Feed processing and feeding management to enhance nutrient utilization in commercial livestock production

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Summary

The efficiency of nutrient extraction from feeds and subsequent utilization by commercially produced livestock often falls far short of full potential. There are numerous contributing factors to this shortfall but prominent amongst these are the manner in which the feed is prepared and the management of how this feed is presented to the target animals. This paper discusses various aspects of feed preparation and feeding management, which can be manipulated to enhance nutrient utilization in commercial livestock. It highlights the trade–off between feed processing to maximise nutrient digestibility and the risk of gastrointestinal disturbance; the need for disciplined feed milling and the significance of inconsistent nutrient supply on the physiological efficiency of nutrient utilization.

Introduction

In recent years global competition has placed considerable pressure on the economics of commercial livestock production. Of the various factors within the profit equation the producer has the most influence over the cost of production component. Prominent within the cost profile is the cost of feed, and so nutrient utilization and feed conversion efficiency are key matters requiring constant attention.

The nutrient requirements for tissue synthesis in most livestock species have been well established and the complex physiological mechanics of this have been addressed with the development of various simulation models (Black *et al.*1986).

The problem for applied commercial nutritionists is the translation of these tissue requirements into dietary requirements that can accommodate the variable efficiencies of nutrient extraction and utilization that occur with different feedstuffs, feed preparation methods, and feeding management strategies.

The achievement of a high efficiency of nutrient utilization from feedstuffs requires an appreciation of the digestive competence of the stock involved (so that feed can be adequately prepared to expedite nutrient extraction) and of their growth characteristics (so that nutrients can be delivered in a manner which maximises productive efficiency).

This paper discusses practical aspects of feed preparation and feeding management to enhance nutrient utilization, with a primary focus on intensive monogastric production.

Feed preparation

Once a dietary specification has been decided upon there is a chain of sequential events which must all be completed satisfactorily if the appropriate feed is to be delivered to the target animal. These include:

Preliminary activities

These begin with ingredient selection and screening to ensure that minimum quality assurance standards have been met. Strict discipline is required to ensure satisfactory raw material quality; any shortfalls at this point represent a loss of control, which renders the rest of the manufacturing sequence futile.

Precision in feed manufacture demands that the nutrient content of each feedstuff is known with a strong degree of confidence and, if variable, that some allowance is made with a statistical appreciation of the variance (Fawcett and Webster 1995). The time delay associated with 'wet chemistry' has long been a frustration in commercial feedmills but recent developments in the field of NIR spectroscopy have made this problem less acute. As well as the traditional estimates of moisture, protein and fat, recent research (Valdez and Leeson 1992; Jackson *et al.* 1996; Givens *et al.* 1997; Van Barneveld *et al.* 1998) has indicated that NIR technology can also be used to estimate pig digestible energy and poultry metabolisable energy values, as well as total and available amino acid content in feedstuffs. Once robust calibrations are available, the ability to make real time estimates of these parameters will substantially enhance feedstuff utilization via formulation precision.

Feed formulation, though being facilitated by sophisticated software packages capable of very complex mathematical optimisations, still relies heavily on the subjective judgements of the operator to accommodate some of the biological and logistical complexities, outside the scope of the objective linear programming exercise. This includes an appreciation of the gastro–intestinal limitations of each animal species (or developmental stages within species) to accommodate various feedstuffs, or specific components such as fibre in its various forms, fats, starch, specific non–starch polysaccharides, salt, mineral tolerances, anti–nutritional factors, nutrient density, digestibility, etc. If any of these factors induce dietetic stress, metabolic toxicity or depressed intake, the feed will not deliver its intended nutrient contribution, and nutrient utilization/feed efficiency will be compromised.

Physical processing

Although various livestock species have evolved mechanisms for physically breaking down feedstuffs (e.g. mastication or gizzard grinding) their effectiveness in preparing some feedstuffs for subsequent digestion is relatively poor. This is particularly so for cereal grains. Consequently to ensure a high level of utilization of the nutrients in grains, various processing procedures are employed before their incorporation in formulated diets. Since the digestion of most feedstuffs involves enzymic hydrolysis the prime purpose of processing is to facilitate enzyme access to the substrates.

Grinding

In its simplest form this involves breaking the seed coat to expose the starchy endosperm, and in many situations this is all that is required. However, there are numerous other barriers, which deny the enzymes access to the substrates and these require treatment with more comprehensive processes. In pigs, particle size of grains has been shown to influence digestibility and subsequent performance (Hancock *et al.* 1997; Wondra *et al.* 1995a). These authors demonstrated an improvement in nutrient utilization with reducing particle size (e.g. 1.3 % improvement in feed conversion efficiency for each 100 micron reduction in mean particle size from 1200 to 400 microns) and nominate an optimum particle size of 600µ. This recommendation needs to be interpreted with caution however, as it relates to corn and sorghum only and to mash feeds. Optimum particle size is influenced by many factors including:

- the grain in question
- the animal species being fed
- the physiological age of the animal
- other processes involved (expansion, pelleting, crumbling, wet feeding, etc.)
- the incidence of gastro–intestinal disturbance
- the incremental cost of milling relative to the additional benefit derived
- influence on palatability and feed intake
- changes in the physical handling characteristics e.g. bridging in silos, resistance to added fat
- the level of respirable dust and its affects on animal and human health
- and in ruminants, what it is fed with, the level of feeding, the preferred rate of fermentation and the preferred site of digestion

The benefits of fine grinding (improved digestibility, improved pellet durability) need to be weighed against negative influences such as the exponential increase in energy requirement for finer grinding, the incidence of gastrointestinal disorders (gastric dilations, bowel torsions, enterotoxaemia, prolapses), physical handling difficulties (bridging, poor added fat distribution) and respiratory irritation from dust. The serious compromises that these latter factors can induce on animal health and performance in pigs far outweigh the advantages of a minor improvement in digestibility, and have led to a preference for a coarser grind size than that recommended above.

Other factors influencing particle size effects are the type of mill employed (hammer versus roller) and the uniformity of particle size. Roller mills produce more uniform particles, and this attribute has been shown to improve digestibility independent of mean particle size (Wondra *et al.* 1995b).

In poultry, grain particle size is of less consequence, particularly where the feed is presented as pellets or crumbles (Waldroup 1997). Nir *et al.* (1990) fed chicks on mash diets containing sorghum varying in particle size from 555µ to 888µ and found that bird preference was inversely related to particle size (larger particles preferred), and that this resulted in higher intakes and increased growth. Nir *et al.* (1994) also demonstrated the importance of particle size uniformity. He showed that chicks fed a diet based on medium sized ground corn (770µ) performed better than those fed a diet comprised of fine (525µ) and coarse (1100µ) mixed to deliver the same average particle size as the medium diet.

Dehulling

The cellulosic seed coats of some grains used in animal feeding are of limited value to monogastrics e.g. the hulls of oats, barley, rice, lupins and faba beans. Although not toxic these hulls have almost zero nutritive value for poultry and act as a diluent in the diet. In pigs some food value can be recovered by hindgut fermentation but the overall efficiency of nutrient extraction is lowered by their presence in the feed. By removing the hulls the nutritive value of the residual kernels is raised (higher energy and protein, less fibre) but the economics of the dehulling process depends heavily on having a productive use for the hulls (e.g. directed to ruminant feeds).

The advantages of dehulling are increased nutrient density, reduced heat increment effects from fibre digestion, improved digestibility and reduced faecal volume.

Batching, mixing and conveying

These processes need to be conducted with precision and thoroughness so as to achieve a homogeneous product of tight specification with a minimum of contamination. Inadequate feed mixing can significantly impair subsequent animal performance (Mc Coy *et al.* 1994). Similarly, if variation in particle size or density leads to feed separation during conveying then the feed presented to the stock may bear little resemblance to the original formulation and hence result in poor utilization.

Pelleting

The pelleting of feeds for pigs and poultry has long been established as a valuable method of enhancing nutrient utilization. Probably the most comprehensive review of the effects of pelleted feed in growing pigs was conducted by Vanshoubroek *et al.* (1971). They concluded that the average advantage to pelleting across 117 trials, was a 6.6% improvement in daily gain, a 2.1% reduction in daily feed intake and a 7.9% improvement in feed conversion efficiency. Numerous other research studies have confirmed responses of this magnitude. However, under practical commercial conditions responses to pelleting can be even more favorable depending on the level of feed wastage/feed separation involved with the mash diets. A monitor of the effects of a conversion from mash to pellets in a large commercial piggery in central Queensland in 1996 (comparing the first six months of production on pellets with the corresponding period in the previous year on mash) revealed an improvement in average daily gain of 7.2%, a 5.8% reduction in feed usage and an 11.4% improvement in total herd feed conversion efficiency.

Expansion

Expanders are being adopted with increasing frequency in feed milling operations around the world, as a means of achieving a more comprehensive conditioning of feed. The high temperature, short time conditioning of the expander is not meant to replace but rather to complement pelleting (Peisker 1992).

Table 1 demonstrates the effect of pelleting and expansion of broiler diets independently or in combination, calculated from the data of Williams (1997).

These results demonstrate the magnitude of the independent responses of pelleting and expansion, and their additive effect. Expansion can not only improve the overall digestibility of feeds but also the rate of digestion which in some circumstances can allow improved voluntary feed intake.

A series of trials conducted at Bunge Meat Industries with growing pigs demonstrated similar advantages from expansion over and above pelleting (Edwards 1997). The first experiment involved two base diets, a corn/soya diet and a second diet incorporating 60% wheat pollard replacing corn/soya. Both diets were pelleted at 90°C or expanded at 115°C prior to pelleting. The feeds were evaluated in individually housed female grower pigs for 40 days commencing at 26kg liveweight, with 10 pigs per treatment. At the conclusion of the trial the pigs were re–weighed after 2 days of feed withdrawal to compare empty bodyweight responses. As shown in Table 2 expansion of the diets appeared to have little effect on liveweight gain but tended to reduce feed intake resulting in a feed:gain improvement of the order

Table 1 Responses to pelleting and expansion of corn/soya broiler diets relative to the performance of the base mash (from Williams 1997).

Treatment	Av. 49 day Weight	Feed Consumption	F.C.R.
Mash	100	100	100
Pelleted	107.8	105.2	97.5
Expanded (crumbled)	104.9	102.9	98.0
Expanded/Pelleted	110.7	106.2	96.0

Table 2 Effects of expanding corn/soya and pollard soya diets on the growth performance of female pigs (Edwards 1997).

	Corn/Soya		Pollard/Soya	
	Pelleted	Expand/Pelleted	Pelleted	Expand/Pelleted
Av. daily gain g/d	934	947	928	935
Av. daily feed intake kg/d	1.91	1.84	1.90	1.89
Feed:Gain	2.06	1.96	2.06	1.97
Empty body wt. gain g/d	791	815	768	805
Feed:EBW gain	2.42	2.27	2.49	2.28

of 4.5% for both diets. However, when the effects of the gut fill were removed the growth and feed efficiency advantages from expansion became more pronounced. Expanding improved empty bodyweight gains by 3.0 and 4.8%, and empty bodyweight feed efficiency by 6.2 and 8.4% for the corn/soya and pollard/soya diets respectively, over and above pelleting.

In a second part of the experiment similar diets based on wheat/barley/lupin kernels or wheat/millmix (30%)/lupin kernels, were evaluated following pelleting or expansion and pelleting. These diets were evaluated in individual female pigs (10 pigs/treatment) for 28 days commencing at 30 kg liveweight (Table 3).

In this instance there was no additional advantage to expansion over pelleting and in fact a trend for poorer growth. The explanation for this may lie in the fact that expansion not only ruptures structural carbohydrates and gelatinises starch but also tends to solubilise some non–starch polysaccharide fractions and eliminate endogenous enzyme activity in the feeds. These latter effects could negate the positive influences of expansion. However, if coupled with a post–processing application of an appropriate supplementary enzyme combination, the advantage of expansion could well be restored and even extended.

The experience with expansion to date has demonstrated that its advantages are very much dependent on substrate and processing parameters. As well as potential improvements in feed digestibility, expanding offers several other advantages to feedmillers including, improved pellet quality, increased rate of pellet production, an ability to add high levels of liquids to the mash prior to pelleting, and improved feed hygiene (especially Salmonella elimination).

Other hydrothermal processes

Extrusion is employed to process a number of feedstuffs to enhance digestibility and eliminate anti–nutritional factors such as the trypsin inhibitors of soyabeans or the lectins in leguminous seeds. However, apart from the production of full fat oilseed meals, and speciality diets for aquaculture, pet food and baby pigs/calves, the costs of this process tend to preclude its use in commercial stockfeed production. Also included in this category are processes such as infrared micronisation, microwave cooking, conventional pressure–cooking, roasting, popping, and jetsploding.

For ruminant feeding the most common forms of grain processing are dry rolling, steam rolling or flaking, and reconstitution.

Final preparation

Factors which influence nutrient utilization at this stage include:

Additives

Beyond the standard nutrient profile of the diet, there is a wide range of potential feed additives that can be employed. Decisions to include these need to be made judiciously with sound logic justifying their inclusion and a high probability of a cost–effective response. Included here are exogenous enzymes, acidulants, buffers, antibacterials/antibiotics, emulsifiers, tissue repartitioning agents, probiotics, anthelmintics, and flavors.

Storage/Stability

The nutritive value and palatability of a prepared feed can decline markedly in storage, particularly if subjected to oxidative rancidity, protein putrefaction, mould attack or insect infestation. Feed hygiene and sound silo management practices need to be exercised and, dependent on risk, it may be advisable to employ insurance measures such as anti–oxidant and mould inhibitor additions.

Delivery

Nutrient utilization can be compromised if feed is not delivered to the intended silo, is delivered in an untimely manner, or is contaminated with other feed.

Feeding management

The exercise of meeting the nutritional requirements of the stock in question does not finish with the manufacture of an appropriate feed. Considerable feeding management inputs are required to ensure that feed nutrients are fully utilized.

Table 3 Effects of exanding wheat/barley/lupin and wheat/millmix/lupin diets on the growth performanceof female pigs (Edwards 1997).

	Wheat/Barley/Lupin		Wheat/Millmix/Lupin	
	Pelleted	**Expand/Pelleted**	**Pelleted**	**Expand/Pelleted**
Av. daily gain g/d	875	819	854	830
Av. daily feed intake kg/d	1.90	1.81	1.80	1.74
Feed:Gain	2.19	2.23	2.12	2.09

Managing changing requirements

Nutrient requirements change progressively through the various stages of production and hence a strategy needs to be implemented to best meet these requirements that trades feeding simplicity off against biological complexity and economic optimisation. The tools available for this are phase feeding (multiple diets to follow the changing requirements), and separate sex feeding (where either common diets are changed at different points or entirely different diets are employed to address the specific requirements of each sex).

Common to this is a focus on daily nutrient supply.

Daily Nutrient Supply = Nutrient Concentration in the Diet x Daily Feed Intake

The end point can be achieved by manipulating either factor in the equation. Even though there is a degree of interrelationship between the factors there is a disproportionate amount of effort in commercial livestock production directed to feed formulation with a sad neglect of feed intake monitoring. The precision of feed formulation and nutrient utilization could be enhanced with regular feedback on actual feed intake rates.

As well as accommodating the changes in requirement with genotype, liveweight, sex and feed intake there is also the need to address the question of applying a common dietary specification to a heterogeneous population to optimise the response. This requires a statistical approach in which requirements are generally raised by one standard deviation above the mean to cover the requirement of 83% of the population rather than pitching them at the mean and covering only 50% of the population.

Not only is it important to balance the full essential amino acid profile in diets in line with the ideal protein concept and provide an adequate pool of non–essential amino acids (Fuller *et al.* 1987), but there is a need to recognise that the amino acid profile of 'ideal' protein is not static, but alters with the changing relationship between maintenance and growth as the animal matures, and hence requires regular adjustment (Baker and Chung 1992). Failure to make these progressive adjustments will result in inefficient use of nutrients.

Consistency of nutrient delivery

In meat producing stock, feed conversion efficiency is generally optimised at a level of intake which supports maximum lean tissue growth, and fat deposition rates which are consistent with acceptable carcass quality. As depicted in Figure 1, as feed intake falls below this optimum level, feed efficiency deteriorates due to a greater proportion of the feed being lost to maintenance; excessive intake also causes deterioration in feed efficiency due to a larger proportion of fat in the gain.

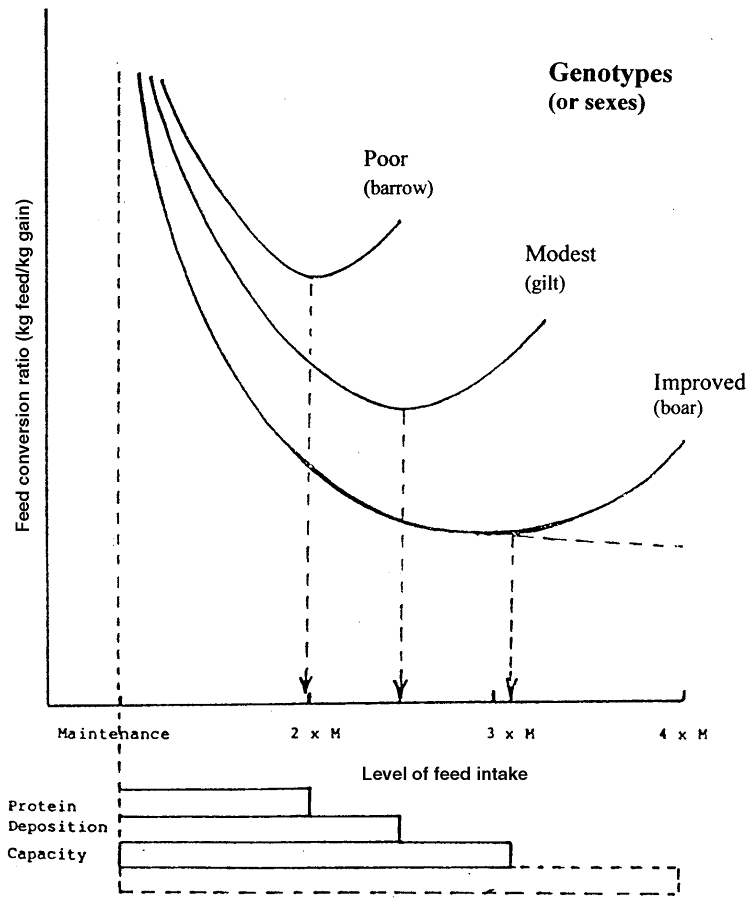

Figure 1 Feed conversion responses in pigs of different genotypes/ sexes to increasing levels of feeding.

At any given level of feeding, those pigs with a higher inherent level of fat in their gain (poorer genotypes or barrows>gilts>boars) will have higher FCR values due to the greater energy cost of synthesis of fat relative to lean. Feed efficiency tends to improve with increasing intake and subsequent growth rate until protein deposition capacity is exhausted, and then deteriorates as all subsequent intake is directed to fat deposition. Consequently feed efficiency is generally optimised at the point of maximum lean growth.

To achieve a high level of feed efficiency it is critical that feed intake be optimised on a daily basis. An irregular pattern of intake will generally result in slower growth, poorer overall efficiency, and the potential for more fat in the final carcass. This point is demonstrated in Table 4. A comparison of a number of simulations by AUSPIG (Black *et al.* 1986; DSL Systems Centre, CSIRO Animal Production, Blacktown NSW 2148) of a 55 kg liveweight pig consuming a standard grower diet were made. Treatment 1 was the normal situation of constant intake at a level which supported performance close to the animal's genetic potential. Treatment 2 involved a daily alternation of low (1 x maintenance or 0.76 kg/d) and high (4.5 x maintenance or 3.42 kg/d) consumption rates to mimic the extreme case of feed restriction followed by engorgement on a daily basis. This revealed that although the average daily feed intake was identical to Treatment 1 the growth of the animal is markedly distorted. Growth rate was reduced by 28%, and feed efficiency deteriorated by 39% with the pig depositing more fat and less protein. The reason for this phenomenon is primarily associated with the fact that protein deposition occurs as a daily function up to genetic ceiling. A day forgone (when the pig is eating at the maintenance level) is a day lost, as there is no potential for compensatory protein growth the following day despite the high feed intake. In this instance the pig gains its protein up to its deposition potential and the rest of the ingested nutrients from the high intake are simply directed to fat deposition. Consequently uniform growth where pigs achieve their potential every day is of great importance. Any interruption immediately compromises feed efficiency.

Feed distribution within a group

Despite the fact that the average level of feed intake may appear appropriate, feed efficiency and carcass gradings can be eroded if the distribution of feed between the individuals in a group is uneven. By much the same principles as demonstrated in Figure 1, intake above and below the optimum will result in reduced overall efficiency. The variance in subsequent growth rates creates an ever–widening disparity in liveweights and hence complicates the nomination of appropriate dietary changepoints. Not only is feed efficiency compromised in this instance but also the lack of homogeneity in the population creates marketing difficulties (e.g. heavy/fat pigs and light/lean pigs).

This situation has been simulated in Treatments 3 and 4 in Table 4. Again the average feed intake is identical to the normal treatment but performance is compromised, and the coefficients of variation on weight and backfat would be much wider than those of the control group. Treatment 5 simulates the same feed intakes as those applied in Treatments 3 and 4 but with daily alternation. The comparison of the results of Treatment 5, with the mean of Treatments 3 and 4, reveals that there is a substantially greater negative effect on the average growth rate and protein deposition rate from a daily fluctuation in feed intake within animals than from a similar variation in intake between animals. However, when the variance in final carcass weight and grades is considered, both situations represent a substantial reduction in nutrient utilization efficiency and subsequent profitability.

Table 4 Effect of feeding regime on growth and body composition of pigs. AUSPIG Simulation for 14 days from 55 kg liveweight.

Treatment	Feed intake kg/d	Growth rate g/d	Feed:gain	Fat deposition g/d	Protein deposition g/d
1	2.09	936	2.23	193.6	154.5
2	2.09	676	3.09	236.2	90.1
3	2.73	1167	2.33	350.9	168.3
4	1.45	656	2.23	127.1	110.1
mean 3 & 4	2.09	912	2.28	239.0	139.2
5	2.09	779	2.68	156.2	129.6

Treatments 1 Normal constant daily intake (2.09 kg/d)
2 Daily alternating high (3.42 kg) and low (0.76 kg) intakes (average = 2.09 kg/d)
3 Constant high intake 2.73 kg/d
4 Constant low intake 1.45 kg/d
5 Daily alternation of 3 and 4

Continuity in feed ingredients

Although livestock can accommodate a wide range of feedstuffs to meet their dietary needs it is important that a degree of continuity be maintained in dietary ingredients. Sudden changes in the substrates employed can result in disturbance of the microfloral balance in the gut and lead to temporary depression in performance and reduced feed utilization. Changes in the grain base or the levels of legumes, vegetable protein, by–products or fats need to be regulated in the diet–to–diet progression and in month–to–month reformulation so as to avoid any unnecessary dietetic stress.

Site of digestion

Nutrient utilization can be substantially affected by the site of digestion, e.g. sugars derived from polysaccharide hydrolysis in the small intestine of the pig are utilized far more efficiently than volatile fatty acids derived from fermentation of the same substrates in the hindgut; and amino acids yielded from protein digested in the small intestine are available for protein synthesis in the animal, while those released by protein digestion in the hindgut are largely lost to the animal.

The site of digestion is, primarily, determined by digestive competence and rate of passage. These in turn are influenced by a number of manageable factors including non–starch polysaccharides (ingesta viscosity), particle size, levels of inclusion, anti–nutritive factors, irritants, mineral tolerances and electrolyte balance. Exogenous enzymes have been shown to be of considerable value in enhancing digestive competence.

Non–nutritional constraints

One aspect of general management, which overlaps with feeding management, is the practice of moving and/or mixing of stock in the production cycle. The aggression and confusion created by the mixing of 'foreign' groups seriously erodes production efficiency and compromises feeding management. The effects of such disturbances appear to be more far reaching than the interruption to feed intake patterns would indicate. Full production efficiency will only be reached if this practice is minimised.

Conclusions

The achievement of full productive efficiency in commercial livestock production can be elusive. Of the many factors which can erode efficiency, nutrition is prominent as a discipline requiring constant management. Its significance is not only because it is the primary driver of tissue synthesis, but also because it is the dominant component of the cost of production. With the twin pressures of increasing global competitiveness and limited feed resources, the need to maximise nutrient utilization from commercial feeds is crucial.

With a detailed knowledge of the composition of specific feedstuffs, the tissue requirements of the target animal species, and the limits to digestive competence, feed processing and feeding management can be manipulated to achieve maximal utilization of feed nutrients.

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