AMINO ACIDS IN PIG NUTRITION

INTRODUCTION

E.S. BATTERHAM*

There are considerable differences in the basic feeds used by the Australian Pig Industry relative to those used overseas. Maize and soyabean meal form the basis of the USA and Canadian feeding systems, and barley and soyabean meal the basis of the feeding systems in Western Europe. In Australia, wheat, barley and sorghum are the major cereals fed, and meat and bone meal, soyabean meal, cottonseed meal, sunflower meal and lupins the main protein concentrates. A characteristic of the Australian feeds is the lack of adequate quantities of high quality, uniform protein concentrate. The low lysine status of most protein concentrates, together with the relatively low lysine status of cereal protein means that lysine is normally the first and major limiting dietary amino acid. Thus there is considerable potential for the use of free (synthetic) lysine in diets, particularly for grower-finisher pigs.

In order for the Australian feeds industry to make optimal use of existing and new sources of feeds there is the need for information on their total and available amino acid composition. There is also a need for an awareness of possible growth inhibitors or undesirable factors that may be present in such meals. Research has concentrated on providing this information. Of particular interest currently is the development of triticale as anew source of energy and amino acids, development of techniques for assessing amino acid availability in cereals and protein concentrates, research into the utilization of free lysine and its implications to diet formulation and design of experiments for assessing amino acid requirements.

TRITICALE'S POTENTIAL AS A SOURCE OF AMINO ACIDS FOR PIGS

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Commercial triticale production in Australia began with the release of the line Groquick (Seatonberry 1978). This release occurred at about the time a number of projects began in various parts of Australia to screen imported and locally developed lines for those with commercial potential. The data in this paper were selected from results of a triticale screening project undertaken jointly by the Plant and Animal Industry Divisions of the South Australian Department of Agriculture.

MATERIALS AND METHODS

With few exceptions the triticale lines originated from the third and fourth International triticale nurseries of the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT).

The'experiments were conducted at Turretfield in 1976 and 1978 and at Turretfield and Perponda in 1979. Turretfield provides a favourable South Australian grain growing environment (red brown earth, mean annual rainfall 460 mm) whereas Perponda provides a much less favourable environment (sandy Mallee soil, mean annual rainfall 290 mm).

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The design of each experiment was a randomised block with each line being sown in four 20 m by 7-row plots, Wheat (cv. Halberd) and barley (cv. Clipper) were controls. Grain samples taken at harvest were pooled across replicates within sites and milled through a 1 mm screen for analysis of moisture, crude protein and amino acid composition.

RESULTS AND DISCUSSION

Overall yield results from the four experiments are contained in Table 1.

TABLE 1 Grain yield of triticale, wheat and barley (kg dry matter/ha)

Site Year	Turretfield 1976	Turretfield 1978	Turretfield 1979	Perponda 1979
Wheat	2720	1440	1880	1060
Barley	3640	1820	2610	-
Triticale				
Mean	1940	980	3000	930
Range	1080-2640	690-1360	2260-4100	750-1200
SD	260	130	470	140
No. of lines	79	92	42	28

There were significant triticale yield differences between the lines planted at Turretfield in 1976 and 1978 (comparison A) and between the lines planted at Turretfield and Perponda in 1979 (comparison B). Seventy-six lines were common to both the 1976 and the 1978 experiments, and 28 lines were common to both 1979 experiments. Only 11 lines were common to all experiments so the data illustrated the response of two substantially different groups of triticale lines to more and less favourable growing conditions.

Rank correlation coefficients for yield were highly significant in both comparison A and B (0.45 and 0.70 respectively). Considering the yield differences which occurred in both comparisons this suggests that genotype-environment interactions on yield were relatively unimportant in these triticale lines.

In 1976 and 1978 the highest yielding of the triticale lines yielded approximately 90% as much as wheat. This was in contrast to 1979 when a number of triticale lines out-yielded wheat at both sites. A comparison of yield data for wheat and the 11 triticales grown in all Turretfield experiments suggests that part of the disparity between 1979 and earlier Turretfield figures can be attributed to the introduction of higher yielding triticales in 1979, but at the same time the 1979 Turretfield wheat yield was unusually low. Our data indicates that the highest yielding triticales in the present collection (Coorong, Drira and 117DN) may out-yield Halberd wheat by up to 20% on relatively fertile soils in 'normal' seasons.

Most triticale lines contained higher levels of protein and lysine than wheat or barley (Table 2). There was less variation in protein and lysine than in yield (Tables 1 and 2) and the ranking of triticales for protein and lysine was less stable than for yield (only one of three rank correlation coefficients was significant, $P < 0.05$).

TABLE 2 Crude protein (CP) (N x 6.25) and lysine (Lys) levels of triticale, wheat and barley (% of dry matter)

Site	Turretfield		Turretfield		Turretfield	Perponda
Year	1976		1978		1979	1979
	CP	Lys	CP	Lys	CP	CP
Wheat	14.9	0.42	14.9	0.39	16.3	-
Barley	14.5	0.47	16.0	0.44	13.5	-
Triticale						
Mean	16.6	0.50	16.9	0.51	16.5	12.8
Range	14.8-19.3	0.42-0.59	14.4-18.9	0.46-0.58	14.6-18.1	11.6-14.5
SD	0.8	0.03	0.9	0.03	0.8	0.7
No. of lines	79	79	92	67	42	28

Selected regressions between yield, crude protein and the derived variate crude protein yield are shown in Table 3. Triticale may offer more scope for selection without interference from correlated characters than other cereals.

TABLE 3 Linear regressions for triticales

Variate		Site	Turretfield		Turretfield		Turretfield		Perponda	
y	x	Year	1976		1978		1979		1979	
CP[a]	Yld[b]		-1[c]	0.11[d]	0	0.01	-1	0.23	-2	0.22
CP Y[e]	CP		0	0.01	1	0.16	0	0.04	0	0.03
CP Y	Yld		1	0.87	1	0.88	1	0.92	1	0.89
Lys[f]	Yld		0	0.10	0	0.02		+		+
Lys	CP		6	0.25	7	0.33		+		+

a, crude protein (% of dry matter); b, yield; c, the mean percentage change in y associated with a 10% change in x; d, the coefficient of determination (R_{xy}^2); e, crude protein yield; f, lysine (% of dry matter); +, not determined).

Triticale will have to demonstrate a number of attributes before it can become a broadly-based substitute for other cereals in stock feed rather than a curiosity. These include agronomic adaptation to dry-land production and yields at least comparable to conventional cereals, particularly wheat and barley. It seems that some more recently developed lines may have achieved this. It is unclear whether these improvements have been made at the expense of nutritional quality, There are significant differences in the nutritive value of triticales (Hulse and Laing 1974). It is important that the digestible energy content and essential amino acid availability of the high yielding lines which are to be released are determined in animal studies at the earliest opportunity. Growth depression in pigs fed triticale was highly correlated with trypsin inhibitor activity (Erickson *et al.* 1979) and nutritional inhibitors have been reported in lines under test in Australia (Radcliffe 1979). These effects need to'be assessed in lines proposed for commercial release. It is also important that triticale lines are fully identified when results are reported.

One line, to be registered as Coorong, was released by the Waite Agricultural Research Institute in December 1979. It was the highest yielding triticale in the 1979 Turretfield experiment (Table 1) and the fifth highest yielding line at Perponda. Essential amino acid profiles of Coorong, wheat and

barley from the 1979 Turretfield experiment are shown in Table 4. Pig studies on Coorong beganin March 1980 at the Northfield Pig Research Unit.

TABLE 4 Essential amino acid profile of wheat, barley and triticale (% of dry matter; Turretfield 1979)

	Barley (cv. Clipper)	Wheat (cv. Halberd)	Triticale (cv. Coorong)
Threonine	0.23	0.27	0.26
Valine	0.68	0.71	0.72
Methionine	0.23	0.27	0.26
Methionine + cystine	0.55	0.64	0.63
Isoleucine	0.52	0.57	0.59
Leucine	0.95	1.11	1.12
Phenylalanine	0.75	0.82	0.82
Phenylalanine + tyrosine	1.21	1.38	1.38
Histidine	0.31	0.38	0.38
Lysine	0.47	0.46	0.53
Arginine	0.73	0.86	0.87

I should like to record my gratitude to Mr. T.G. Heard for his co-operation on this project, to Miss J. Bryce for her capable assistance and to Mr. R.V. Kenyon for statistical advice and analysis.

AMINO ACID AVAILABILITY IN CEREALS

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Experiments with rats and pigs have shown that up to 20% of the total protein in some cereal grains passes unabsorbed through the digestive tract. More important, Taverner *et al.* (1980) found that this unabsorbed protein contained a relatively high content of lysine, of which more than 22% of the total in the grain could remain unabsorbed by the pig. Clearly, if the total levels of amino acid present in a grain are not those available to the animal, then available and not total amino acid levels in grains are required for optimal formulation of dietary amino acids. As nutrient requirements become more clearly defined the need increases for information regarding variation in nutritive value of grain, including variation in amino acid availability. This paper discusses the problems and prospects for the feed industry of monitoring the variation in available amino acid levels in cereal grains.

MEASURES OF AMINO ACID AVAILABILITY IN CEREALS

A variety of methods has been employed to estimate amino acid availability in grains, but as each method may estimate a different parameter, the meaning of 'availability' often depends upon the method used. To avoid confusion, Batterham (1979a) suggested that the term availability apply to estimates from techniques that account for the digestion, absorption and utilization of dietary amino acids. This is usually measured with slope-ratio assays (growth assays). However, growth assays are generally not suited to measure amino acid availability in low protein feeds such as cereals for the reasons discussed by De Muelenaere *et al.* (1967) and most availability estimates in grains have been made using digestibility techniques.

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The faecal assay of amino acid digestibility developed by Kuiken and Lyman (1948) has been widely used for grains and Sarwar and Bowland (1975) have obtained comparable values of lysine availability for different wheat samples by growth assay (80 to 89%) and faecal digestibility (80 to 85%). However, Taverner and Farrell (1980a) found that for pigs faecal digestibility values are not necessarily a reliable measure of the quantity of amino acids absorbed from the gut. They found differences among grains and among amino acids in the disappearance of amino acids due to bacterial activity in the hind gut. For example, more threonine than lysine disappeared in the hind gut and further, this probable deamination of amino acids by bacteria was increased as the digestibility of the grain decreased. Thus, Sauer *et al.* (1977) and Taverner *et al.* (1980) used ileal analysis techniques to measure the absorption in the small intestine, the ileal digestibility, of cereal amino acids. In the absence of growth assay values of amino acid availability in grains for pigs, ileal digestibility values such as those in Table 5 have been used as standard measures.

TABLE 5 True ileal digestibility values (%) of lysine and threonine in cereal grains (Taverner *et al.* 1980)

	Lysine	Threonine
Wheat	86	88
Barley	84	87
Maize	83	86
Sorghum	88	91
Triticale	88	87

However, because ileal digestibility assays are time-consuming and costly, they are unsuitable for screening or monitoring the variation in amino acid availability among grain samples. Unfortunately, chemical measures of available or reactive lysine that have been widely used to monitor variation in availability in pig feeds have recently been found unsuitable for this purpose in grains (Taverner and Farrell 1980a) and other proteins (Batterham *et al.* 1978). The general lack of agreement between the chemical and biological estimates for cereals is presented in Table 6.

TABLE 6 Chemically-'available' lysine, *in vitro*-N digestibility and the true digestibilities at the ileum of N and lysine in wheat samples (%) (Taverner and Farrell 1980a)

	Lysine		N digestibility	
	Ileal digestibility	Chemically 'available'	Ileal	*In vitro*
Wheat 1	89.0	90.7	92.3	91.4
2	83.3	89.2	90.9	87.0
3	78.7	90.0	87.0	81.8
4	70.7	90.4	83.0	79.9
5	85.8	93.9	91.6	87.8

Another approach has been to measure protein digestibility using an *in vitro* assay. For example, Buchmann (1979) studied protein digestibility in barley using a relatively simple assay with the proteolytic enzymes pepsin and pancreatin, and Taverner and Farrell (1980b) used pronase enzyme to study protein digestibility in wheat. The assays were inapplicable to a range of

different cereals, but once standardized against a biological measure of availability they provided a rapid and accurate means of studying variation in availability within a grain.

VARIATION IN AMINO ACID AVAILABILITY IN CEREAL GRAINS

Using in *vitro* digestibility methods, Buchmann (1979) found that protein digestibility in more than 300 barley samples varied between 82.9 and 92.5%, with a mean value of 87.8 ± 1.9%. Taverner and Farrell (1980b) found a similar range in protein digestibility (87 to 95%, mean 92 ± 1.1%) among 47 wheat samples but estimated a wider range of values for lysine digestibility (81 to 92%, mean 86 ± 2.1%). In both studies, grain variety and environment had only small effects on protein digestibility. Taverner and Farrell (1980b) found that although protein content varied both between grain varieties and to a larger extent between grains from different localities, they estimated that lysine availability varied between these grains by 4.5% (Table 7). Buchmann (1979) and others have found protein content to be positively correlated to protein digestibility in barley, but for both barley and wheat, Taverner and Farrell (1980b) found protein content was a less important factor influencing protein digestibility than fibre content. They found that hemicellulose was the fibre component most closely associated with protein digestibility and amino acid availability. Neutral detergent fibre (NDF), of which hemicellulose is the major component, was also related to protein digestibility such that the amino acids in grain with a high NDF content are likely to be less digestible than those in grains with low NDF values (Table 7). Taverner and Farrell (1980b) used this relationship to predict the availability of lysine in wheat, Similarly, Eggum and Christensen (1975) found that the digestibility of barley protein was linearly related to the N and tannin content of the grain. Clearly, there is potential practical application in this approach of monitoring a variable such as lysine availability through the variation in some simpler parameter such as fibre or tannin content. An equation for the prediction of available lysine was developed from the relationship between the ileal digestibility of lysine in wheat and its N (mg/g) and NDF (%) contents:

Available lysine (mg/g) = 2.19 + 0.11 N - 0.09 NDF; R^2 = 0.76 ($P < 0.001$).

TABLE 7 True ileal digestibility values of lysine and content of N and NDF in wheats grown at five different localities (%) (Taverner and Farrell 1980b)

Locality	Lysine digestibility	N	NDF
1	$88^{ab\dagger}$	2.25^{a}	10.0
2	86^{bc}	1.93^{b}	10.5
3	89^{a}	1.59^{c}	9.4
4	86^{bc}	2.77^{d}	10.1
5	85^{c}	2.92^{d}	11.2

† Within columns, means followed by different superscripts are significantly different ($P < 0.05$).

Thus it is possible to monitor the major variable of nutritive value of wheat protein by the measurement of N and NDF contents. Unfortunately, the original van Soest and Wine (1967) method of determining NDF appears to require some modification for cereal grains (Taverner 1979) and also a close specification of sample preparation (Butcher 1975). Taverner (1979) found the acid detergent fibre (ADF) assay simpler and more repeatable for grains than NDF though not as

closely correlated with amino acid digestibility. Nevertheless, the prediction of available amino acid content in wheat using ADF values may be adopted more easily than other fibre assays because of the close relationship between ADF and digestible energy content (Taverner and Farrell 1980b).

Available lysine (mg/g) = 2.08 + 0.11 N - 0.24 ADF; R^2 = 0.69 ($P < 0.01$).

DE (MJ/kg) = 17.54 - 0.46 ADF; R^2 = 0.61 ($P < 0.001$).

Grain is included in diets for pigs as a source of both energy and protein and its nutritive value is influenced both by the content of available amino acids and of available, or digestible energy. Therefore, it seems that the values of the major variables of the nutritive value of wheat can be estimated from its content of N and ADF.

IMPLICATIONS IN DIET FORMULATION

The intensive livestock industry cannot tolerate wide variation in the quality of feed, its major input. It is important for feed manufacturers to meet nutrient levels stipulated for each feed and many strategies have been proposed for dealing with feed nutrient variability, Most commonly, the chances of violating nutrient requirements are minimized by reducing the expected levels of a feed by an amount that is proportional to its variability. Unfortunately, this approach is often limited by the lack of adequate information on the probability distribution of feedstuff nutrient levels.

Clearly, it is preferable to monitor important nutrient levels of major feed ingredients and, at its simplest level, it appears that this is possible for wheat by measuring N and fibre content. Similar relationships have not been determined for other grains where tannin or alkylresorcinol levels may also affect amino acid availability.

AMINO ACID AVAILABILITY IN PROTEIN CONCENTRATES

E.S. BATTERHAM

Protein concentrates differ from cereals in that the majority of them undergo some form of heat processing, usually to extract oil or tallow, and to reduce moisture content. Excessive heat in processing can result in marked reductions in amino acid availability. Lysine, being dibasic, is especially susceptible as the free ε-amino group may react with aldehyde groups of reducing sugars to form indigestible linkages.

A chemical estimation of 'available' lysine, based on a reaction of the free E-amino group of lysine with dinitrofluorobenzene to form dinitrophenyl lysine was developed by Carpenter (1960). This technique had most application to animal proteins, as carbohydrates interfered with the stability of the dinitrophenyl lysine in vegetable proteins. This problem was avoided by modifications to the assay procedure by Roach *et al.* (1967) when developing the Silcock or 'difference' technique. Additionally the Silcock technique was suitable for estimating free (synthetic) lysine in compounded feeds. Simpler, dye-binding procedures, which also measure the free E-amino group of lysine, have also been developed (e.g. Hurrell and Carpenter 1976).

The underlying principle of the above chemical techniques for estimating lysine availability is that if the E-amino group of lysine is free; then that molecule of lysine is nutritionally available. In order to test this hypothesis and to estimate the availability of lysine in the major protein concentrates for pigs, a series of experiments are being conducted at Wollongbar.

In the initial experiment, eight protein concentrates were compared on an equal total lysine basis in lysine-deficient diets. If there were any differences in growth performance of the pigs fed these diets, then these differences could be taken as reflecting differences in the availability of lysine in these test proteins. The actual diets contained 0.3% lysine from the test proteins and 0.3% lysine from the wheat base (Batterham et *al.* 1978). Additional free lysine (0.4%) was added to a further eight diets to verify that the original diets were in fact lysine deficient. The results are presented in Table 8.

TABLE 8 Availability of lysine (% of total values) in eight protein concentrates as estimated from pig growth response? rat slope-ratio assays and the Silcock test

	Cot	Meat	Meat	Sun	Fish	Rape	Milk	Soya
Gain* - g/d	460	484	475	468	517	538	536	534
Availability - %								
Pigs†	35	52	45	40	90	90	90	90
Rat assay*	76	64	48	64	95	-	103	90
Silcock test*	93	87	84	92	90	93	97	94

* Batterham *et al. (1978).*

† Recalculated from Batterham et *al.* 1978 using a factor of estimated 90% for the high quality meals and assuming 0.1% lysine produces 47 g/d of pig growth. This latter estimate was based on the response to free lysine in a series of pig growth assays (unpublished data).

The results indicate that there were considerable differences in the growth-promoting ability of the meals, with cottonseed meal, two meat meals and sunflower meal inferior to fish meal, rapeseed meal, skim-milk powder and soyabean meal. Using estimates of the response of pigs to free lysine from other experiments, it was estimated that the availability of lysine in the former four meals was approximately 50% less than that of the latter four meals.

The eight protein concentrates were also analysed for available lysine by a rat slope-ratio assay and by the Silcock assay. The results (Table 8) show' that there was general agreement between the rat and pig results. By contrast, the Silcock estimates indicated that all meals had high lysine availabilities.

While the above experiment gives a direct comparison of the protein concentrates on a total lysine basis, it only gives an approximate indication of lysine availability. This occurs because the responses to free lysine were conducted in separate experiments and only one level of test lysine (0.3%) was used. In order to make a valid estimate of lysine availability, a slope-ratio assay was developed with growing pigs (Batterham *et al.* 1979). with this assay, a lysine-deficient diet was formulated and the response to free lysine assessed over a 0.3% range using six increments, each of 0.05% lysine. Test proteins were incorporated into the basal diets in five increments, from 0.05 to 0.25%. A multiple assay was conducted with five test proteins assayed at the one time. Overall, the assay involved 32 diets (seven for the lysine responses, five for each of the five protein concentrates) and 128 pigs (four per diet). The pigs were fed at restricted intakes in an attempt to ensure similar intakes on a liveweight basis.' They were also fed frequently, at three-hourly intervals, to ensure full utilization of added free amino acids (Batterham and O'Neill 1978).

The availability of lysine in five protein concentrates, as assessed by the slope-ratio assay with pigs is presented in Table 9. Also presented are availability estimates in the five meals as assessed by slope-ratio assays with rats and by the Silcock and Carpenter assays.

TABLE 9 Availability of lysine (% of total values) in five protein concentrates as estimated by slope-ratio assays with pigs and rats and by two chemical tests (Batterham et *al.* 1979)

	Cottonseed meal	Fish meal	Meat-and-bone meal	Skim-milk powder	Soyabean meal
Pig assay	43	89	49	85	84
Rat assay	58	104	64	94	89
Silcock test	93	89	84	96	93
Carpenter test	65	90	79	79	77

The results confirm the estimates from the initial growth experiment that the availability of lysine in cottonseed meal and meat-and-bone meal is very low compared to fish meal, skim-milk powder and soyabean meal. These differences were in general detected by rat slope-ratio estimates. In contrast, the differences were not detected by either the Silcock or Carpenter 'available' lysine tests.

The slope-ratio assay is being used to determine the availability of lysine in all the major protein concentrates for pigs. Initial results indicate that low availability is also a problem in sunflower meal (60%), peanut meal (60%) but not in ring-dried blood meal (102%), rapeseed meal (77-97%) or field peas (90%). Of particular interest are the assay results for lupin-seed meal (*L. angustifolius*) where low availability has been recorded in five samples (mean of 54%). These availability 'estimates conflict with an earlier assessment of Batterham (1979b) which indicated that lupins had similar growth-promoting abilities to soyabean meal for pigs. An explanation of the differences may be that slope-ratio assays are more sensitive. than growth evaluation studies in that the former are conducted with lysine-deficient diets while the latter are conducted with optimal or near-optimal diets. As the low availability of lysine in lupins is not a result of excessive heat treatment, it is possibly a reflection of growth inhibitors in the seed preventing the full release of the lysine. Such growth inhibitors are common in leguminous seeds e.g. anti-trypsin factors in raw soyabean seeds. An alternate explanation may be that the lysine molecule is tied up in the seed in a manner that restricts its full release during digestion by the pig.

As with earlier work, the differences in lysine availability were not detected by the Silcock or Carpenter assays.

IMPLICATIONS OF RESULTS

The lack of agreement between the chemical and pig results indicates that factors other than those involving the E-amino group of lysine may be involved in reducing the availability of lysine in these meals. It is possible that the lysine could be absorbed in a form unsuitable for utilization, as both the cottonseed meal and meat-and-bone meal used in Experiment 2 had high true digestibilities with rats (91%, 'Dr. B.O. Eggum, personal communication). It is also possible that binding may be occurring between other amino acids within the

protein molecule. If this is the case, then it is possible that all other amino acids could be similarly affected.

The chemical techniques for available lysine have been used as reference standards in the development of other techniques for lysine availability. This is unfortunate because, as there was little agreement between the chemical and pig results, it is probable that the majority of other laboratory techniques for assessing available lysine may also be inapplicable to pigs. Slope-ratio assays are time-consuming and expensive to conduct and are unsuitable for routine assays. There is a need for the development of simpler, inexpensive techniques for assessing the availability of all essential amino acids in feeds for pigs.

The availability of lysine in the protein concentrates used in the pig assays was also determined with slope-ratio assays with chickens. Preliminary results (Major and Batterham, unpublished data) indicate that all the meals had high availabilities. This means that a between-species difference may exist in the ability to digest and utilize protein concentrates, with pigs and rats being more sensitive than chickens. If this is confirmed, then there is a need for separate available lysine assays for chickens and pigs.

In the past, the term 'availability' has been loosely applied to estimates derived from various biological and laboratory techniques. This had created a lot of confusion in both terminology and estimate values. A suitable definition of availability is, 'an amino acid in a form suitable for digestion, absorption and utilization'. If the term 'availability' was only applied to those techniques which are capable of taking all three factors into account (digestion, absorption and utilization), then this would help reduce the confusion in terminology that presently exists.

The results also indicate that cottonseed meal, meat-and-bone meal, peanut meal and sunflower meals have low availabilities of lysine for pigs. These meals account for most of the protein concentrate produced in Australia and, as such, the results have considerable economic implications to the stock feeds industry. The low availability is presumably a reflection of processing damage. If this is so, then there is considerable scope for developing less severe processing conditions for these meals.

UTILIZATION OF SYNTHETIC LYSINE BY THE GROWING PIG

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Synthetic amino acids have been used in diets fed to experimental animals for more than 50 years. Although synthetic lysine (SL) has been produced industrially for many years (Ottenheym and Jenneskens 1970), economics have favoured its use in commercial pig diets only in comparatively recent times.

It is a common system of management to provide growing pigs (and dry sows) with restricted amounts of food in the form of one or two meals per day. If, as indicated in the studies of Batterham (1974) and Batterham and O'Neill (1978), this method of feeding results in a reduced efficiency of SL utilization, the economic consequences are readily apparent. Moreover, if restricted feeding results in a reduced efficiency of SL utilization, the validity of estimates of lysine requirements derived in this way is open to question.

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RATES OF ABSORPTION

Batterham and O'Neill (1978) attributed the poorer response to SL of pigs fed once daily to differential rates of absorption of free (synthetic) lysine and protein-bound amino acids. It was suggested that frequent feeding enabled a better balance of amino acids to arrive at the sites of absorption and metabolism and thereby result in more efficient utilization.

The time elapsing between the ingestion of protein-bound amino acids and their arrival in the small intestine will be related to the solubility of the foods in question. In the case of cereal-based diets, the constituent protein-bound amino acids are expected to empty from the stomach much more slowly than soluble additives such as SL. Reducing the frequency of feeding, with proportionate increases in meal size, is likely to prolong the course of digestion and, thus, exaggerate differences in the rate SL and protein-bound amino acids are transported to the small intestine.

To confirm that SL is rapidly absorbed from the gut, a study was made of plasma free lysine (PFL) responses to gastric infusions of SL. A wheat-based diet containing 4.8 g lysine/kg was fed as a single daily meal in amounts equal to 10% of metabolic live weight to pigs initially weighing 30.5 (SD, ± 1.2) kg. Gastric infusions of SL were given for durations of either 1, 6 or 12 h following feeding, for 9-d periods in a 3 x 3 latin-square design. In each period, the amount of SL infused was randomly varied at 3-d intervals between doses corresponding to either 0, 2.5 or 5.0 g lysine/kg of food offered. Blood samples were obtained from an indwelling venous catheter at set times after feeding during the post-prandial period on the third day of the treatment.

PFL response to SL dose was marked but was, however, modified by infusion duration (Table 10). In respect of both the 2.5 and 5.0 g lysine doses, the peak concentration of PFL decreased as the duration of infusion was extended. Moreover, with each infusion duration, the peak concentration of PFL for the 5.0 lysine dose was almost exactly double that for the 2.5 lysine dose. Such a close correlation between PFL peak concentration and both dose and duration of SL administration suggests that SL was rapidly and quantitatively absorbed.

TABLE 10 Plasma free lysine levels (μM/100 ml) of pigs given gastric infusions of synthetic lysine

Sampling time (h)	Duration of infusion (h) 1			6			12			SEM
	L-lysine dose (g/kg of food offered) 0	2.5	5.0	0	2.5	5.0	0	2.5	5.0	
1	16^{cd}	32^{bc}	58^{a}	13^{d}	23^{cd}	44^{ab}	15^{cd}	27^{bcd}	31^{bc}	3
1.5	17^{ef}	45^{cd}	89^{a}	15^{f}	31^{de}	51^{b}	13^{f}	27^{ef}	48^{bc}	5
2.5	13^{d}	44^{bc}	87^{a}	11^{d}	31^{bcd}	53^{b}	11^{d}	23^{cd}	47^{bc}	6
4	9^{d}	32^{bc}	63^{a}	6^{d}	36^{b}	69^{a}	10^{d}	18^{cd}	38^{b}	4
6	6^{d}	33^{ab}	36^{ab}	7^{cd}	24^{bc}	42^{a}	7^{cd}	20^{bcd}	28^{ab}	4
12	7^{b}	13^{ab}	10^{b}	8^{b}	10^{b}	11^{b}	5^{b}	16^{ab}	26^{a}	3
24	9^{a}	15^{a}	9^{a}	9^{a}	13^{a}	8^{a}	16^{a}	15^{a}	18^{a}	3

a,b,c,d,e,f - Within rows, means without a common superscript differ ($P < 0.05$).

UTILIZATION OF SYNTHETIC LYSINE

In order to test the hypothesis that differential rates of absorption of free lysine and protein-bound amino acids cause lower growth responses to SL, the effectiveness of providing graded doses of SL by gastric infusion was examined. Pigs were restrictively fed a lysine deficient wheat-based diet as described in the above experiment and growth and food conversion responses to SL supplementation measured when the animals were grown from approximately 22 to 37 kg live weight. SL (in increments of 1 g lysine/kg of food offered from 1 to 6 g inclusive) was infused into the stomach for durations of either 0.5 or 10 h following feeding. The former infusion was intended to simulate the rate that SL would leave the stomach had the lysine supplement been mixed in the food. On the other hand, the latter infusion was intended to supply SL to the duodenum at approximately the same rate that the protein-bound amino acids were thought to be entering the duodenum. One pig was given no SL and acted as a control animal.

There were significant linear relationships between lysine dose and food conversion ratio (FCR) for both the 0.5 h ($P < 0.05$) and the 10 h ($P < 0.01$) infusions. Comparison of these two regressions showed no heterogeneity amongst the residual variances. Although the test for parallelism ($P = 0.07$) did not quite attain statistical significance, there were differences ($P < 0.05$) in FCR response to SL between the two methods of infusion. Based on the derived regressions, the 0.5 h infusion resulted in only 48% as much improvement in FCR as that of the 10 h infusion.

The latter result is similar to the finding in the studies of Batterham (1974) and Batterham and O'Neill (1978) where growth responses of pigs to SL in diets fed once daily were, respectively, 43 and 67% lower than those of pigs fed the same ration six-times daily. As there was not a similar effect of frequency of feeding on diets without SL, Batterham concluded that feeding frequency influenced efficiency of SL utilization. However, the validity of this concept depends on the contentious issue of whether or not nutrient utilization (apart from SL) is affected by feeding frequency. In rats a decrease in feeding frequency, with a proportional increase in meal size, resulted in more of the dietary energy being deposited as fat and less as protein in the body (Pocknee and Heaton 1976). Although a decrease in frequency of feeding has been shown to have an opposite effect in the pig (Friend and Cunningham 1967), these and other similar studies indicate that nutrient utilization can be affected by feeding frequency. For this reason, differences in response to SL associated with the frequency with which the food is fed cannot be accepted unequivocally as being due only to differences in SL utilization.

To resolve this question, the effect of providing pigs with the same daily amount of SL at various frequencies on average daily gain (ADG), FCR and carcass composition and on N retention was examined in experiments with 48 and 16 animals respectively. This was done without frequency of feeding confounding the effect of frequency of SL administration by providing the daily allowance of food in seven equal portions fed at two-hourly intervals. The daily allowance of SL (equal to 3.5 g lysine/kg offered food) was given either once/d in the first meal or at frequencies increasing serially to seven/d. Pigs on an eighth treatment (control) were fed the basal diet (4.8 g lysine/kg) seven-times daily.

In both experiments, response to SL supplementation was significantly ($P < 0.05$) affected by the frequency the lysine supplement was fed. Mid backfat and percentage dissected fat in the hind leg decreased linearly and *N* retention increased linearly with increasing frequency of SL administration up to four-times daily beyond which no additional response occurred. ADG and FCR for the

22.2-51.0 kg liveweight growth stage remained unchanged with increasing frequency of SL administration up to and including three-times daily, but with more frequent administration there was a uniform improvement in the response. Results are summarised in Table 11.

TABLE 11 Response to synthetic lysine (SL) and the relative utilization (RU) of SL indicated by minimum and maximum responses to frequency of giving SL

Criterion	Control	Response to frequency of giving SL			
		Minimum	Maximum	% RU	R^{2*}
ADG (g/d)	441	527	554	76	0.80
FCR (g food/g gain)	3.03	2.58	2.43	75	0.95
Mid-backfat (mm)	19.5	16.7	14.8	60	0.95
Fat in leg (%)	30.6	27.4	25.0	57	0.89
N retention (g/d)	10.5	14.8	16.6	71	0.95

* Variance explained for relationships of response to frequency of giving SL.

Timing of SL administration in relation to the ingestion of a lysine-deficient diet has been shown to influence the growth-promotant effectiveness of SL. These results confirm the findings of Batterham (1974) and Batterham and O'Neill (1978) that dietary supplements of SL are utilized less efficiently for growth when diets are restrictively fed once daily than when fed more frequently. Under systems of once daily restricted feeding, the efficiency with which SL is utilized for growth relative to its potential utilization is considered to be about 70%.

CONCLUSIONS

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The successful agronomic developments with triticale have provided the pig industry with a new source of energy and amino acids. However, the possibility exists that as with lupins the seeds may contain anti-nutritional factors that could inhibit amino acid availability. There is a need for greater awareness of the potential of such factors in new feeds and greater screening of new varieties as they are developed. This work should be done where possible using laboratory screening techniques in conjunction with agronomic assessment, and before the product is ready for release as a stock feed.

The pig has been shown to be extremely sensitive to the availability of lysine in both cereals and protein concentrates. There is the need for the development of rapid, inexpensive techniques for assessing available lysine. As the mechanisms for reducing lysine availability are likely to vary, particularly between cereals and protein concentrates, it is probable no one technique will be suitable for all sources of feeds. There is also considerable scope for modifying processing conditions for protein concentrates, with the aim of reducing the degree of damage associated with processing. This is the preferable long term solution and would reduce the need for assays for amino acid availability.

The large variation in lysine availability in feeds indicates the need for both nutrient composition and requirements to be expressed in terms of 'available rather than total amino acids. Care should also be taken when interpreting past work based on crude protein or total amino acid levels, as these may not reflect

dietary available amino acid contents, In the evaluation of new sources of protein it is preferable to use uniform high quality meal, such as soyabean meal, as the control rather than a more variable meal, such as meat-and-bone meal, as has been the practice in past Australian research.

The inefficient utilization of free lysine under once daily feeding systems has considerable implications for both research and the pig industry. For research it is necessary to ensure that supplements of free amino acids are fully utilized. This can best be achieved by either frequent or ad *lib.* feeding. Care is also needed when interpreting past estimates of amino acid requirements as these may be over-estimates if the supplements of free amino acids used to define the response curves were not fully utilized.

For the pig producer, full utilization should be achieved by either frequent or ***ad*** *lib.* feeding. The former is only practical in larger units using automatic feeding. The latter is more likely to be adopted as the industry adopts more liberal feeding. systems. This should occur as a result of the industry producing meat from entire males together with genetic selection for lean meat production.

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