *et al.,* 1992; Murphy and Webster, 1996; Sturm-Ramirez *et al.,* 2005). These wild birds have probably carried low pathogenicity forms of these influenza viruses, with no apparent harm, for long periods of time. Virulent strains can emerge either by genetic mutation or by reassortment of less virulent strains. It is believed that AI H5N1 has been circulating in wild bird populations in China for some time before the discovery of the A/goose/Guangdong/1/96 (GSGD/96) virus and its subsequent transfer to Hong Kong in sick chickens in 1997.

Domestic poultry are particularly susceptible to the more virulent forms (H5N1, H5N2, H7N2, H7N3, H7N7, and H9N2) (CDC, 2005; Mase *et al.,* 2001; 2005b; Munster *et al.,* 2005; Nakatani *et al.,* 2005). They spread rapidly through poultry flocks, cause disease affecting multiple internal organs, and have a mortality that can approach 100%, often within 48 hr. Once avian flu is established in domestic poultry, it is a highly contagious disease and wild birds are no longer an essential ingredient for spread. Infected birds excrete virus in high concentration in feces and in nasal and ocular discharges. The disease generally spreads rapidly in a flock by direct contact, but occasionally the spread is erratic. Pathogenic strains can emerge and cause disease in domestic poultry in any country at any time without warning. In poultry flocks, AI exists in two main forms and is distinguished by low and high pathogenicity extremes of virulence (Swayne and Halvorson, 2003; Suarez *et al.,* 2004; Perdue and Swayne, 2005). The highly pathogenic form causes systemic disease with rapid death in domestic poultry, but the low pathogenicity form, which causes localised infection, often causes little or no disease unless exacerbated by intercurrent disease or environmental stressors that may induce immunosuppression. Low pathogenic AI viruses are found in wild birds around the world (Stallknecht and Shane, 1988; Murphy and Webster, 1996; Webster *et al.,* 1992; Munster *et al.,* 2005), and highly pathogenic H5 and H7 AI virus subtypes have been isolated from wild birds in Europe and Asia where the current outbreaks of H5N1 have occurred (Murphy and Webster, 1996; Webster *et al.,* 1992; Munster *et al.,* 2005). Highly pathogenic AI infections in poultry are rare and should not be confused with viruses of low pathogenicity, which can also be of H5 and H7 subtypes (Suarez *et al.,* 2004; Perdue and Swayne, 2005).

Each virus has one HA and one NA protein which can be, potentially, in any combination. All of the HA and NA subtype combinations have been isolated from wild avian species (Swayne and Halvorson, 2003; SCWDS Fact Sheet, 2005). All highly pathogenic isolates have been influenza A viruses of subtypes H5 and H7, but not all H5 and H7 virus subtypes cause highly pathogenic influenza (Swayne and Halvorson, 2003; Suarez *et al.,* 2004). It has been demonstrated that avirulent H7 viruses can pass through chickens and mutate via antigenic shift into the highly pathogenic form (Li *et al.,* 1991; Ito *et al.,* 2001; Suarez *et al.,* 2004). This potential for conversion of avirulent to virulent status via passage through a common host is why it is so important to monitor for AI and to depopulate flocks if AI is detected, even if few or no signs of diseases are present, in order to prevent highly pathogenic viruses from developing.

8. Antigenic shift vs. antigenic drift as a means for virus evolution

Influenza strains are named after their types of HA and NA surface proteins for example, H3N2 for type-3 HA and type-2 NA. If two different strains of influenza infect the same cell simultaneously, their protein capsids and lipid envelopes are removed, exposing their RNA, which is then transcribed to mRNA. The host cell then forms new viruses that combine antigens, for example, H3N2 and H5N1 can form H5N2 or H3N1 this way. Because the human immune system has difficulty recognising the new influenza strain, it might become a highly infectious lethal virus responsible for global pandemics. One increasingly worrying situation is the possible antigenic shift between avian influenza and human influenza. This antigenic shift could cause the formation of a highly virulent virus as is believed to have happened with the highly pathogenic AI H5N1 virus (Perdue and Swayne, 2005).

Recombination among low pathogenic AI viruses to form highly pathogenic AI viruses appears to be the manner in which the lethal forms evolve (Chen *et al.,* 1999; Chin *et al.,* 2002; Claas *et al.,* 1998; Li *et al.,* 2005; Peiris *et al.,* 2004; Subbarao *et al.,* 1998; Xu *et al.,* 1999). Therefore, it is important to understand how these transformations can take place. Antigenic shift is the process by which two different strains of influenza viruses combine and exchange genetic information to form a new subtype having a mixture of the surface antigens (HA and NA) of the two original strains. The term 'antigenic shift' is specific to the influenza literature (Figure 2) and in other viral systems, the same process is called reassortment or viral shift.

Antigenic shift can happen in three ways:

- *Antigenic shift 1:*
  - Without undergoing genetic change, a bird strain of influenza A can jump directly from a duck or other aquatic bird to an intermediate animal host and then to humans.
  - The new strain may further evolve to spread from person to person. If so, a flu pandemic could arise.
- *Antigenic shift 2:*
  - A duck or other aquatic bird passes a bird strain of influenza A to an intermediate host such as a chicken or pig.

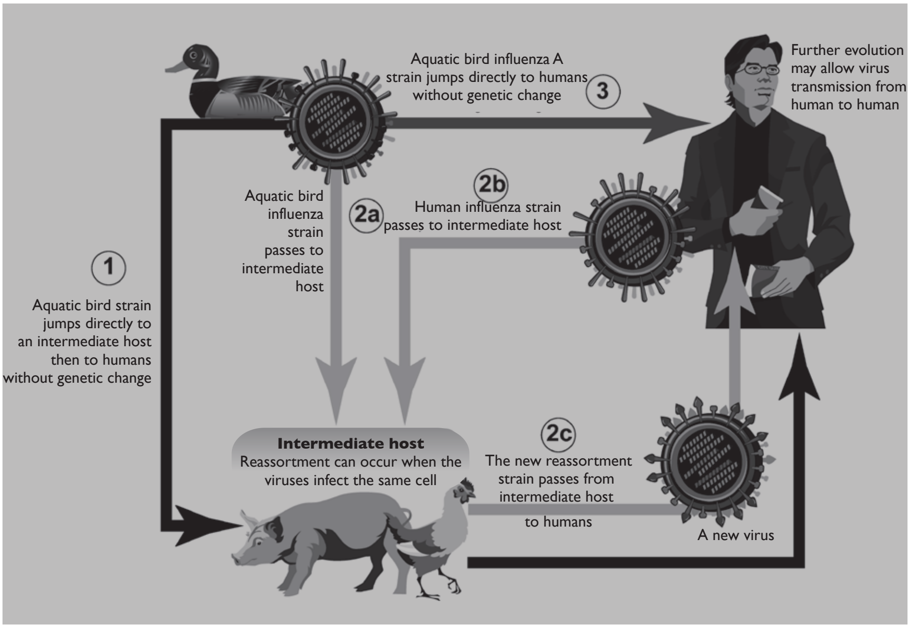

Figure 2. Illustration of the concept of antigenic shift in influenza viruses, showing the three ways that antigenic shift can occur.

- A person passes a human strain of influenza A to the same chicken or pig.
- When the viruses infect the same cell, the genes from the bird strain mix with genes from the human strain to yield a new strain.
- The new strain can spread from the intermediate host to humans.

- *Antigenic shift 3:*
  - Without undergoing genetic change, a bird strain of influenza A can jump directly from a duck or other aquatic bird to humans.

Antigenic shift is contrasted with antigenic drift (Figure 3), which is the natural mutation over time of known strains of influenza viruses to evade the immune system. Antigenic drift occurs in all types of influenza including influenza A, B and C. Antigenic shift, however, occurs only in influenza A because it infects more than just humans. Affected species include other mammals and birds, giving influenza A the opportunity for a major reorganization of surface antigens. Influenza B and C only infect humans, drastically minimising the chance to mutate.

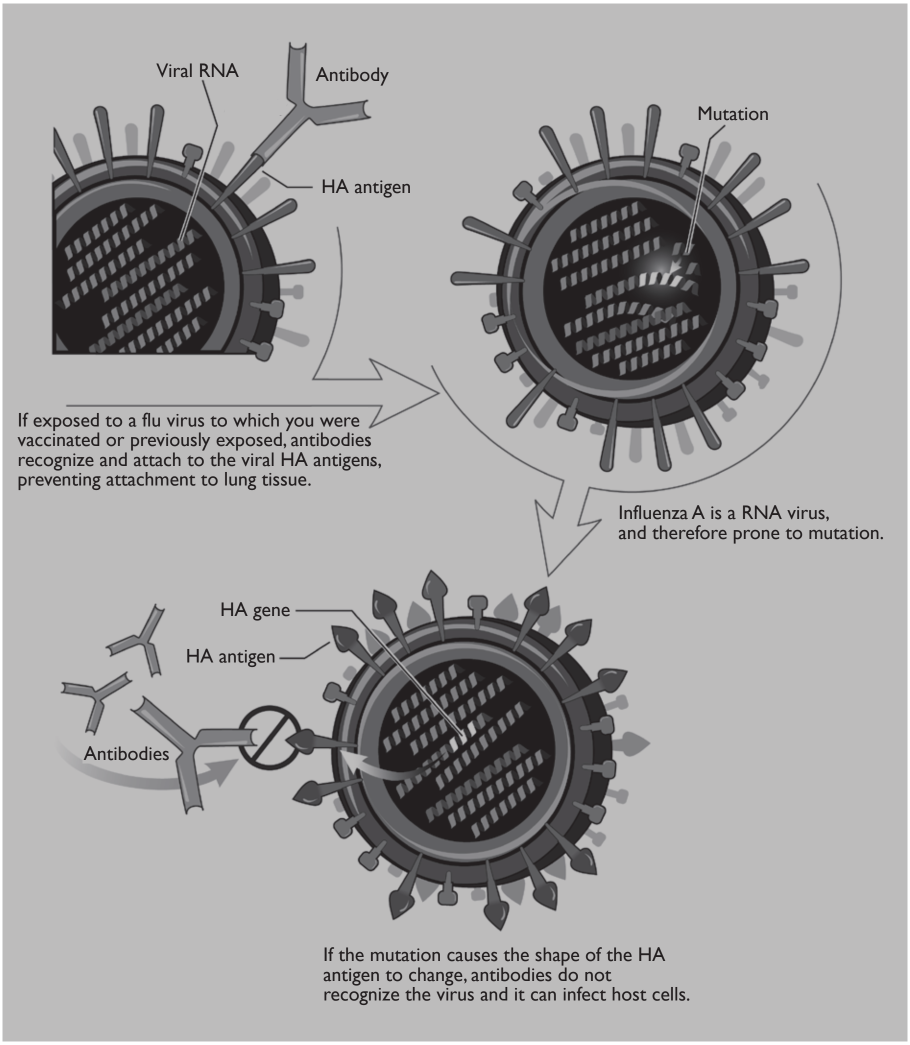

Figure 3. Illustration of the concept of antigenic drift in influenza viruses.

Each year's flu vaccine contains three flu strains - two A strains and one B strain, which change from year to year. After vaccination, the body produces infection-fighting antibodies against the three flu strains in the vaccine. If exposure occurs to any of the three flu strains during the flu season, the antibodies will bind to the virus's HA antigens, preventing the flu virus from attaching to and infecting healthy cells. Influenza virus genes, made of RNA, are more prone to mutations than genes made of DNA, and if there is a nucleotide alteration, the HA gene can change, causing the surface glycoprotein antigen to change conformation. If the HA antigen on the surface of the virus is altered, antibodies that normally would bind the viral antigen can no longer do so, allowing the newly mutated virus to infect the body's cells. This type of genetic mutation is called 'antigenic drift'.

9. Control and prevention of H5N1 infection in poultry and human populations

Influenza A viruses are found in many different animals, including ducks, chickens, pigs, whales, horses, and seals (Webster *et al.,* 1992), but wild birds, which often are asymptomatic or show only mild infection, are the primary natural reservoir for all subtypes of influenza A viruses. However, the range of symptoms in birds varies greatly, depending on the strain of virus. Infection with certain avian influenza A viruses (for example, some strains of H5 and H7 viruses) can cause widespread disease and death among some species of wild and especially domestic birds such as chickens and turkeys (Swayne and Halvorson, 2003). The potential for antigenic shift in influenza viruses with development of a new virus capable of person-to-person transmission is a constant problem that virologists have long feared. Suarez *et al.* (2004) and Webster *et al.* (2006) pointed out that the avian influenza virus might undergo an antigenic shift with the human flu virus and cause a global influenza pandemic like the one in 1918. The human health implications have now gained importance, both for illness and fatalities that have occurred following natural infection with avian viruses, and for the potential of generating a reassortment virus that could give rise to a pandemic strain (Capua and Alexander, 2004). Thus, it is important that strategies for the control and prevention of highly pathogenic influenza A viruses be developed.

In the modern poultry industry, it is possible to contain H5N1 if coordinated programs involving depopulation, vaccination and strict biosecurity are practiced, but there is no known treatment. Recovered flocks still shed virus on an intermittent basis, requiring intense surveillance and subsequent removal. After an infected flock has been removed, it is possible to use commonly available detergents and disinfectants with heating and drying to inactivate AI H5N1 virus. Nevertheless, any remaining organic material, such as feces, will continue to protect the virus, and active virus can be isolated from that material for at least 105 days. Thus, it is imperative that after an infected flock has been removed, all facilities and equipment must be cleaned and disinfected; and composting of litter is also recommended as a means to destroy residual virus (AVMA, 2005).

In Southeast Asia, more than 200 million chickens, ducks and other kinds of poultry have been culled in an effort to eliminate the virus. Swayne (2004) pointed out that all AI control programs should have three primary goals: (1) to prevent, (2) to manage, or (3) to eradicate AI. To achieve these three goals, management procedures to prevent introduction or escape of the pathogen at the farm level (biosecurity enhancements) must be in place. Adequate diagnostic and surveillance detection of the pathogen or infections caused by it must be available. Infected animals must be destroyed and marketing of animals that have recovered or do not show signs of disease must be prevented. Host susceptibility must be decreased via vaccination programs or genetic selection pressure on animal breeds/strains that are resistant to the pathogen; and educational programs for people who produce poultry must be expanded to provide a better understanding of AI and to teach how to prevent or minimise transmission.

It has been reported that in Southeast Asia the spread of highly pathogenic AI H5N1 has occurred in small villages and hamlets, signifying that the spread is primarily among domestic fowl and ducks. These animals are raised in open pens/fields and can have contact with wild or migratory birds, which serve as a reservoir for H5N1. Direct contact between humans and infected domestic fowl appears to be a mechanism for vectoring the virus to humans, and this has been demonstrated by the movement of the infected birds to wet markets in urban areas. The constant contact of the domestic fowl with infected wild birds/ducks will then provide the circumstance that allows recurring infections in the domestic fowl and further transfer to humans. This management practice for poultry production is problematic in the control of the spread of H5N1. Since these domestic fowl represent a significant portion of the livelihood of the rural people, the people will be unwilling to voluntarily destroy the birds without just compensation. Therefore, it will be difficult to eliminate potential vectors of H5N1. Nevertheless, if just compensation were to be made for the eradication of the potentially infected poultry, control and management of its presence would be made easier. However, part of the control, management and eradication program is adequate diagnostic, surveillance, and detection of the pathogen or infections by the pathogen. Even with the intense interest in H5N1, the lack of sufficiently trained healthcare workers in the rural and small urban areas of the affected countries makes it difficult to keep a potentially pandemic virus under control. Thus, developing countries, such as Vietnam, Cambodia, Laos, and Indonesia, where the H5N1 virus is endemic in birds, must become the battleground on which the virus must be contained to prevent transmission from birds to humans. Thailand has adopted a policy of eradication of infected flocks with compensation to their owners. This approach will be much less costly to contain the virus before it becomes a pandemic causing virus.

10. Impact of avian influenza H5N1 on local poultry industries

It has been estimated by the World Bank that direct costs of the AI H5N1 outbreaks in the poultry industry in Vietnam can range from $30 million to more than $105 million. After the first outbreak in 2003-2004, there was an approximate 15% decline in poultry production that amounted to a revenue loss of $45 million. Nearly 50 million birds were slaughtered. Additionally, there was a decline in egg production of almost 913 million eggs representing an additional $46 million in lost revenue. Compensation amounted to about $2 million. Currently, there is an AI vaccination program planned for Vietnam costing an estimated $22 million. In Vietnam, after the 2003-2004 outbreaks, the swine industry raised its production by approximately 12% partially off-setting the economic impact of such large losses to poultry production. In Turkey after the initial outbreak of H5N1 in October 2005, there was an almost 95% decline in poultry production and an almost total loss of egg sales. People were frightened to consume the poultry and eggs. Temporarily, nearly 100,000 people who worked in the poultry industry were directly affected by the H5N1 outbreaks.

In other countries where outbreaks of highly pathogenic H5N1 have occurred, nearly 200 million birds have been slaughtered in an attempt to contain the virus. The reported economic impact of H5N1 infection in the poultry industries in China, Turkey, Vietnam, Indonesia and Malaysia pales in comparison to the impact in Thailand. In Thailand and much of Southeast Asia, the poultry industry has been characterised as being divided into four separate but interactive sectors (FAO, 2005): commercial with high biosecurity (sector 1), commercial with moderate to high biosecurity (sector 2), local commercial with low biosecurity (sector 3), and local [backyard] with no biosecurity (sector 4). Sector 1 is represented by an industrial integrated system, sector 2 is represented by a semivertical integrated system, sector 3 is represented by small, locally operated farms on which there may be caged layers and birds with access to the outdoors or even free roaming birds, and sector 4 is characterised by village or backyard flocks which include fighting cocks. Among these sectors, the vast majority of the AI H5N1 positive flocks have been associated with sector 4 birds (83%), and ducks were determined to be the silent carriers of the virus (Tiensin *et al.,* 2005). To date Thailand has suffered more than $1.06

billion in lost revenue as the result of H5N1 infections in the poultry industry. Most of the lost revenue was due to loss of export markets and there was a roughly 5% contraction in the poultry industry as a result of this loss. After the resurfacing of H5N1 in 2005, Thailand is now the leader in Southeast Asia in its attempts to eradicate the highly pathogenic virus and is aggressively combating the problem. Thailand believes that one of the most critical problems associated with the spread of H5N1 in the country is movement of birds. As a means to control the spread of H5N1, movement of birds from sector 4 production is strictly regulated, more slaughter of infected birds, registration and regulation of fighting cocks is mandatory, mobile checkpoints were set up in the provinces most affected to enhance scrutiny of such movements, and surveillance teams have been deployed throughout the country. At this time, Thailand is not vaccinating against avian influenza, but Thailand has promoted regional cooperation on containing the flu, proposing an Association of Southeast Asian Nations (ASEAN) animal hygienic fund and pledging substantial funds to start the project. The resulting center would enhance cross-border surveillance and control measures, as well as serve as an information distribution center for all ASEAN countries on the spread of H5N1. These measures are absolutely required, and any effort that is not coordinated among the Southeast Asian regional governments is doomed to failure.

While there is no known vaccine to protect humans against H5N1 at this time, massive vaccination programs have been designed to protect poultry from other forms of AI. In a report concerning the Hong Kong outbreaks, vaccination of chickens with a commercially available killed H5N2 vaccine was evaluated as an additional tool to enhance biosecurity measures and intensive surveillance for control of highly pathogenic AI H5N1 (Ellis *et al.,* 2004). In December 2002 to January 2003, there were outbreaks of H5N1 disease in waterfowl in two recreational parks, wild water birds, several poultry markets and five chicken farms. In addition to quarantine, depopulation of the affected sheds and increased biosecurity, vaccination of the unaffected sheds and surrounding unvaccinated farms was undertaken on three farms. On at least two farms, infection spread to recently vaccinated sheds with low rates of H5N1 mortality when the chickens were between 9 and 18 days post-vaccination, but after 18 days post-vaccination no more deaths from H5N1 avian influenza occurred and intensive monitoring by virus culture on those farms showed no evidence of asymptomatic shedding of the virus. These observations suggested that an appropriate H5 vaccine might interrupt virus transmission in a field setting. China now plans to vaccinate more than 5 billion chickens, there are over 150 million doses of AI vaccines scheduled for Vietnam, and other countries are considering the use of massive vaccination programs, as well.

Swayne and colleagues also have shown that it is possible to protect poultry species from highly pathogenic AI via vaccination similar to earlier reports (Taylor *et al.,* 1988; Beard *et al.,* 1991; Webster *et al.,* 1991). Using a recombinant fowlpox-AI hemagglutinin subtype H5 gene insert vaccine, Swayne *et al.* (2000a) demonstrated that it was possible to protect broiler breeders and leghorn pullets from highly pathogenic H5 AI, but if the birds were given a secondary recombinant vaccination after a primary fowlpox vaccination, they found inconsistent protection. Nevertheless, these observations supported the concept that highly pathogenic AI could be controlled via vaccination with an appropriate vaccine. Swayne and colleagues (2000b) further demonstrated that by using a recombinant fowlpox vaccine with the H5 gene insert, it was possible to protect poultry from several highly pathogenic H5 AI viruses. Even more important was the observation that the recombinant fowlpox vaccine with the H5 gene insert could protect against changes in field viruses if the H5 gene insert was similar to the challenge virus, and in this case natural antigenic drift did not interfere with general protection as has been reported for human influenza viruses.

The use of an AI vaccination program will control some of the pathogenic forms of AI, but not all forms (Capua and Marangon, 2004). It is known that vaccination for both low pathogenic and highly pathogenic forms of AI protects against clinical signs and mortality, reduces virus shedding, and increases resistance to infection (Capua *et al.,* 2004). Capua and Marangon (2004) point out that the use of vaccination by itself is not going to eradicate AI. Much more is involved, because one must be able to differentiate vaccinated from infected animals. In 2003 a method, Differentiating Infected from Vaccinated Animals (DIVA), was reported in Italy and was used in the regional effort to eradicate highly pathogenic AI (Capua *et al.,* 2003). In Italy, where DIVA is widely credited for the eradication of AI, not only was vaccination used, but a territorial strategy was used in which biosecurity was upgraded, increased monitoring of vaccine efficacy was instituted, increased laboratory testing, more vigorous slaughter/controlled marketing of infected flocks, and financial compensation to farmers were instituted as well.

Capua and Marangon (2004) emphasise that in Asian countries where it is possible to implement an AI vaccination/DIVA plan such as that used in Italy, it might be possible to eradicate AI H5N1 before it becomes even more widespread. Some of the affected countries in Asia have not been able to develop such a plan and implement it, which suggests that the weakened plan would not be effective, leading to an endemic condition with highly pathogenic AI in poultry flocks in those countries. This then leaves upgrading biosecurity, use of an aggressive vaccination program coupled with depopulation of infected farms followed by disinfection and some down time. The use of AI vaccination without DIVA is a problem because the vaccine virus in products might preclude their export to many other countries. Since it is possible to differentiate between vaccine virus and infective virus (Capua *et al.*, 2003), the prospect of continued export trade becomes a distinct possibility, but all trading partners must reach a political/veterinary health agreement on the export/import of poultry that have been vaccinated. This lessens the prospect for lost revenue due to AI infections in poultry if trading partners have equivalent AI management and control programs.

11. A nutritional deficiency to exacerbate the avian influenza problem?

There are more than 13,000 scientific studies demonstrating increased susceptibility to infection in association with malnourishment in both lower vertebrate animals and humans, and a thorough review would be too extensive and complex for this paper. Most of those studies have focused on poor diets and how the host immune system had been negatively affected. In comparison, little is known about how the malnourished host may affect a virus and how that virus then interacts with the host. There is one ultramicro trace element, selenium, that seems to play a major role in the infections due to RNA viruses (Combs, 2001; Field *et al.*, 2002; Lyons *et al.*, 2003; Beck *et al.*, 2004). Research into the influence of malnutrition on host-viral interactions was initiated by Melinda A. Beck and colleagues at the University of North Carolina when she discovered the emergence of new viral variants in a Se-deficient model (Beck *et al.*, 1994, 1995, 1998, 2003). Their observations revealed that selenium deficiency also affected the activity of infectious microorganisms invading the malnourished individuals. In Beck's research, the scientists found that mice deficient in selenium were more susceptible to coxsackievirus B3. Those mice infected with a normally harmless strain of coxsackievirus developed myocarditis because in the Se-deficient mice, the avirulent virus had mutated to a virulent form. The re-isolated virus was then shown to be virulent by inducing myocarditis in normal mice. GSH-Px knockout mice also developed myocarditis after being infected with a normally harmless viral strain, indicating that the antioxidant selenoenzyme GSH-Px-1 was critical in the normal, successful battle against viral infection. The researchers sequenced viral samples isolated from Se-deficient mice and found mutations in the viral genome of the coxsackievirus that indicated increased virulence. The nutritional status of an individual is important not only for ensuring an optimal response of the immune system to an invading virus, but also in preventing viral mutations that can lead to increased pathogenicity of the virus itself.

Following Beck's pioneering work, numerous other studies have revealed similar relationships involving host selenium deficiency and virulence of RNA viruses. Selenium is very important in the maintenance of health status in HIV-infected patients (Foster, 2003). It has been reported that selenium inhibits HIV replication (Look *et al.,* 1997) and reactivation by hydrogen peroxide (Sappey *et al.,* 1994). Selenium also plays a protective role in patients with hepatitis B and C infections by preventing progression to cirrhosis and liver cancer (Yu *et al.,* 1997; 1999). Measles virus-infected children given a 12 month nutritional supplement with selenium had significantly lower incidences of diarrhea, fever, and acute lower respiratory infection (Juyal *et al.*, 2004). Additionally, Broome *et al.* (2004) reported that patients given a live attenuated polio vaccine along with selenium supplementation had improved immune function and stopped shedding the polio vaccine virus more quickly, and higher rates of selenium supplementation (100 μg/day) was better than a lower rate (50 μg/day) of supplementation.

While the viruses mentioned above are important in the health status of people around the world, they do not necessarily represent risks for global pandemic infections in humans and animals alike. However, the work done with those viruses, which show the importance of selenium status in the host and how that status can affect virulence of the virus, is extremely important to the problem of influenza, especially today with AI H5N1 threatening to expand worldwide. Again, Beck and colleagues have demonstrated that even influenza virus is influenced by host selenium status (Beck *et al.,* 2001; Nelson *et al.,* 2001; Beck *et al.,* 2004). Using the low pathogenic influenza A/Bangkok/1/79 (H3N2) virus strain that produces a mild pneumatitis in mice, Beck *et al.* (2001) found much more severe pathology in Se-deficient mice than in mice fed a Se-adequate diet. Part of the increased level of pathology was due to increased proinflammatory cytokine and proinflammatory chemokine production in lungs of Se-deficient mice. Additional studies by Beck *et al.* (2001) revealed that influenza virus re-isolated from Se-deficient mice, when passed back to Se-adequate mice, caused those mice to develop much more severe pathology than in the Se-adequate mice challenged with virus re-isolated from selenium adequate mice.

The fact that Se-deficient mice developed more severe pathology than Se-adequate mice prompted investigation as to whether genomic change in the influenza virus in the Se-deficient mice. Beck and colleagues sequenced influenza A/Bangkok/1/79 RNA segments encoding for hemagglutinin (HA), neuraminidase (NA), and the matrix protein gene (M1), which are known virulence factors, from virus isolated from both Se-adequate and Se-deficient mice (Nelson *et al.,* 2001). The increased virulence in the Se-deficient mice was due to mutations in the influenza virus genome, which resulted in a more virulent genotype. Most of the mutations occurred in the gene for the M1 protein. A total of 29 different nucleotide changes were observed, and these changes were identical in three separate isolates taken from three separate Se-deficient mice. One to three mutations were seen in the genes encoding HA and NA in the Se-deficient mice. Once these mutations occur, selenium adequate hosts become susceptible to the new virulent variants of the influenza virus. Thus, poor selenium status might contribute to the emergence of new virus strains such as H5N1.

12. Conclusion

The veterinary and human medical workers involved in the worldwide efforts to prevent an AI H5N1 pandemic are doing a very difficult job with multitudinous obstacles before them. The media has portrayed AI H5N1 as a killer of immense proportions and has created fear that has had far-reaching consequences. Even though more than 50% of the people infected with highly pathogenic AI H5N1 have died, potential exposures to the virus have yielded less than 200 human cases. It is apparent that H5N1 must have certain requirements met before it is capable of infecting and causing illness in humans. Based on reports from around the world, it would appear that AI H5N1 is not the best candidate for creating the next global influenza pandemic. However, involvement of AI H5N1 in the generation of another virus, via antigenic shift, that can easily pass from birds to humans and then from human to human is highly probable. Therefore, it is imperative that control and management programs are put into place and that every flock known to be infected with highly pathogenic AI H5N1 be destroyed. Vaccination strategies against AI must be developed and development of DIVA programs for monitoring the progress of the vaccination/disease outbreaks must be made mandatory for all domestic poultry species in affected areas. Without these types of programs that ultimately lead to eradication of highly pathogenic AI virus in domestic poultry, the probability for a global influenza pandemic will continue to increase. Control and eradication of AI H5N1 and other highly pathogenic influenza viruses is not the problem of a single country, but must become the mandate of all countries, especially in Southeast Asia. Highly coordinated control and eradication measures and even vaccination programs for AI in poultry must be implemented. More importantly, control of movement of infected birds within and between countries that are affected by the AI H5N1 virus must be strictly regulated.

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Meeting the demands of the consumer today and tomorrow: trends and lifestyles - with particular reference to food related lifestyles in Britain

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1. Introduction

New product development (NPD) is crucial to the long-term survival and profitability of food manufacturers. Consumers and markets change and companies need to proactively develop new products to satisfy these changing needs of the consumer. In a food and drink industry characterised by low overall volume growth, increasing consolidation and competition, efficient NPD is essential to gaining competitive advantage. For NPD to be efficient, consumer research is essential and should be carried out at the initial stage (idea generation stage) of the NPD process, to ensure that products are developed with the consumer foremost in mind.

Consumer research is an integral part of the marketing research process as it yields information about the motives and needs of different classes of consumers. Such information is essential in segmenting the market into groups with distinct characteristics. Market segmentation provides a better understanding of the market enables behaviour to be predicted with greater accuracy, and allows potential market opportunities to be identified and exploited. Furthermore, it provides the necessary information on which to arrange all other marketing strategies, including product development, pricing decisions and communication.

Traditional methods of segmentation, such as those based on demographics, are becoming less practical in the analysis and prediction of consumer behaviour. Consumer lifestyles, which are seen as a more multi-dimensional basis for explaining behaviour, are increasingly being used by marketers today. One instrument that was specifically designed to segment food markets is the food-related lifestyle (FRL) instrument. The FRL was developed in the early 1990's by the MAPP Centre in Denmark. It is a cross-culturally valid instrument that measures consumers' attitudes towards the purchase, preparation, and consumption of food products.

This particular study provides a brief background to the FRL instrument, highlighting the five life domains forming the basis of the model. The instrument was applied to the British food market, with the view to segmenting it into groups with distinct food-related lifestyles. The British market was chosen, as it is the largest export market for Irish food manufacturers. One thousand consumers, representing the main food shopper in the household, were interviewed in late 2002. Six segments with distinct lifestyles were identified: the snacking (20%), the careless (14%), the uninvolved (14%), the rational (26%), the adventurous (17%) and the conservative food consumers (9%). The attitudes and behaviour of each segment towards the purchasing, preparation and consumption of food products are discussed, as is the convenience orientation of each group. However, prior to discussing the respective segments, a general profile of those surveyed is presented.

In addition to the above, the FRL was adapted to specifically segment the convenience food market. Four consumer groups were identified and a profile of each segment was drawn up.

2. Food related lifestyle instrument

The food-related lifestyle (FRL) instrument is a measurement instrument that collects consumer information on attitudes and behaviour relating to the purchase, preparation and consumption of food products. The information gathered provides a greater awareness of the market, enabling it to be segmented into a number of distinct groups that can be targeted independently. While the FRL instrument forms the core of this study, other information was collected in relation to consumers' attitudes towards convenience food and their demographic details. Such information complements that from the FRL and provides a greater insight into each consumer segment.

The FRL instrument is essentially made up of five main sections or domains:

- *Ways of shopping:* Ways of shopping reflects consumers' shopping behaviour for food with regard to whether their decision-making is characterised by impulse buying or by extensive deliberation, their tendency to read labels, their reliance on the advice of others, their views towards one-stop shopping and speciality food shops and their use of shopping lists whilst shopping.

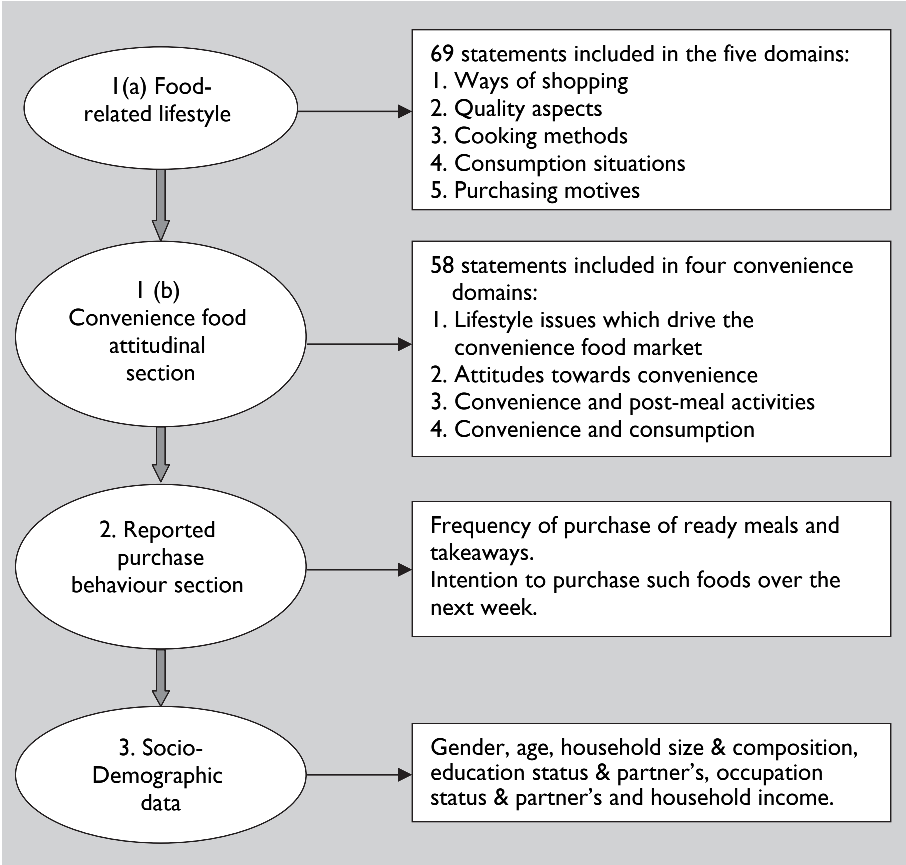

Figure 1. Outline of questionnaire.

- *Cooking methods:* Cooking methods examines how products purchased are transformed into meals, the amount of time to do this and the extent to which the meal is planned. It investigates whether it is a social activity, or one characterised by family division of labour or if it is simply a woman's task.
- *Quality aspects:* Quality aspects refer to attitudes towards health, nutrition, freshness and the luxury attributes of a product.
- *Purchasing motives:* Purchasing motives explores what consumers expect from a meal and the importance of these expectations. It also addresses its importance with regards to social aspects, tradition and security.

- *Consumption situations:* Consumption situations refer to where the meal takes place, and whether the meal is thought of differently when eaten alone or with family or friends.

The FRL instrument contains sixty nine statements that measure twenty three lifestyle dimensions within the five domains described above (Appendix I). Each statement is answered on a seven-point scale ranging from (1) "completely disagree" to (7) "completely agree".

In order to capture the convenience orientation of respondents, additional statements pertaining to one's attitudes towards convenience foods and convenient lifestyles were included. This section includes four elements, within which there are sixteen dimensions. Each dimension contains between two and four statements. A total of fifty-eight statements were included in the questionnaire (Appendix II). Although discussed and illustrated separately, these two sections were presented as one in the actual questionnaire.

The second section concentrated on the frequency of consumption of ready meals and takeaways in addition to one's intention to consume such foods over the next week. The final section was dedicated to obtaining the respondent's socio-demographic details.

3. Results

3.1. Profile of British consumers

Prior to segmenting the market, a general profile of British consumers based on their food-related lifestyles, their attitudes towards convenience and convenience food and their reported behaviour was drawn up. The profile was developed using frequency tests and is presented below under the aforementioned headings. The demographic details of the sample are included in Appendix III.

3.1.1. Food-related lifestyle of British consumers

Ways of shopping: Product information appears to be widely used by the respondents when shopping for food. Over 65% of respondents state that it is important to know what the product contains. Despite this, product information is not widely used when comparing one product with another. Many of the respondents claim that they are not influenced by advertisements, although they are persuaded by what other people say about a product (43%). Many of the consumers do not enjoy shopping for food. Over 55% of them claim that food shopping holds no interest for them. This is also the case with regard to speciality food shops. Sixty three per cent do not see any need for expert advice and 44% do not see any reason to shop in speciality food shops. British consumers typically make a list before they go food shopping, although many admit that they invariably buy more than they had planned. Generally, British consumers appear to be price conscious – over 60% of the consumers interviewed agreed that they notice when products they purchase on a frequent basis change in price.

Cooking methods: The majority of those interviewed (60%) are interested in cooking. Almost half are adamant that cooking is not just something to get over and done with. Their degree of interest in cooking is further emphasised by their interest in seeking out new methods of cooking. Sixty three per cent indicate that they like to try new recipes and over 40% say that they look out for new recipes and ideas. As to whether cooking should be quick and easy, a majority of consumers (63%) say that they neither use frozen food, ready-to-eat foods or different types of instant food. A majority (63%) are also inclined to disagree that the woman is responsible for food shopping, cooking and the health of the family. Sixty per cent do not consider the kitchen to be the woman's domain. The importance attached to the whole family participating in meal preparation and cooking activities appears to be split (47% agree, 44% disagree). Over half of the sample stated that meals are not planned. This is confirmed by almost 46% of respondents who agree that decisions about meals are often spontaneous. However, almost 54% indicate that plan what they are going to eat in advance (Appendix I).

Purchasing motives: Self-fulfilment through food appears to play an important role in the lives of a majority (66%) of the consumers interviewed. Being complimented for their cooking is important to many of them (66%). The respondents appear confident about their cooking skills – 49% regard themselves as excellent cooks. Food as a means of security is important to 42% of the consumers, while being unimportant to 46% of consumers. A majority (64%) indicate that meals are important in the context of their social lives (Appendix I).

Quality aspects: The health aspect of food is very important to the majority of consumers, with 64% stating that the naturalness of food influences their food choice. There is little doubt that the price/quality relation, health and freshness are important quality attributes. Eighty-eight per cent say that it is important to feel that you are getting value for money; 86% agree that taste is important to them when eating; and, 82% agree that freshness is important. Organic products are not very popular among consumers – 72% do not purchase them, even when they are available and 69% are not willing to pay more for organic products. The majority (57%) of respondents are interested in novel aspects of foods. Fifty four per cent like to try recipes from other countries and 62% like to try new food products (Appendix I).

Consumption situations: The majority (76%) of respondents do not snack instead of eating regular meals. A minority (18%) eat before they get hungry and 71% stated that snacks have not replaced fixed meals. Half the sample population do not eat out regularly, although many respondents enjoy eating out with family and friends. Forty-eight per cent of the sample does not have friends around for a meal on a regular basis (Appendix I).

3.1.2. Attitudes towards convenience and convenience food

As stated previously, consumers were presented with a number of statements in relation to their attitudes towards convenience and convenience foods. Responses to such statements are discussed below.

Drivers of demand for convenience: Almost half of the respondents feel that they are time pressured to some extent. Most consumers do not believe that they are stressed – over 65% disagreed that they do not feel in control of their own lives. A majority of consumers do not believe that there has been a breakdown of mealtime structures in their households, although 52% of the sample population often watch television while eating their meals. Half the sample is in agreement that they do not enjoy cooking for themselves alone. Thirty-one percent of respondents believe that there is at least one person in his/her family who often needs a separately prepared meal. Saving time while shopping for food is important to 46% of respondents, with 54% conducting their food purchasing as quickly as possible. Meal preparation appears to be an activity that is enjoyed by a majority (64%) of consumers, with 47% admitting that they like spending time in the kitchen preparing meals. Sixty-eight per cent of consumers appear to be confident about their culinary skills, with only 17% resorting to meals that have been prepared by someone else, simply because they are unable to do so themselves (Appendix II (a)).

Attitudes towards convenience food: Convenience food products are not perceived by the sample population to offer good value for money, with 56% believing that they are over-priced. Nor are convenience foods thought to be healthy – 43% do not think that convenience foods are nutritious. However, 57% of the British consumers interviewed believe that convenience foods save time, thus allowing them more time to relax and to engage in other activities. Despite this, 68% of consumers do not feel involved with convenience food products – 64% admit that convenience food consumption does not bring pleasure into their lives and 46% disagree that convenience foods are of importance to them (Appendix II (a)).

Convenience and post-meal activities: Convenience while clearing up after a meal is unimportant to a majority (76%) of consumers. Likewise, convenience foods do not appear to be important to 69% of consumers for the function of saving on ingredients' disposal while preparing a meal (Appendix II (a)).

Convenience and consumption: The sample of consumers interviewed does not appear to have a tendency towards the use of convenience products during the week or at the weekend. Forty-eight per cent and 43% of respondents do not choose convenience foods for their weekday or weekend meals respectively. Likewise, these consumers do not appear to have a propensity towards the utilisation of labour-saving equipment in meal preparation. For example, 56% do not use a microwave to cook their evening meal during the week on a normal basis (Appendix II (a)).

3.1.3. Reported behaviour regarding convenience foods

Eating out is an activity enjoyed by many of the consumers interviewed. Sixty per cent of respondents go out for a meal occasionally. Buying a takeaway meal to eat away from home is not a very frequent activity for many with over 50% of respondents claiming that they infrequently or never purchase a takeaway meal to eat away from home. However, buying a takeaway to consume at home proved to be more a popular choice with 75% claiming to do so frequently or occasionally. Cooking a meal from ingredients is an activity that is undertaken frequently by the majority of respondents (82%). Thirty-eight per cent of consumers frequently consume ready meals. Frozen, chilled and dried ready meals are popular choices among consumers. They are frequently purchased by over 40% of consumers (Table 1).

Table 1. Reported behaviour frequencies (%) for the sample[1].

	Frequently	Occasionally	Infrequently/ never
Go out for a meal	14	60	26
Buy a takeaway meal to eat away from home	14	36	51
Buy a takeaway meal to eat at home	25	50	25
Cook a meal from ingredients	82	12	6
Do not eat a 'proper' meal, just snack	29	24	47
Eat ready meals	38	34	27
Ready meal form			
Purchase frozen ready meals	42	40	18
Purchase chilled ready meals	41	37	22
Purchase canned ready meals	32	33	34
Purchase dried ready meals	44	36	20
Ready meal type			
Purchase ethnic ready meals	21	46	33
Purchase healthy ready meals	11	25	64
Purchase traditional ready meals	22	29	49
Purchase vegetarian/meat free ready meals	7	17	75
Purchase organic ready meals	3	10	87
Purchase fish-based ready meals	13	35	52
Purchase pizzas	30	47	24

[1]The reported behaviour statements were measured on a 1–7 scale in the questionnaire, where 1=everyday or almost everyday and 7=never. The numbers 1–3 were recoded to 'frequently', 4–5 to 'occasionally', and 6–7 to 'infrequently or never'.

The samples interest in seeking out new methods of cooking and in novel food products is highlighted by the fact that ethnic ready meals are purchased by 67% of consumers on a frequent or occasional basis, whereas almost half of the respondents infrequently or never purchase traditional ready meals.

The sample as a whole appears interested in the health aspects of food products. However, many respondents believe that convenience foods are not healthy. This is highlighted by the fact that only 11% of the customers claim to frequently purchase healthy ready meals. Seventy five per cent of respondents infrequently or never purchase vegetarian/meat free ready meals. The sample's general lack of interest in organic foods is further highlighted by the fact that 87% of respondents claim that they infrequently or never purchase organic ready meals. Almost half of the respondents purchase fish-based ready meals frequently or occasionally. Pizzas appear to be a popular choice among the sample of customers with over three-quarters purchasing them on a frequent or occasional basis (Table 1).

3.2. Food-related lifestyle segments

Six segments with distinct food-related lifestyles were identified and labelled the snacking food consumer (20% of consumers), the careless food consumer (14%), the uninvolved food consumer (14%), the rational food consumer (26%), the adventurous food consumer (17%) and the conservative food consumer (9%) (Figure 2). The former three, the snacking, careless and the uninvolved were identified as convenience seeking segments. Each of the six segments was named on the basis of the interpretation of their pattern of scores on the FRL dimensions, as well as comparisons with segments identified in previous FRL studies. Further profiling was carried out on the segments based on their attitudes towards convenience and convenience food, their reported behaviour and demographic characteristics.

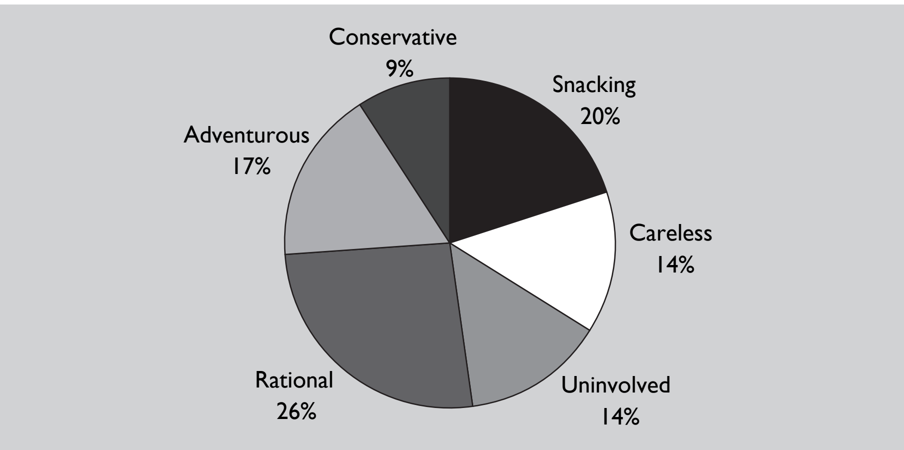

Figure 2. Percentage (%) of respondents within each segmnent.

3.2.1. The snacking food consumers

As their name suggests, the snacking food consumers (20%) are more likely to snack compared with the other segments. Of all segments identified, the snacking food consumers place the greatest emphasis on products that entail quick and easy cooking. These consumers indicate a preference for shopping in speciality food stores and for purchasing organically produced foods to a greater extent than most of the other segments. They attach less importance to the social interaction associated with food and gaining self-fulfilment than other segments. These consumers are the least interested in getting value for money. In addition, they have a below average interest in new food products. Furthermore, the taste and freshness aspects of a food product matter less to this segment than to any other segment (Appendix IV (a)).

The snacking consumers exhibit the highest stress levels of all the segments (Appendix IV (b)). Compared to some of the other groups, meal preparation is enjoyed less by these consumers and they feel less confident about their cooking abilities. Time and energy saving with respect to post-meal clearing up is more important to this group than to any of the other groups. Furthermore, convenience foods are bought more frequently by these consumers than any other segment, as a means to coping with ingredient wastage. Thus, these consumers feel the highest level of involvement with convenience foods. They are more likely than consumers from any other segment to perceive such foods as healthy.

The snacking food consumers are more likely than some of the other groups to believe that ready meals are good value for money and that takeaway meals are worth the extra cost (Appendix IV (c)). However, compared to the other segments, these consumers are the least likely to think that ready meals are a good backup to have in the home, that takeaway meals are an opportune last minute solution and that takeaway meals are convenient.

Snacking food consumers purchase many convenience food products (Appendix IV (e)). They are ranked in first place for most of the convenience behaviours investigated (Appendix IV (d)). They are ranked joint first for eating out and for consumption of ready meals. They are ranked first for purchasing takeaway meals to eat both at home and away from home and they are ranked first for snacking instead of eating 'proper' meals. Consistent with these findings, they are ranked fifth for cooking a meal from ingredients (Appendix IV (d)).

The snacking food segment is more likely to have a greater proportion of younger males, to live in larger households, with a partner/spouse and not to have young children. Furthermore, they are less likely to be well-educated and more likely to work less than fifteen hours per week or be unemployed. Consistent with this, these individuals are more likely to fit in the C2 and DE social groups and earn lower levels of income (Appendix IV (f)).

3.2.2. The careless food consumers

The careless food consumers attribute less importance to food as an approach to the achievement of the their life values than most other segments. They are the least interested in shopping and in the information provided through advertising. They are less concerned about product information than some of the other groups and use speciality food stores less frequently. They are the least likely of all the segments to plan their food shopping in advance. Compared to most of the other groups, they have a below average interest in cooking and meal preparation, meal planning occurs to a lesser extent, and their belief that cooking is the sole responsibility of the woman in the household is less than for some of the other groups. Self-fulfilment through food and security mean less to this group. They express a higher than average interest in new food products and they are less interested in organic foods (Appendix IV (a)).

The careless food consumers experience the highest level of time pressures in their lives and they have the greatest desire to spend as little time as possible on food shopping. These consumers, along with the uninvolved, perceive ready meals as a good backup to have in the home. They believe that takeaway meals are worth the extra cost and they believe, more than any other group, that takeaway meals are a good last minute meal solution (Appendix IV (b)).

The careless food consumers are frequent purchasers of convenience foods (Appendix IV (e)). They are ranked as the second highest group who purchase takeaway meals to consume away from home and the third highest who buy takeaway meals to eat at home. They were ranked in third position for snacking instead of eating 'proper' meals and also for consumption of ready meals (Appendix IV (d)).

The careless food consumers are more likely to be young or middle-aged, living in larger households and are more likely to have young children (Appendix IV (f)). Moreover, they are likely to be working full-time or housewives and earn modest levels of income.

3.2.3. The uninvolved food consumers

The uninvolved food consumers are characterised by their lack of interest in food and food-related activities. Compared to all other segments, these consumers are the least interested in product information, use speciality shops the least and are the least concerned about price (Appendix IV (a)). Compared to some of the other segments, they gain less enjoyment from food shopping, they use shopping lists less and advertising has less of an influence on the food purchase decision. The low involvement level of these consumers is further emphasised by the fact that they are the least interested in cooking. Of all the segments, they are the least likely to seek innovation and challenge when cooking, and they tend to be less interested in novel food products. Their neophobic tendencies are further emphasised by the lower importance that they place on security through tradition as a purchasing motive compared to some of the other segments. Meal planning takes place to the least extent amongst these consumers. Self-fulfilment through food and the development of social relationships are of less importance as purchasing motives than for any other group. They have a below average interest in eating out and with friends. They attach less importance to the quality aspects of food; they are more indifferent to the price/quality, taste and freshness dimensions. Furthermore, they are the least interested in the health and organic attributes of a food.

Compared to the other segments identified, the uninvolved food consumers find it most difficult to have family meals together (Appendix IV (b)). They have the highest tendency to eat alone and demonstrate the most individualistic eating habits. Saving time while shopping for food is more important than for most other groups and meal preparation activities are enjoyed the least by these individuals. They are the least confident in their culinary abilities and thus turn to convenience foods as a meal solution. They have above average interest in saving on the disposal of waste ingredients by purchasing convenience foods.

Convenience foods offer value for money to the uninvolved consumer more than any other segment and convenience in terms of saving time is more important than for any other group (Appendix IV (c)). Compared to most of the other groups, convenience foods are very important to them. They believe to the greatest extent that ready meals offer value for money, that ready meals are good backup to have in the home and that ready meals are convenient. Furthermore, consumers in this group are more likely to believe that takeaway meals are convenient and that they are worth the extra cost.

The uninvolved food consumer segment are ranked joint first for consumption of ready meals (Appendix IV (d)). They are ranked second for buying a takeaway meal to eat away from home and for snacking instead of eating 'proper' meals. They are ranked fourth for going out for a meal and joint fourth for buying a takeaway meal to eat at home.

The uninvolved food consumer segment is more likely to have a greater proportion of younger males than other segments, to live in smaller households and are less likely to have a partner. They tend to be less well educated, working full-time and in the DE social bracket (Appendix IV (f)).

3.2.4. The rational food consumers

Food and food products play an important role in the life of the rational food consumer. They have above average interest in product information and advertising plays a greater role in influencing the food purchase decision of these consumers more than any other segment (Appendix IV (a)). These consumers gain the most enjoyment from shopping for food. They are the most price conscious and acquiring quality food for their money is more important than for some of the other groups. They plan meals and food shopping to the greatest extent. They have above average interest in cooking. In particular, they are interested in pursuing new ways of cooking and they are attracted to new food products. Self-fulfilment through food is more important to these consumers than for any other group and the development of social relationships is more important than for most of the other groups. Quality food products are more important to these consumers; the health, freshness and taste attributes of a product are more important than for most other segments.

The rational food consumers enjoy meal preparation and thus do not generally tend to be convenience oriented towards this activity (Appendix IV (b)). However, they do have a more positive view of takeaway meals as a good last minute meal solution (Appendix IV (c)). The rational food consumers are ranked second for cooking a meal from ingredients. They are ranked fourth for buying a takeaway meal to eat at home and joint fourth for purchasing a takeaway meal to eat away from home and for snacking instead of eating a 'proper' meal. They are ranked fourth for consumption of ready meals (Appendix IV (d)).

The rational food consumers tend to be represented by individuals who are middle-aged or older and who are more likely to live with a partner or spouse in larger households. They are more likely to be retired and in the C2 social band (Appendix IV (f)).

3.2.5. The adventurous food consumers

Food has an important place in the life of the adventurous food consumer. These consumers have the greatest interest in product information and they shop in speciality food stores the most frequently. Advertising has less of an influence on these consumers than for some of the other segments. They are the most interested in cooking and are the least concerned about convenience foods. They are the most enthusiastic about seeking out new ways in meal preparation and cooking and express the highest interest in the novel aspects of food products. Similarly, security through familiar eating patterns is less important to these consumers than to any of the other groups. These consumers have the strongest belief that cooking should be a family affair and not solely the responsibility of the woman. They have above average interest in self-fulfilment through food and the development of social relationships is more important than to any other group. These consumers are very interested in the quality attributes of foods. They express the highest interest in health, taste, freshness and foods that have been organically produced. Furthermore, compared to most other segments, they expect quality for the money that they spend on food. The degree of snacking between meals is lowest for this segment. Eating out and eating with friends is considered more important than for any other group (Appendix IV (a)).

Of all the segments the adventurous food consumers are the least likely to feel time pressured or stressed (Appendix IV (b)). More than any other group, meals tend to be consumed with other family members rather than alone. They spend the longest time shopping for food and they enjoy meal preparation more than any other segment. They are the most confident in their culinary abilities. A higher proportion of this group than any other group cook a meal from ingredients (Appendix IV (e)). The adventurous food consumers do not tend to have a positive perception about convenience foods. These consumers thus do not feel involved with convenience foods. They are the least likely to believe that convenience foods offer value for money, that convenience foods are healthy and that convenience foods represent a time saving for the consumer. Furthermore, they are the least likely to believe that ready meals offer value for money or that they are convenient. They are less likely to think that ready meals are good backup to have in the home and that takeaway meals are worth the extra cost. The adventurous consumers are ranked in sixth position for both consumption of ready meals and snacking instead of eating a ‘proper’ meal (Appendix IV (d)). They are ranked first for cooking a meal from ingredients. They are ranked joint fifth for purchasing a takeaway meal to eat away from home and fifth for consuming a takeaway meal at home.

Demographically, consumers in the adventurous segment are more likely to be middle-aged and living with a spouse or partner. They are more likely to have reached a high standard of education, be working full-time, be distributed among the A, B and C1 social groups and have high-income levels (Appendix IV (f)).

3.2.6. The conservative food consumers

The conservative food consumers are quite traditional in their attitudes towards cooking and shopping. They are less interested in shopping for food and shopping in speciality food stores (Appendix IV (a)). They are more price conscious than some of the other segments and getting value for money is more important to these consumers than for any other segment. Cooking is enjoyed less and convenience foods are less widely purchased. Familiarity is important as they prefer to use well-known recipes when cooking, they are the least interested in novel food products and security is more important as a purchasing motive than for any other segment. Helping out in the kitchen is not thought of as a family duty, but rather these consumers view cooking and shopping as the sole responsibility of the woman to the greatest extent. The development of social relationships is less important to these consumers. They are less interested in organic foods and they attach more importance to freshness. Snacking occurs to a lesser extent among the conservative consumers and eating out and with friends is less important than for any other group (Appendix IV (a)).

The conservative food consumers have a low level of involvement with convenience foods and saving time and effort when clearing up after a meal is less important to these consumers (Appendix IV (b)). They are the least likely to perceive takeaway meals to be worth the extra cost (Appendix IV (c)). Consistent with these findings, the conservative consumers are ranked joint fifth for purchasing a takeaway meal to eat away from home and sixth for buying a takeaway meal to eat at home. Furthermore, they are ranked fifth for consumption of ready meals and third for cooking a meal from ingredients (Appendix IV (d)).

The conservative segment contains a greater proportion of older females, they are more likely to live in smaller households and are less likely to have young children. They are less likely to have reached a high standard of education, they are more likely to be retired or housewives, earning low incomes and are more likely to be in the DE social group ((Appendix IV (f)).

4. Discussion and conclusions

This study provides an insight into the lifestyles of food consumers in Great Britain. The study identified the drivers of the demand for convenience food and developed a series of dimensions based on these drivers. Consumers were segmented using the food-related lifestyle instrument. Further profiling of these segments was conducted based on attitudes towards and behaviour with respect to convenience food, highlighting three segments that were particularly convenience oriented, namely the snacking food consumers, the careless food consumers and the uninvolved food consumers. The rational food consumers, the adventurous food consumers and the conservative food consumers were less convenience-oriented in their attitudes and behaviours and more concerned with the quality attributes of foods, including health, taste and freshness. Information of this nature is an essential component of the NPD process and should be carried out at the initial stage (idea generation stage) to ensure that products are tailored to meet the specific needs of the target market. Some implications for the food industry, in particular for the convenience food manufacturing sector are outlined below.

Eating between mealtimes is firmly instilled in the consumption habits of the snacking food consumer. For this segment, snacking represents an important consumption occasion; these consumers are eating more frequent, smaller meals. Promoting quick and easy, yet substantial non-main meals should be the main priority if targeting this segment. The interest of these consumers in organic food also presents an opportunity for the development of organic snack foods. This segment also has low price sensitivity, thus enabling a price premium to be charged. Approaches likely to reflect positively on the success of a product include portraying a stress-free experience regarding meal preparation and clearing up.

The careless food consumer attaches limited importance to food. These consumers are generally enticed by new food products, as long as they do not require a greater amount of labour or new cooking competencies. Manufacturers who develop new foods regularly will reap the benefits of targeting this segment.

The uninvolved food consumer is indifferent to virtually all aspects of food, with the exception of security through familiar eating patterns. Convenience is important to these consumers; thus promoting time saving and convenience of preparation should be a priority.

Quality food products are important to the rational food consumer. Promotion of products to this group should reflect on the health, taste and freshness attributes of the products. Acquiring value for money is very important and food marketers should also focus on the deliverance of new food products.

The adventurous food consumer is very involved with food. Promotion of products to this group should focus on meal preparation as a creative and social process, as well as highlighting the quality attributes of the products.

The conservative consumers are very traditional in their attitudes towards food; they do not like change and security is a strong purchasing motive. Foods that are fresh and offer quality for money are of interest to this group.

The extent to which convenience foods can be made more attractive to the latter three segments is uncertain. Development of products that encompass the important quality attributes as well as convenience may provide a market opportunity.

By assessing the differences in attitudes and reported behaviour towards convenience foods between the FRL segments, information is provided to food manufacturers which would prove helpful since it provides an understanding of what motivates consumers to purchase convenience food products. In this study, three of the food-related lifestyle segments were identified as particularly convenience-oriented in their attitudes and these segments were also the highest purchasers of convenience products. These segments were the snacking, careless and uninvolved consumers and they represented 48 percent of the sample. Furthermore, inspection of segment sizes shows that British consumers have become more convenience oriented in their attitudes to food. The careless and uninvolved segments combined represented 36 percent of consumers in 1994. The proportion of convenience oriented consumers was 48 percent in 2002. Furthermore, the proportions of rational and conservative consumers has declined over the eight year period, while the size of the adventurous segment has increased, indicating that consumers have become less traditional in their food habits.

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Appendix I. Frequencies (%) of the FRL dimensions and statements

Ways of shopping	**Disagree overall**	Completely disagree 1	2	<--- 3	Neutral 4	---> 5	6	Completely agree 7	**Agree overall**
Importance of product information*	**37**				**8**				**55**
To me product information is of high importance. I need to know what the food product contains	**16.1**	3.6	4.4	8.1	18.6	18.1	15.4	31.8	**65.3**
I compare product information labels to decided which brand to buy	**41.3**	15.4	12.2	13.7	20.4	15.8	12.6	9.8	**38.2**
I compare labels to select the most nutritious food	**38.6**	12.3	12.0	14.3	23.3	18.5	11.0	8.5	**38.0**
Attitudes towards advertising	**54**				**12**				**34**
I have more confidence in products that I have seen advertised than in unadvertised products.	**49.8**	20.6	11.8	17.4	27.6	11.7	6.9	4.1	**22.7**
I am influenced by what people say about a food product	**31.9**	9.6	8.4	13.9	25.2	23.3	12.1	7.5	**42.9**
Information from advertising helps me to make better buying decisions	**43.3**	12.8	11.3	19.2	28.4	17.2	6.9	4.1	**28.2**
Enjoyment from shopping	**50**				**10**				**40**
Shopping for food does not interest me at all	**56.9**	24.3	18.8	13.8	18.3	11.3	7.0	6.4	**24.7**
Shopping for food is like a game to me	**62.8**	28.8	19.3	14.7	20.8	8.5	4.8	3.2	**16.5**
I just love shopping for food	**43.4**	15.3	12.8	15.3	20.7	17.7	10.7	7.7	**36.1**

* These percentages for this and the other the dimension are based on a measurement scale ranging from 3 to 21, derived as follows. The summary percentages for each dimension are derived from addition of the scores for each of the 3 statements comprising that dimension. Thus while the scale for each statement is from 1 to 7, the scale for the dimension ranges from a minimum 3 (where a person scored 1 for each of the 3 statements) to a maximum of 21 (a score of 7 for each statement). Scores from 3 to 11 are shown as agree, 12 is neutral and 13 to 21 are disagree. Thus the percentage for neutral will be lower for the dimension than for the individual statements.

Speciality shops	**65**				**9**				**26**
I like buying products in speciality stores where I can get expert advice	**63.2**	27.7	19.6	15.9	17.2	9.4	6.1	4.2	**19.7**
I do not see any reason to shop in speciality food stores	**35.1**	9.9	10.8	14.4	21.0	13.7	12.1	18.2	**44.0**
I like to know what I am buying so I often ask questions in stores where I shop for food	**55.3**	21.3	16.9	17.1	21.0	12.1	6.4	5.2	**23.7**
Price criteria	**32**				**8**				**60**
I notice when products I buy regularly change in price	**22.2**	6.1	5.9	10.2	15.7	18.3	20.9	23.0	**62.2**
I look for ads in the newspaper and plan to take advantage of them when I go shopping	**47.4**	20.0	13.8	13.6	17.9	13.7	9.8	11.2	**34.7**
I always check prices, even on small items	**24.4**	7.4	6.8	10.2	17.8	15.8	18.3	23.7	**57.8**
Shopping list	**40**				**10**				**50**
Usually I don't decide what to buy until I'm in the shop	**39.0**	14.0	12.3	12.7	19.8	15.6	12.6	13.2	**41.4**
Before I go shopping for food I make a list of everything I need	**33.0**	15.6	8.0	9.4	18.2	14.9	12.9	21.2	**49.0**
I make a shopping list to guide my food purchases	**36.1**	14.8	8.8	12.5	17.3	14.0	16.0	16.7	**46.7**

Appendix I. Continued.

Cooking method	**Disagree overall**	Completely disagree	<–––		Neutral	–––>		Completely agree	**Agree overall**
		1	2	3	4	5	6	7	
Interest in cooking	**30**				**10**				**60**
I don't like spending too much time on cooking	**42.6**	12.6	13.3	16.7	16.6	17.5	12.0	11.2	**40.7**
I like to have ample time in the kitchen (for cooking/preparing meals)	**17.9**	4.1	5.0	8.8	20.0	23.0	18.6	20.7	**62.3**
Cooking is a task that is best over and done with	**48.9**	14.7	15.8	18.4	21.0	13.4	7.4	9.4	**30.2**
Looking for new ways	**35**				**9**				**56**
I look for ways to prepare unusual meals	**36.3**	11.8	10.6	13.9	25.1	18.1	13.0	7.5	**38.6**
Recipes and articles on food from other culinary (cooking) traditions make me want to experiment in the kitchen	**38.9**	13.6	10.4	14.9	19.9	20.8	12.2	8.3	**41.3**
I like to try out new recipes	**17.9**	4.6	5.2	8.1	19.4	22.0	20.7	20.1	**62.8**
Convenience	**63**				**12**				**25**
We use a lot of ready-to-eat foods in our household	**51.7**	24.7	13.6	13.4	19.9	12.1	9.7	6.7	**28.5**
Frozen foods account for a large part of the food products I use in our household	**46.6**	14.3	15.1	17.2	24.8	14.4	9.0	5.4	**28.8**
I use a lot of mixes, for instance baking mixes and powder soups	**62.3**	24.7	21.2	16.4	17.0	10.6	6.7	3.4	**20.7**

Whole family	**44**				**9**				**47**
The kids or other members of the family always help in the kitchen e.g. they peel the potatoes and cut the veg	**47.4**	22.2	12.0	13.3	21.0	12.3	9.0	10.2	**31.5**
My family helps with other mealtime chores, such as setting the table and doing the dishes	**27.8**	10.4	9.7	7.7	17.0	16.0	17.7	21.6	**55.3**
When I do not really feel like cooking, I can get one of the other members of my family to do it	**39.7**	18.4	10.8	10.5	14.7	17.5	14.1	14.1	**45.7**
Planning	**51**				**10**				**38**
I always plan what we are going to eat a couple days in advance	**53.6**	26.9	13.5	13.2	19.7	10.3	8.8	7.7	**26.8**
What we are going to have for supper is very often a last minute decision	**33.4**	9.8	11.2	12.4	20.8	17.0	14.6	14.1	**45.7**
Cooking needs to be planned in advance	**29.4**	8.6	9.1	11.7	24.8	21.0	14.9	9.8	**45.7**
Woman's task	**63**				**8**				**29**
It is the woman's responsibility to keep the family healthy by serving a nutritious diet	**39.4**	20.7	9.4	9.3	15.8	15.0	12.7	17.1	**44.8**
Nowadays the responsibility for shopping & cooking ought to lie just as much with the husband as with the wife	**16.3**	4.8	3.7	7.8	16.7	14.4	16.4	36.2	**67.0**
I consider the kitchen to be the women's domain	**59.7**	34.5	11.9	13.3	15.2	10.6	7.2	7.2	**25.0**

Appendix I. Continued.

	Disagree overall	Completely disagree		<---	Neutral	--->		Completely agree	**Agree overall**
Purchasing motives		1	2	3	4	5	6	7	
Self-fulfillment in food	**24**				**9**				**66**
Being praise for my cooking adds a lot to my self-esteem	**17.0**	5.1	4.0	7.9	16.8	19.6	21.8	24.7	**66.1**
I am an excellent cook	**27.0**	7.7	7.4	11.9	24.2	22.4	17.1	9.1	**48.6**
Eating is a matter of touching, smelling, tasting and seeing, all the senses are involved. It is a very exciting sensation	**21.6**	4.1	6.0	11.5	25.1	23.1	14.5	15.8	**53.4**
Security	**46**				**12**				**42**
I only buy & eat foods which are familiar to me	**36.1**	9.6	11.2	15.3	18.0	17.7	14.9	13.3	**45.9**
I dislike anything that might change my eating habits	**55.3**	20.2	16.1	19.0	24.8	10.2	5.0	4.9	**20.1**
A familiar dish gives me a sense of security	**24.6**	8.1	6.5	10.0	27.2	21.0	14.4	12.7	**48.1**
Social relationships	**24**				**12**				**64**
Dining with friends is an important part of my social life	**43.1**	16.8	10.5	15.8	18.8	16.1	9.7	12.4	**38.2**
Over a meal one have a lovely chat	**15.9**	3.4	3.5	9.0	17.6	19.4	21.4	25.8	**66.6**
When I serve a dinner to friends, the most important thing that we are together	**16.0**	4.6	3.2	8.2	19.9	21.9	19.9	22.1	**63.9**

Quality aspects									
Health	**25**				**10**				**65**
To me the naturalness of the food I buy is an important quality	**15.1**	2.8	3.5	8.8	21.1	26.0	18.0	19.7	**63.7**
I try to avoid food products with additives	**23.2**	4.7	5.7	12.8	26.9	18.6	13.9	17.5	**50.0**
I prefer to buy natural products i.e. products without preservatives	**23.4**	6.0	5.4	12.0	24.9	22.0	15.4	14.5	**51.9**
Price/quality relationship	**8**				**4**				**88**
It is important for me to get quality for all my money	**5.5**	1.6	1.1	2.8	6.9	13.4	24.0	50.2	**87.6**
I compare prices between product variants (i.e. various brands of same product) in order to get the best value for money	**20.9**	6.3	5.4	9.2	15.9	16.6	20.2	26.5	**63.3**
I always try to get the best quality for the best price	**8.3**	0.8	1.8	5.7	11.4	19.3	26.0	35.1	**80.4**
Novelty	**32**				**11**				**57**
Well know recipes are indeed the best	**23.9**	4.9	6.6	12.4	28.5	18.9	14.6	14.0	**47.5**
I love to try recipes from foreign countries	**27.3**	10.7	7.0	9.6	18.5	16.5	17.0	20.7	**54.2**
I like to try new foods that I have never tasted before	**18.9**	5.7	4.2	9.0	19.5	20.3	21.3	20.2	**61.8**
Organic	**78**				**6**				**16**
I make a point of using organic food products	**69**	36.4	18.5	14.1	15.9	7.8	3.4	3.8	**15.0**
I always buy organically grown food products if I have the opportunity	**72**	42.2	16.3	13.5	12.7	6.8	3.9	4.7	**15.4**
I don't mind paying a premium for organic products	**68.8**	37.2	18.3	13.3	14.1	7.8	5.2	4.0	**17.0**

Appendix I. Continued.

	Disagree overall	Completely disagree		<---	Neutral	--->		Completely agree	**Agree overall**
		1	2	3	4	5	6	7	
Taste	**4**				**3**				**94**
Enjoying the taste of food products is important to me when I am eating	**5.6**	0.9	1.7	3.0	8.1	15.1	26.6	44.6	**86.3**
It is important to me to be able to eat delicious food on weekdays as well as weekends	**7.7**	1.6	2.1	4.0	14.9	20.3	25.2	31.9	**77.4**
I enjoy a good meal	**2.9**	0.7	0.5	1.7	5.9	9.7	22.8	58.7	**91.2**
Freshness	**7**				**4**				**89**
I prefer fresh products to canned or frozen products	**10.8**	2.3	2.4	6.1	14.3	15.0	19.5	40.3	**74.8**
It is important to me that food products are fresh	**7.1**	0.9	1.1	5.1	10.4	17.7	21.0	43.7	**82.4**
I prefer to buy meat and vegetables fresh rather than frozen	**9.0**	1.9	2.6	4.5	12.5	13.2	20.8	44.4	**78.4**
I prefer to buy meat and vegetables fresh rather than canned	**7.5**	1.6	1.4	4.5	12.0	13.4	21.1	46.1	**80.6**

Consumption situations									
Snacks vs. meals	**76**				**8**				**16**
I eat before I get hungry which means I am never hungry at mealtimes	**66.4**	31.5	19.7	15.2	16.0	7.6	5.8	4.2	**17.6**
In our house, nibbling has taken over and replaced set eating hours	**71.4**	35.7	20.1	15.6	12.5	8.8	3.8	3.5	**16.1**
I eat whenever I feel the slightest bit hungry	**52.4**	16.9	19.4	16.1	21.6	13.3	8.8	3.8	**25.9**
Social event	**40**				**9**				**50**
Going out for dinner is a regular part of our eating habits	**49.5**	18.6	15.1	15.8	20.3	13.6	9.0	7.7	**30.3**
I enjoy going out to dinner with my family and friends	**14.4**	3.5	4.0	6.9	16.0	14.8	20.0	34.7	**69.5**
We often get together with friends to enjoy an easy-to-cook casual dinner	**47.6**	16.1	13.8	17.7	20.0	14.8	10.1	7.7	**32.6**

Appendix II. (a) Frequencies (%) of the convenience measures and statements for the sample surveyed

	Disagree overall	Completely disagree		<---	Neutral	--->		Completely agree	**Agree overall**
Forces driving the convenience food market		1	2	3	4	5	6	7	
Time pressures	**43**				**10**				**47**
I am always looking to save time	**32.2**	8.2	8.5	15.5	26.3	18.1	10.4	12.9	**41.4**
I am often in a rush to get everything done	**34.2**	12.3	8.7	13.2	21.8	16.0	11.6	16.4	**44.0**
I am always in a rush	**42.6**	14.9	12.1	15.6	20.2	13.7	10.9	12.6	**37.2**
Stress levels	**70**				**11**				**19**
In the last month difficulties were piling up so high that I could not overcome them	**62.2**	32.0	18.3	11.9	20.7	9.3	4.4	3.3	**17.0**
Recently I have been unable to control the important things in my life	**65.6**	33.1	18.2	14.3	16.8	9.3	5.1	3.2	**17.6**
Lately things have been going my way	**24.7**	6.4	6.2	12.1	33.0	19.9	12.8	9.6	**42.3**
Breakdown of mealtimes	**56**				**10**				**34**
We often like to watch TV when eating meals	**27.7**	10.7	6.3	10.7	20.1	16.1	16.0	20.0	**52.1**
In my house family members often have their meals at separate times	**54.4**	26.6	13.9	13.9	12.8	12.7	10.7	9.4	**32.8**
It is difficult for us to have a family meal together	**61.8**	30.5	19.3	12.0	16.7	9.4	8.2	4.0	**21.6**
Eating alone	**40**				**10**				**50**
I don't usually prepare a proper meal when there's just me	**30.9**	11.0	7.8	12.1	15.6	15.5	14.6	23.5	**53.6**
I don't enjoy cooking just for myself	**34.1**	10.9	10.8	12.4	16.1	13.6	14.0	22.3	**49.9**
I snack a lot when I am at home on my own	**50.7**	21.7	16.3	12.7	17.1	13.3	10.5	8.3	**32.1**

Individuality	**49**				**7**				**44**
There is at least one person in my family who often needs a separately prepared meal	**55.4**	32.1	14.1	9.2	13.5	10.4	8.3	12.5	**31.2**
Certain members of my family have different tastes in food to the rest of the family	**35.9**	15.2	9.8	10.9	17.6	17.8	13.9	14.7	**46.4**
Certain members of my family are choosy/picky in what they eat	**35.6**	15.5	10.1	10.0	18.4	18.4	12.9	14.7	**27.6**
Time and shopping	**42**				**12**				**46**
I try to do my food shopping as quickly as possible	**23.0**	4.1	8.3	10.6	22.6	21.1	14.1	19.2	**54.4**
I do not like spending much time shopping for food	**37.2**	10.7	10.2	16.3	22.2	16.8	12.6	11.4	**40.8**
Food shopping takes up too much of my time	**49.0**	16.1	14.2	18.7	25.3	12.3	7.1	6.3	**25.7**
Enjoyment of meal preparation	**31**				**5**				**64**
Meal preparation brings a bit of pleasure into my life	**33.9**	8.9	9.6	15.4	24.7	19.7	14.8	6.8	**41.3**
I am very creative when preparing meals	**29.0**	6.2	8.9	13.9	24.7	23.8	13.3	9.2	**46.3**
I love spending time in the kitchen preparing food	**29.5**	8.4	7.0	14.1	23.3	20.5	15.8	10.9	**47.2**
Preparing meals gives me a lot of satisfaction	**19.4**	4.8	4.8	9.8	21.9	24.2	20.5	13.9	**58.6**
I enjoy preparing meals from scratch	**19.3**	4.4	5.2	9.7	18.3	20.3	20.4	21.8	**62.5**

Appendix II. (a) Continued.

	Disagree overall	Completely disagree		<---	Neutral	--->		Completely agree	Agree overall
		1	2	3	4	5	6	7	
Skills requirement	**68**				**8**				**24**
Convenience foods allow me to have something that I wouldn't normally know how to cook	**45.3**	18.4	14.3	12.6	19.5	18.1	10.7	6.4	**35.2**
I choose meals that have been prepared by someone else because they do it much better than I can	**66.2**	32.7	16.6	16.9	17.0	8.9	4.5	3.4	**16.8**
I avoid preparing new dishes because I do not have the culinary skills to do so	**62.0**	27.0	16.6	18.4	16.9	9.5	6.5	5.1	**21.1**
Beliefs about convenience food									
Convenience food value for money	**59**				**14**				**28**
Convenience foods are not that expensive	**50.3**	17.9	15.0	17.4	24.1	13.9	6.4	5.3	**25.6**
Convenience foods are over-priced	**20.2**	3.7	4.5	12.0	24.0	21.6	16.1	18.1	**55.8**
Convenience foods are not good value for money	**33.1**	7.2	9.1	16.8	28.8	14.1	12.7	11.4	**38.2**
Health value of convenience food	**55**				**14**				**31**
Convenience foods are nutritious	**43.0**	10.9	12.9	19.2	32.4	16.2	4.7	3.8	**24.7**
Convenience foods are healthy	**50.2**	15.1	15.8	19.3	29.2	14.2	3.6	2.8	**20.6**
Convenience foods are safe	**36.1**	6.8	10.5	18.8	32.6	19.5	7.6	4.1	**31.2**
Time and convenience food	**32**				**11**				**57**
Convenience food saves time	**17.9**	6.1	4.3	7.5	17.0	19.3	20.8	25.0	**65.1**
Eating convenience food allows me more time to relax	**36.7**	10.6	11.3	14.8	23.3	18.0	9.7	12.4	**40.1**
Convenience food allows me more time for other activities	**33.2**	8.9	9.8	14.5	28.2	16.1	11.4	11.0	**38.5**

Involvement with convenience food	**68**				**6**				**26**
Convenience food products are very important to me	**46.2**	16.8	13.4	16.0	25.9	14.5	6.9	6.4	**27.8**
I am interested in convenience food products	**49.2**	18.0	14.8	16.4	23.5	15.5	8.3	3.5	**27.3**
Consuming convenience food products brings pleasure into my life	**63.8**	27.3	17.9	18.6	20.2	10.4	4.2	1.3	**15.9**
I feel very involved with convenience food products	**65.3**	31.4	18.8	15.1	16.4	11.3	4.4	2.6	**18.3**
Post-meal convenience									
Clearing up	**76**				**7**				**16**
One of the reasons I use convenience foods is to reduce the amount of washing up	**69.7**	40.1	15.6	14.0	13.8	7.3	5.1	4.1	**16.5**
Foods that do not require clearing up following a meal are an important part of my shopping list	**63.5**	26.0	19.7	17.8	19.2	9.2	4.5	3.5	**17.2**
I choose foods that don't create much, if any, washing up	**63.3**	28.4	18.7	16.2	18.7	9.5	4.0	4.5	**18.0**
Disposal of waste ingredients	**69**				**7**				**23**
I find that I often have to throw away ingredients when cooking a meal from scratch	**58.4**	26.9	16.4	15.1	19.3	12.7	5.3	4.2	**22.2**
Throwing out leftover ingredients is all to common in this household	**57.9**	22.8	18.6	16.5	18.8	12.8	5.7	4.8	**23.3**
For me the solution to throwing out leftover ingredients is to buy convenience foods	**68.8**	38.9	16.5	13.4	16.0	8.7	3.7	2.8	**15.2**
I often find that I buy ingredients, use them once, then leave them in the cupboard and never use them again	**49.0**	19.6	14.5	14.9	20.0	15.1	9.8	5.9	**30.8**

Appendix II. (a) Continued.

Convenience consumption	**Disagree overall**	Completely disagree		<---	Neutral	--->		Completely agree	**Agree overall**
		1	2	3	4	5	6	7	
Propensity towards convenience products	**68**				**8**				**24**
I choose easy, quick-to-prepare food for weekday evening meals	**47.7**	18.7	15.2	13.8	20.3	17.8	8.3	5.7	**31.8**
I rarely cook from scratch during the week	**66.8**	33.5	18.0	15.3	12.5	9.5	6.1	5.1	**20.7**
I choose easy, quick-to-prepare food for weekend evening meals	**43.0**	17.4	12.8	12.8	20.7	17.9	10.4	8.0	**36.3**
I rarely cook from scratch during the weekend	**68.3**	35.4	18.0	14.9	14.8	7.9	4.4	4.5	**16.8**
Propensity towards convenience processes	**63**				**11**				**26**
I regularly use the microwave to cook my evening meal during the week	**56.3**	26.1	15.9	14.3	16.6	11.6	7.2	8.3	**27.1**
I regularly use the microwave to cook my evening meal during the weekend	**60.6**	32.6	15.7	12.3	17.5	10.3	6.1	5.6	**22.0**

Appendix II. (b) Frequencies of ready meals and takeaway meals attitude statements

	Disagree overall	Completely disagree		<---	Neutral	--->		Completely agree	**Agree overall**
		1	2	3	4	5	6	7	
Attitude towards ready meals									
Ready meals are good value for money	**54.3**	17.1	16.7	20.5	**24.5**	13.5	4.5	3.2	**21.2**
Ready meals are good backup to have in the home	**18.8**	3.4	6.4	9.0	**16.8**	23.7	21.9	18.8	**64.4**
Ready meals are convenient	**20.0**	6.4	5.6	8.0	**20.3**	21.9	19.5	18.4	**59.8**
Attitude towards takeaway meals									
Takeaway meals are convenient	**14.6**	4.8	3.7	6.1	**12.1**	21.7	22.5	29.1	**73.3**
Takeaway meals are worth the extra cost	**44.0**	15.8	11.9	16.3	**23.5**	16.9	9.5	6.1	**32.5**
Takeaway meals are a good last minute meal solution	**15.9**	5.2	3.2	7.5	**16.0**	22.1	23.5	22.5	**68.1**

Appendix III. Demographic profile of the sample surveyed

Variable		Percentage (%)
Gender	Male	14
	Female	86
No of persons in household	1	11
	2	29
	3	22
	4	25
	5	9
	6 or more	4
Partner	Yes	71
	No	29
Education	Left at 17/under	59
	Left at 18	8
	Further education	20
	Degree	8
	Postgraduate	2
	Prof. Qualification	3
No of children under 16 in household	None	45
	1	21
	2 or more	34
Occupational status	Full time	34
	Part time	19
	<15hrs per week	2
	Unemployed	3
	Student	2
	Retired	14
	Housewife	24
Social grade	AB	17
	C1	28
	C2	23
	DE	30
Household income per month after tax and other deductions	Under £400	12
	£400 – 799	18
	£800 – 1199	23
	£1200 – 1599	15
	£1600 – 1999	12
	£2000 – 2499	10
	£2500 – 2999	6
	Over £3000	5.7

Appendix IV. (a) Comparison of the mean scores of the FRL segments with the sample mean scores of the FRL dimensions (Minimum score = 3; maximum = 21)

	FRL sample	Snacking	Careless	Uninvolved	Rational	Adventurous	Conservative
Ways of shopping							
Importance of product information	12.98	-0.33	-1.46	-5.05	+1.61	+2.98	+0.28
Attitudes to advertising	11.03	+0.96	-1.62	-1.43	+1.88	-1.43	-0.30
Enjoyment from shopping	11.49	+0.71	-2.65	-2.17	+1.77	+0.97	-1.39
Speciality shops	9.99	+1.25	-2.20	-3.14	+0.52	+3.15	-2.30
Price criteria	13.37	-0.55	-0.91	-1.69	+1.72	-0.52	+1.19
Shopping list	12.54	-0.61	-3.37	-1.63	+2.16	+0.96	+0.73
Cooking methods							
Interest in cooking	12.64	-0.48	-2.19	-2.64	+1.06	+3.51	-1.50
Looking for new ways	12.78	-0.34	+0.10	-4.70	+1.90	+3.29	-4.37
Convenience	10.11	+1.69	+0.33	+0.89	+0.69	-2.90	-2.12
Whole family	12.11	-0.38	-0.38	-0.65	+0.08	+2.13	-2.01
Planning	11.17	+0.20	-2.29	-2.60	+2.01	+0.71	-0.34
Woman's task	9.76	+1.51	-1.60	-1.33	+0.94	-2.07	+2.57
Purchasing motives							
Self-fulfilment in food	14.00	-1.49	-1.09	-3.67	+2.42	+2.23	-0.94
Security	11.80	+0.32	-1.70	+1.25	+0.62	-1.99	+2.04
Social relationships	13.96	-1.14	-0.02	-2.52	+1.28	+2.19	-1.05
Quality aspects							
Health	13.10	-0.70	-0.97	-3.70	+1.21	+2.53	+0.24
Price/quality relation	16.66	-2.47	+0.22	-1.60	+1.12	+1.26	+1.84
Novelty	14.22	-1.30	+2.52	-4.05	+1.66	+2.57	-4.88
Organic products	7.84	+1.45	-1.43	-3.47	-0.38	+4.02	-2.20
Taste	17.70	-3.30	+0.70	-1.51	+1.36	+1.85	+0.94
Freshness	17.14	-2.98	-0.26	-2.67	+1.65	+2.43	+1.56
Consumption situations							
Snacks versus meals	8.86	+1.96	+0.06	+0.60	+0.20	-2.38	-1.36
Social event	12.57	-0.32	+0.13	-1.39	+0.75	+1.51	-2.63

Note: A minus score (-) indicates that the segment is less interested than the sample as a whole in that particular dimension, while a plus sign (+) indicates that they are more interested.

Appendix IV. (b) Comparison of the mean scores of the FRL segments & sample mean scores of the convenience measures (Minimum score = 3; maximum = 21)

	FRL sample	Snacking	Careless	Uninvolved	Rational	Adventurous	Conservative
Forces driving convenience food market							
Time pressures	12.43	-0.20	+1.33	+0.77	-0.19	-1.04	-0.30
Stress levels	9.41	+1.90	-0.12	+0.84	-0.38	-1.78	-0.71
Breakdown of mealtimes	11.20	+0.74	+0.15	+0.96	-0.32	-1.36	+0.26
Eating alone	12.56	-0.24	+0.92	+1.34	+0.13	-1.80	+0.23
Individuality	11.75	+0.08	+0.13	+0.48	+0.10	-0.78	+0.16
Time and ways of shopping	12.24	+0.06	+2.00	+1.40	-0.76	-1.44	-0.31
Enjoyment of meal preparation	10.18	+1.47	+0.97	+4.42	-1.94	-3.39	+0.78
Skills requirement	9.48	+1.89	-0.39	+2.49	-0.61	-2.78	-0.09
Beliefs about convenience food							
Convenience food value for money	10.53	+0.94	+0.12	+1.05	-0.30	-1.31	-0.49
Health value of convenience food	10.95	+1.14	+0.16	+0.93	-0.12	-1.68	-0.65
Time and convenience food	13.30	-0.44	+0.58	+1.47	+0.28	-1.25	-0.73
Involvement with convenience foods	9.62	+2.21	+0.23	+1.36	+0.03	-2.99	-1.78
Post-meal convenience							
Clearing up	8.57	+2.26	+0.25	+0.95	-0.10	-2.65	-1.32
Disposal of waste ingredients	9.77	+1.64	+0.48	+1.30	-0.30	-2.43	-0.78
Convenience consumption							
Propensity towards convenience products	9.64	+1.75	+0.65	+1.86	-0.76	-2.68	-0.25
Propensity towards convenience processes	9.44	+1.78	-0.38	+1.18	-0.40	-2.27	-0.72

Appendix IV. (c) Attitudes towards ready meals and takeaways by sample and segment (Minimum score = 1; maximum = 7)

	Sample mean score	Snacking consumer	Careless consumer	Uninvolved consumer	Rational consumer	Adventurous consumer	Conservative consumer
Ready meals are good value for money	3.25	+0.43	+0.05	+0.59	+0.04	-0.82	-0.25
Ready meals are good backup to have in the home	4.89	-0.32	+0.32	+0.34	+0.16	-0.31	+0.11
Ready meals are convenient	4.71	-	+0.25	+0.66	+0.15	-0.52	-0.11
Takeaway meals are convenient	5.20	-0.59	+0.53	+0.53	+0.12	-0.06	-0.17
Takeaway meals are worth the extra cost	3.61	+0.27	+0.37	+0.41	+0.15	-0.44	-0.75
Takeaway meals are a good last minute meal solution	5.00	-0.51	+0.51	+0.29	+0.30	-0.08	-0.03

Appendix IV. (d) Ranking of reported behaviour of FRL segments

	Snacking	Careless	Uninvolved	Rational	Adventurous	Conservative
Go out for a meal	1	5	4	1	1	5
Buy a takeaway meal to eat away from home	1	2	4	4	5	5
Buy a takeaway meal to eat at home	1	3	2	4	5	6
Cook a meal from ingredients	5	4	6	2	1	3
Do not eat a 'proper' meal, just snack	1	3	2	4	6	4
Eat ready meals	1	3	1	4	6	5
Ready meal form						
Purchase frozen ready meals	1	4	2	2	6	5
Purchase chilled ready meals	1	2	3	3	5	5
Purchase canned ready meals	1	3	2	4	6	5
Purchase dried ready meals	1	2	4	3	5	5
Ready meal type						
Purchase ethnic ready meals	1	2	3	3	5	6
Purchase healthy ready meals	1	3	3	2	3	6
Purchase traditional ready meals	1	3	2	3	6	5
Purchase vegetarian/ meat free ready meals	1	2	2	2	2	2
Purchase organic ready meals	1	4	6	3	1	4
Purchase fish-based ready meals	1	6	3	2	3	3
Purchase pizzas	1	3	2	4	4	6

Appendix IV. (e) Frequencies of reported purchase and consumption behaviour (%) for the FRL segments and the FRL sample

		FRL sample	Snacking	Careless	Uninvolved	Rational	Adventurous	Conservative
Go out for a meal	Frequently	13.9	13.8	11.6	18.3[a]	14.1	12.6	12.9
	Occassionally	60.1	64.4	54.5	49.6	63.6	68.5	48.6
	Infrequently or never	26.0	21.9	33.9	32.2	22.3	18.9	38.6
Buy a takeaway meal to eat away from home	Frequently	13.3	23.8[a]	11.6	20.0	9.1	5.6	10.0
	Occassionally	36.6	46.9	34.8	37.4	37.7	31.0	22.9
	Infrequently or never	50.1	29.4	53.6	42.6	53.2	63.4	67.1
Buy a takeaway meal to eat at home	Frequently	25.2	33.8	20.5	37.2[a]	25.9	16.3	10.0
	Occassionally	51.4	51.9	60.7	43.4	49.5	56.7	42.9
	Infrequently or never	23.4	14.4	18.8	19.5	24.5	27.0	47.1
Cook a meal from ingredients	Frequently	83.0	76.1	77.7	67.8	90.4	95.8[a]	82.9
	Occassionally	11.0	18.2	18.8	14.8	6.9	1.4	8.6
	Infrequently or never	6.0	5.7	3.6	17.4	2.8	2.8	8.6
Do not eat a 'proper' meal, just snack	Frequently	30.1	41.3	33.0	41.7[a]	24.8	14.0	30.0
	Occassionally	24.1	30.6	22.3	23.5	22.5	23.8	18.6
	Infrequently or never	45.8	28.1	44.6	34.8	52.8	62.2	51.4
Eat ready meals	Frequently	38.7	56.9[a]	41.1	53.5	34.4	15.4	30.4
	Occassionally	34.4	26.3	37.5	26.3	37.6	44.1	31.9
	Infrequently or never	26.8	16.9	21.4	20.2	28.0	40.6	37.7

Appendix IV. (e) Continued.

		FRL sample	Snacking	Careless	Uninvolved	Rational	Adventurous	Conservative
Purchase frozen ready meals	Frequently	42.1	57.4[a]	37.6	46.1	45.1	22.1	32.1
	Occassionally	41.4	30.4	47.5	42.2	44.0	46.0	39.3
	Infrequently or never	16.5	12.2	14.9	11.8	10.9	31.9	28.6
Purchase chilled ready meals	Frequently	40.5	58.1[a]	49.0	41.7	38.5	18.4	28.1
	Occassionally	38.5	31.8	37.0	36.9	40.6	48.2	35.1
	Infrequently or never	21.0	10.1	14.0	21.4	20.8	33.3	36.8
Purchase canned ready meals	Frequently	31.6	44.9[a]	26.7	39.6	31.8	14.0	26.8
	Occassionally	34.3	36.1	40.6	33.7	32.8	30.7	32.1
	Infrequently or never	34.0	19.0	32.7	26.7	35.4	55.3	41.1
Purchase dried ready meals	Frequently	44.6	57.8[a]	43.6	36.9	47.4	35.3	35.1
	Occassionally	36.7	32.0	43.6	42.7	34.4	37.9	31.6
	Infrequently or never	18.7	10.2	12.9	20.4	18.2	26.7	33.3
Purchase ethnic ready meals	Frequently	21.3	30.9[a]	21.8	27.6	18.8	12.6	10.3
	Occassionally	46.2	51.7	48.5	38.1	47.1	51.3	29.3
	Infrequently or never	32.5	17.4	29.7	34.3	34.0	36.1	60.3
Purchase healthy ready meals	Frequently	10.5	17.3[a]	7.9	8.6	10.4	6.8	8.6
	Occassionally	24.4	35.3	20.8	15.2	26.6	22.9	15.5
	Infrequently or never	65.1	47.3	71.3	76.2	63.0	70.3	75.9

Purchase traditional ready meals	Frequently	21.6	33.3[a]	24.0	26.7	19.3	8.5	12.1
	Occassionally	28.7	33.3	27.0	30.5	30.7	18.8	29.3
	Infrequently or never	49.7	33.3	49.0	42.9	50.0	72.6	58.6
Purchase vegetarian/ meat free ready meals	Frequently	6.5	10.7[a]	5.0	7.6	3.7	5.1	8.6
	Occassionally	17	27.3	13.9	13.3	10.5	22.9	12.1
	Infrequently or never	76.5	62.0	81.2	79.0	85.8	72.0	79.3
Purchase organic ready meals	Frequently	1.9	4.7[a]	0	1.0	1.6	2.5	0
	Occassionally	10.4	19.5	5.9	2.9	6.9	17.8	5.2
	Infrequently or never	87.6	75.8	94.1	96.2	91.5	79.7	94.8
Purchase fish-based ready meals	Frequently	12.3	22.3[a]	5.0	16.2	12.0	4.2	10.3
	Occassionally	35.8	42.6	31.7	28.6	37.7	40.7	22.4
	Infrequently or never	51.9	35.1	63.4	55.2	50.3	55.1	67.2
Purchase pizzas	Frequently	29.3	45.3[a]	25.0	43.8	25.0	11.9	19.0
	Occassionally	48.3	40.7	56.0	31.4	49.5	68.6	39.7
	Infrequently or never	22.4	14.0	19.0	24.8	25.5	19.5	41.4

[a] Indicates the segment that purchases or consumes the product most frequently

Appendix IV. (f) Socio-demograhic details of sample by segment.

	Snacking consumer	Careless consumer	Uninvolved consumer	Rational consumer	Adventurous consumer	Conservative consumer
Gender[1]	Male	Both	Male	Both	Both	Female
Age[1]	Younger	Young/ middle-aged	Younger	Middle-aged/ older	Middle-aged	Older
Partner[1]	More likely	-	Less likely	More likely	More likely	-
Household size[1]	Slightly larger households	Larger households	Smaller households	Slightly larger households	-	Smaller households
Young children[1]	Less likely	More likely	-	More likely	-	Less likely
Education[1]	Less well educated	-	Less well educated	-	Well-educated	Less well educated
Occupational status[1]	Work <15 hrs/wk, unemployed/ student	Full-time/ housewife	Work full-time	Retired	Work full-time	Retired/
housewife						
Social grade[1,2]	C2DE	-	DE	C2	ABC1	DE
Income[1]	Lower	Modest	-	-	Higher	Lower

[1]Indicates significance difference between the segments for each variable.
[2]A = upper middle class, B = middle class, C1 = lower middle class, C2 = skilled working class, D = working class, E = underclass.

Keyword index