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Effects of genotype and processing technology on the protein quality for ruminants and poultry of UK rapeseed

by

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ABSTRACT

Factors affecting the protein quality of rapeseed meal were investigated. The effect of rapeseed variety was studied by selecting five different varieties (Canberra, Fortress, Gemini, Royal and Winner) taken from three different locations (Cambridgeshire, Hampshire and Northumberland). Samples were divided in two and one subsample of each variety x location combination was extracted with ether on a laboratory scale to produce a simulated rapeseed meal. The whole seeds and meals were analysed for chemical composition, amino acid availability (in chickens) and degradability and digestibility (in ruminants) using *in vitro* techniques. No substantial differences between varieties were observed. The effect of processing mill was investigated by taking samples of rapeseed meal from Unitrition in June and October, Cargill in October, and ADM in December, and these samples were analysed for chemical composition, amino acid availability in chickens (*in vivo*) and rumen protein degradability (*in situ*). There was no evidence that selecting rapeseed meal from a particular processor would achieve a consistent improvement in the protein quality of rapeseed meal.

A range of different treatments was applied to rapeseed meal with the aim of improving its protein quality for ruminant and monogastric animals. The efficacy of the different treatments was estimated *in vitro*. For ruminant animals, treatments consisted of heating the meal to different temperatures for different times in the presence and absence of water and with the application or otherwise of pressure. The two treatments that resulted in the greatest increase in predicted digestible undegradable protein content involved dry heating rapeseed meal in an oven at 80^0C for 80 min (RUM1) or at 130^0C for 20 min (RUM2). When evaluated *in situ*, RUM2 reduced ($P<0.001$) the effective degradability of rapeseed meal (outflow rate 0.06 h^{-1}) and increased ($P<0.01$) the undegradable protein content of rapeseed meal by 9%. For monogastric animals, treatments consisted of adding a cell wall degrading enzyme and a phytase, alone or in combination, to rapeseed meal. The greatest predicted increase in protein digestibility was achieved when the cell wall degrading enzyme was added at rates of 0.4 (POU1) and 0.6 (POU2) g enzyme/kg rapeseed meal dry matter. However, when evaluated *in vivo*, the availability of methionine, cystine, threonine, tryptophan, leucine, phenylalanine and histidine was lower with POU1 than with untreated rapeseed meal.

It is technically and economically feasible to produce rapeseed meal with higher protein quality for ruminant animals (one product is already on the market). It would be possible to do the same for monogastrics, although different approaches would be needed. The advantage of the monogastric market is year-round demand for product, and there is great potential for increasing inclusion rate of rapeseed products in diets. Constraints to be overcome would be the high fibre and relatively low protein content of rapeseed meal (achievable if a means of decorticating the seed could be developed) and increasing the availability of amino acids (achievable by omitting the use of moist heat in the removal of solvent). Further constraints involve reducing the concentration of sinapine (for laying hens) and increasing the palatability of rapeseed meal (which might be achieved by further reducing the concentration of glucosinolates).

SUMMARY

1. An investigation into some of the factors that affect the protein quality of rapeseed meal was conducted. The effects of rapeseed variety, processing mill and treatment of rapeseed meal after processing were studied.

2. Five varieties of rapeseed (Canberra, Fortress, Gemini, Royal and Winner) were collected from three different sites (Northumberland, Cambridgeshire and Hampshire). They were crushed and extracted on a laboratory scale, and the whole seeds and the extracted meals were then analysed for chemical composition and anti-nutritive factors. The rumen degradability and intestinal digestibility of the meals was predicted by an *in vitro* procedure while the amino acid availability to poultry was predicted from a calibration with near infrared reflectance spectroscopy (NIRS).

3. There were no substantial differences between the varieties in terms of their chemical composition, amino acid content or predicted protein quality for either ruminant or monogastric animals. The concentrations of sinapine were approximately half that of typical rapeseed meals from ten years ago, and the concentrations of erucic acid in the rapeseed meals were extremely low. Glucosinolate contents were between 10 and 13 μmol/g rapeseed meal for conventional varieties and between 16 and 21 μmol/g meal for hybrid varieties. Apart from this difference in glucosinolate content, there is little basis for selecting specific varieties to increase the nutritive value and protein quality of rapeseed meal. This would be difficult to achieve anyway as most of the mills do not separate incoming batches of rapeseed on the basis of variety. Two varieties of fully restored hybrids (Toccata and Royal) on the HGCA Recommended List have higher glucosinolate contents than other varieties, but apart from these there is no clear difference in glucosinolate content between conventional and hybrid varieties.

4. Samples of the incoming rapeseed and the rapeseed meal produced were collected from different mills at different times of the year to reflect both freshly harvested and stored rapeseed. Two of the mills operate a continuous extraction process while the other operates a batch extraction process. All mills use steam or heat and moisture to drive off the solvent after extraction. Differences between samples of rapeseed meal taken from different mills were small in terms of chemical composition, rumen degradability of protein (estimated *in situ*), digestibility of protein and gross energy (estimated *in vivo* with growing chicks) or the true availability of essential amino acids (estimated *in vivo* with caecectomised cockerels). The availability of lysine was low, and other researchers have demonstrated that this is a consequence of the process by which the extraction solvent is removed. Solvent can be driven off as quickly without the use of steam and animal performance (particularly pig and poultry performance) is improved when they are fed these non-toasted rapeseed meals compared with rapeseed meals that have been produced conventionally.

5. A range of treatments were applied to a sample of rapeseed meal in an attempt to improve its protein quality for both ruminant and monogastric animals. For ruminant animals, the objective was to reduce

the rumen degradability of protein while not affecting intestinal digestibility. Physical treatments are more effective at this than are chemical treatments, and so the approaches that were tested involved heating the rapeseed meal to different temperatures for different times in the presence or absence of water and with the application or otherwise of different pressures. The rumen protein degradability and intestinal digestibility of the treated rapeseed meals were predicted *in vitro*. From these data, the two treatments that resulted in the greatest predicted increase in digestible undegraded protein content (for ruminants) were selected. These were heating the rapeseed meal to 80^0C for 80 min and heating the rapeseed meal to 130^0C for 20 min. For monogastric animals, the use of two different enzymes was investigated using different enzyme concentrations and different combinations of the two enzymes. The enzymes that were used were a cell wall degrading enzyme and a phytase. The effect of the different treatments on protein digestibility in the monogastric gut was estimated *in vitro*. The two treatments that resulted in the greatest increase in protein digestibility involved treating the rapeseed meal with the cell wall degrading enzyme at rates of 0.4 and 0.6 g enzyme/kg rapeseed meal dry matter.

6. A sample of UK grown double zero rapeseed meal that was harvested in 2001 and stored until June 2002 before being processed was taken and subjected to the two 'ruminant' treatments (RUM1, RUM2) and the two 'monogastric' treatments (POU1, POU2). The rate and extent of ruminal protein degradation of protein in the untreated rapeseed meal (UT), RUM1 and RUM2 was estimated *in situ*. The true availability in caecectomised cockerels of amino acids in UT, POU1 and POU2 was estimated *in vivo*. Heating rapeseed meal to 130^0C for 20 min significantly reduced protein degradability in the rumen but the estimated digestible undegraded protein (DUP) content was not significantly different from untreated rapeseed meal. However, the estimated DUP contents of the treated and untreated rapeseed meals were not significantly different from soyabean meal either. Treating the rapeseed meal with cell wall degrading enzyme did not increase the true availability of amino acids in poultry, nor increase the available essential amino acid content of rapeseed meal. Untreated rapeseed meal provided more available sulphur amino acids than soyabean meal, but otherwise was inferior to soyabean meal as a supplier of essential amino acids to poultry. Other workers have observed that pectinase activity with rapeseed meal increases its efficiency of utilisation by poultry, and proteases and galactosidases have been effective with soyabean meal. Selecting and developing appropriate enzymes may be a means of reliably improving the nutritive value of rapeseed meal to pigs and poultry.

7. Processing mills in the UK are investigating means of treating rapeseed meal to improve its protein quality and nutritive value. A treated rapeseed meal with a lower rumen degradability of protein compared with 'conventional' rapeseed meal is on the market, but there would be considerable opportunities for expanding the utilisation of rapeseed meal if its inclusion rate in pig and poultry diets could be increased. The constraints to increased utilisation of rapeseed meal are its high fibre and low protein content, its low palatability and the problem (perhaps perceived rather than real) of its anti-nutritive factors. Developing a means of removing its hull in a cost effective manner would help address the first two constraints and may enhance palatability. The sinapine content must also be reduced if

rapeseed meal is to be included in the diets of laying hens. Altering the processing technique to reduce the heat damage that occurs when the solvent is removed would do much to increase the availability of the relatively small amount of lysine that is present in rapeseed meal.

TECHNICAL DETAIL

Introduction

Rapeseed meal is an important co-product of rapeseed oil production. In 2002, 745 000 t were produced in the UK, of which 483 000 t were used in compound feed (DEFRA statistics). In terms of quantity, it is the largest indigenous plant protein that is produced, but its usage in compound animal feed is about half that of imported soyabean meal. The reason for the relatively low incorporation rate of rapeseed meal into animal feeds is the presence of anti-nutritive factors in rapeseed meal that reduce its nutritive value to livestock, particularly monogastrics. Previous work has demonstrated that modern varieties of rapeseed with low glucosinolate contents can be fed as freely as soyabean meal in the diets of adult ruminant animals (Moss, 2002; Rymer and Short, 2003). However, problems are encountered when diets with high inclusion rates of rapeseed meal are fed to monogastric animals, and inclusion rates of 0-2 % for laying hens and a maximum of 5% for broilers are industrial norms. There is a tremendous opportunity to increase the utilisation of rapeseed meal in the diets of monogastric animals if the constraints associated with rapeseed meal can be overcome. In 2003 (provisional figures, DEFRA statistics), 4.9 million tonnes of compound feed were made in the UK for the pig and poultry market. If the inclusion rate of rapeseed meal could be increased by just 3 percentage units, this would represent an increase in rapeseed meal utilisation of 147 000 t or 20% of total rapeseed meal production in 2002. Clearly, such an increase in the demand for rapeseed meal would have an impact on the value of the oilseed rape crop that should be reflected in the returns that are made by growers and processors. To achieve such an increase in the utilisation of rapeseed meal, however, the constraints associated with feeding rapeseed meal to monogastric animal need to be overcome.

Rapeseed meal is a feed with, relative to soyabean meal, a low protein and high fibre content. The amino acid profile of rapeseed meal, however, complements soyabean meal well and a 50/50 mix of soyabean meal and rapeseed meal could be an ideal feed for monogastric animals that would reduce the reliance on synthetic amino acids to supply sufficient limiting amino acids to the animal. The lysine content of soyabean meal is relatively high (whereas that of rapeseed meal is low), while the methionine and cystine content of rapeseed meal protein is high and that of soyabean meal is low. When fed together, therefore, the two feeds ought to have a synergistic effect with deficiencies in the limiting amino acid content of one feed being met by the other and vice versa. However, the anti-nutritive factors in rapeseed meal prevent this being a viable proposition at present.

The high fibre content of rapeseed meal (ca 295 g neutral detergent fibre/kg dry matter, Rymer and Short, 2003) contributes to the relative indigestibility of rapeseed meal for monogastric animals as well as diluting the (more important) protein and energy contents of the feed. Most of the fibre will be concentrated in the seeds' hull, but unlike soyabeans it is relatively difficult to remove the rapeseed hull (Hill, 1991). Rapeseed meal is therefore usually undecorticated (Rymer and Short, 2003), with the consequences this has on nutrient content and digestibility. Coupled with this is the glucosinolate content of rapeseed meal, which though much reduced in the industrial standard 'double low' varieties, is still considered too high for pigs and

poultry. In Canada and the USA, the standard for glucosinolate content in dried canola meal is set at a maximum of 30 μmol/g dry matter (Moss, 2002) and in the EU, double low varieties of rapeseed meal should not exceed 20 μmol/g (Moss, 2002). Typical values in UK rapeseed meals are in the range of 10-14 μmol/g fresh weight (I. Mayers, pers. comm.), but it is still believed that even at these relatively low concentrations, problems would be encountered with pigs scouring and broiler meat being tainted. Whether or not it is actually the glucosinolates that are causing these problems is a matter of some conjecture, as work by Schöne *et al.* (2002) indicated that no problems would be encountered when feeding pigs diets containing less than 2 mmol glucosinolates/kg diet. This would suggest a much higher inclusion rate of rapeseed meal would be possible if glucosinolates were the only limiting factor associated with rapeseed meal. Other anti-nutritive factors that need to be countered include sinapine, a choline ester of sinapic acid. This causes a fishy taint to develop in brown eggs. The consequence of this is that some egg processors in the UK will not accept eggs from any birds that have been fed rapeseed. Saponins reduce the efficiency of utilisation of rapeseed meal by pigs, and tannins in rapeseed meal also reduce its digestibility.

To increase the utilisation of rapeseed meal, therefore, its inherently high protein quality must be expressed. This will involve reducing the fibre content, together with the concentration of anti-nutritive factors. There are various factors that may affect the nutritive value of rapeseed meal, and the objective of this project was to investigate the relative importance of some of these factors. Factors that were considered were the effect of genotype and the effect of the processing mill. In addition, means of treating rapeseed meal (following processing) were investigated to determine if the application of such a treatment might overcome some of the constraints that limit the inclusion of rapeseed meal in both monogastric and ruminant diets.

Materials and Methods

Effect of genotype

Five varieties of oilseed rape were investigated. These were Canberra, Fortress, Gemini, Royal and Winner. Canberra, Fortress and Winner are conventional varieties while Royal and Gemini are hybrids. Royal is a fully restored hybrid and Gemini a varietal association. Gemini and Fortress are no longer on the HGCA recommended variety list. In 2002, Gemini had a relatively high gross output, it was resistant to lodging and downy mildew in autumn and its seed consisted of 417 g/kg oil and 15.2 μmol/g glucosinolates. In the 2002 evaluation of Fortress (HGCA Recommended List, 2002/03), this variety had an average gross output, was short-stemmed and resistant to lodging and downy mildew in autumn. Its seed oil content was 427 g/kg, and the glucosinolate content of its seeds was 14.2 μmol/g. According to the HGCA Recommended List (2004/05), the other varieties used may be described as follows. Canberra is short, with a below average gross output in the Southern region. It is resistant to light leaf spot and stem canker, and its seeds have an oil content of 440 g/kg and a glucosinolate content of 11.9 μmol/g seed. Royal is a fully restored hybrid with high gross output and good lodging resistance. It is early maturing but is susceptible to stem canker. Its seeds have an oil content of 421 g/kg and a glucosinolate content of 18.7 μmol/g seed. Winner has the

highest gross output on the recommended list. It is very early flowering and has good resistance to light leaf spot. Its seeds have an oil content of 433 g/kg and a glucosinolate content of 11.2 µmol/g seed.

Samples of each of these five varieties were collected (in 2002) from trial plots in Cambridgeshire, Hampshire and Northumberland. The samples were crushed and then each sample was divided in two. One subsample was retained for analysis of the full fat seed while the other subsample was extracted (in the laboratory) to produce a simulated rapeseed meal. Samples of the full fat seed and the extracted meal were then analysed for dry and organic matter (DM, OM), ether extract (EE), nitrogen (N), neutral detergent fibre (NDF), water soluble carbohydrates (WSC), non-starch polysaccharides (NSP) and neutral detergent cellulase + gammanase digestibility (NCGD). Total and available (in broilers) amino acid content was predicted by near infrared reflectance spectroscopy. Rumen N degradability was predicted *in vitro* by incubation with protease from *Streptomyces griseus*, and intestinal N digestibility was predicted by incubating the residue with pepsin and pancreatin. Samples were also analysed for the anti-nutritive factors sinapine, erucic acid and glucosinolates. The effect of variety was analysed by analysis of variance after removing the effect of location.

Effect of processing mill

Samples of the incoming rapeseed and the processed meal were collected from three mills at different intervals. This was designed so that the samples of incoming rapeseed represented both freshly harvested and stored material. Target collection months were therefore June, August, October and December from the mills of Cargill, ADM and Unitrition. In the event, samples were collected from ADM in December. Unitrition provided samples in June and October while Cargill provided a sample in October. Samples of the incoming rapeseed and the processed meal were analysed for DM, OM, N, EE, NDF, WSC, NSP and amino acids. They were also analysed for sinapine, erucic acid, glucosinolates and acid detergent insoluble N (ADIN). All samples were of UK origin, but the mills do not differentiate between suppliers and varieties, and all incoming seed is bulked and processed together.

The rapeseed meals were further analysed for protein quality *in vivo* in chickens. They were fed to broiler chickens between 14 and 28 d of age. Chicks (male Ross 308) were collected from the hatchery as day-old birds and for the first 14 d were reared as a single group fed a proprietary chick crumb. On day 15, the chicks were weighed and then randomly allocated to one of 20 pens (five birds per pen). When in their pens, the birds were fed one of five diets (four pens per diet). The diets were formulated to be isoenergetic and isonitrogenous (based on literature values) and had as their main source of supplementary protein one of the four rapeseed meals collected from the mills, or soyabean meal that acted as a control. The composition of the diets is presented in Table 1. The chicks were fed these diets *ad libitum* for 14 d. Clean, fresh water was always available and presented to the birds from a fount drinker that was regularly raised so that the lip remained level with the birds' backs. From day 21 to 28, complete collections of feeds, refusals and excreta were made, and analysed for DM, OM, N and gross energy (GE) so that estimates of intake, diet digestibility and N balance could be made. Total and available amino acid content and the availability of individual

amino acids of the samples of rapeseed meal and soyabean meal were also analysed *in vivo* using caecectomised cockerels.

The same samples of rapeseed meal and soyabean meal were also characterised *in situ* (Ørskov and Mehrez, 1977) to estimate the rate and extent of rumen N degradability. Samples were incubated in duplicate in three Holstein cows that were each fitted with a rumen cannula. The cows were fed a total mixed ration based on maize and grass silage. Incubation times were 0, 2, 5, 8, 16, 24 and 48 h, after which the bags were rinsed then washed in cold water, dried, weighed and then the residues analysed for N. The estimates of dry matter and N degradability at different times were fitted to a simplified Miesterlich model (Ørskov and McDonald, 1979) to obtain estimates of the rapidly degraded fraction (*a*), the slowly degraded fraction (*b*) and the rate of degradation of *b* (*c*).

Development of treatments

The protein quality of rapeseed meal may be further improved either by altering the processing procedure, or by applying an appropriate treatment to the meal after it has been processed. The objective of this experiment was to investigate a range of treatments that might increase the protein quality of rapeseed meal for either ruminant or non-ruminant animals. Protein quality for ruminant animals relies on the protein being made more undegradable in the rumen while still maintaining its digestibility to the animal. In this way, the protein's amino acids are protected from microbial degradation, but are still available for absorption in the small intestine. For rapeseed meals, physical treatments have generally been more effective than chemical ones (Mustafa *et al.*, 2000), and so only physical treatments were investigated in this project. The application of heat, with or without moisture, has been used in many situations to decrease rumen protein degradability and this was the approach that was adopted in this experiment. Protein quality for monogastric animals may be increased if the meal's cell walls are removed or digested so that the protein is exposed to the animal's digestive enzymes. Since dehulling rapeseed prior to processing is currently impractical, the addition of digestive enzymes to processed meal may overcome the constraints of the high fibre content in rapeseed meal for monogastric animals. Phytates in plant materials render many minerals but also organic matter unavailable to monogastric animals, and the addition of phytases can help alleviate this problem. The approach taken to improve rapeseed meal protein quality for monogastric animals was therefore to investigate the addition of a phytase and a mixture of cell wall degrading enzymes. For both approaches, a range of treatments was applied that was then evaluated *in vitro*. The most promising treatments were selected and applied to a sample of rapeseed meal that was then characterised *in vivo* (for monogastric animals) or *in situ* (for ruminant animals).

For the development of a treatment to increase protein quality for ruminant animals, a sample of rapeseed meal was taken and treated according to the regimes summarised in Table 2. The samples of treated and untreated rapeseed meal were then analysed for soluble N and acid detergent insoluble N. Soluble N content was taken to provide an estimate of degradable (certainly rapidly degradable) N content, while ADIN provided an estimate of indigestible N content. The treatments that yielded the greatest difference between

the ADIN and soluble N content were therefore selected as being those that maximised the digestible yet undegraded N content of the feed.

For the development of a treatment to increase protein quality for monogastric animals, samples of the rapeseed meal were treated with either a phytase, an enzyme with a range of cell wall degrading activities, or a combination of the two. The treatments applied are summarised in Table 3. The phytase used was Ronozyme P (Novozymes Ltd, activity measured as 6444 FYT/g by Novozymes at time of production, which was 13/8/03) while the cell wall degrading enzyme was Depol 740L (Biocatalysts Ltd). The samples of treated and untreated rapeseed meal were then analysed for N solubility in potassium hydroxide solution (0.09 M), which was used to predict protein digestibility in monogastric animals. The treatments that yielded the highest solubility of N in potassium hydroxide solution were therefore selected for further investigation.

Effect of treatment

In this experiment, rapeseed meal (of UK double zero origin) produced by Unitrition in June 2002 was used. It was divided into five subsamples, one of which was left untreated to act as a control (UT). Two of the other subsamples were subjected to the treatments selected to improve protein quality in ruminant animals (these were heating the meal for 80 min at 80^0C, RUM1, and heating the meal for 20 min at 130^0C, RUM2). The other two subsamples were subjected to the treatments selected to improve protein quality for monogastric animals (these were the application of cell wall degrading enzyme at rates of 0.4 and 0.6 g enzyme/ kg feed DM, sample codes POU1 and POU2 respectively). A sample of soyabean meal (SBM) was also used in the experiment, to act as a positive control.

Samples UT, RUM1, RUM2 and SBM were characterised *in situ* using the same procedure as before. Samples UT, POU1, POU2 and SBM were characterised *in vivo* with caecectomised cockerels to estimate the available amino acid content of the feeds. All samples were analysed for dry matter, organic matter, nitrogen and glucosinolate content. The amino acid contents of UT, POU1, POU2 and SBM were estimated using an amino acid analyser. The amino acid contents of RUM1 and RUM2 were also estimated by NIRS.

Effect of replacing soyabean meal with a mixture of rapeseed meal, peas and field beans on the fatty acid composition of broiler lipid.

In a separate experiment reported elsewhere (2365, LS3607), a home grown protein mixture based on maize gluten 60, rapeseed meal, field peas, field beans and synthetic lysine was produced with the same protein and essential amino acid content as soyabean meal. To determine what effect this non-soya protein mix had on the fatty acid composition of broilers, samples of breast and thigh tissue were taken from the carcases of ten birds from each of three treatments (100% soya, 50% soya 50% non soya protein, and 100% non soya protein). The breast and thigh tissue from each bird was mixed together, and the total lipid, fatty acid content and concentration of the fatty acids 16:0, 16:1, 18:0, 18:1, 18:2, 18:3, 20:1 and 22:1 was determined by GC/MS.

Results

Effect of genotype

The chemical composition of the whole seeds and the laboratory-extracted meals are presented in Tables 4 and 5 respectively. There was little difference between varieties in the chemical composition of the whole seeds. Significant ($P<0.01$) but very small differences were observed in the organic matter content and in the ether extract content ($P<0.05$) of the whole seeds. The ether extract content of the whole seeds was higher than the average values given on the HGCA Recommended Lists, but Canberra, Royal and Winner were ranked in the same order as in the Recommended List. Whole oilseeds consist of approximately 500 g/kg oil, 180 g/kg crude protein and 350 g/kg neutral detergent fibre. The whole seeds are quite digestible, as evidenced by the high values of NCGD (ca 82%). There were no significant differences between the five different varieties of rapeseed meal, which were less digestible (mean NCGD 76.4%) but had a higher crude protein, water soluble carbohydrate and neutral detergent fibre content than the whole seeds.

The concentration of different anti-nutritive factors in the whole seeds and the extracted meals are presented in Tables 6 and 7. There were significant, although again very small, differences between the varieties in the concentration of sinapine and erucic acid. The concentration of erucic acid was very low, even in the whole seed. It was virtually undetectable in the extracted meal as the erucic acid is extracted with the oil fraction. The concentration of sinapine was also low, constituting less than 15 g/kg in the extracted meal. Winner had a lower sinapine content than did Canberra. Royal had a much higher ($P<0.001$) concentration of glucosinolate in the whole seed ($P<0.001$) and extracted meal ($P<0.01$) than the other varieties. It is likely that had all of these samples been extracted commercially, their glucosinolate contents would have been even lower as they would have been subjected to more heating during the processing, which denatures the glucosinolates (Rymer and Short, 2003), particularly the 4-hydroxyglucobrassicin (Jensen *et al*., 1995).

The predicted total and available amino acid contents of the different varieties of rapeseed meal are presented in Tables 8 and 10, with the availabilities of the different amino acids being presented in Table 9. There were significant ($P<0.05$), but small differences in the concentrations of methionine, threonine, isoleucine, phenylalanine and histidine as well as leucine ($P<0.01$). The concentration of these amino acids in Canberra was greater than in Royal, although the difference was only between 1 and 2 g/kg DM. There were significant, but again small, differences in the availability of valine, phenylalanine and histidine, with Royal having a slightly lower availability of these acids compared with Canberra. More noticeable was the much lower availability of lysine and threonine compared with the other amino acids, particularly typtophan and phenylalanine. The consequence of the small differences in total amino acid contents and availabilities of amino acids was that there were few significant differences in the concentration of available amino acids, and those that were observed were very small. The ideal protein contents of the five extracted meals for growing pigs were 896, 952, 879, 915 and 930 for Canberra, Fortress, Gemini, Royal and Winner respectively (SEM 38.9, $P>0.05$).

The effect of variety on *in vitro* N degradability and digestibility is summarised in Table 11. No significant differences were observed between varieties, with a mean predicted rumen degradability of 50.1% and overall digestibility of 75.5%.

Effect of processing mill

The chemical compositions of the whole seeds and meals produced by the different mills are presented in Tables 12 and 13. Table 13 also contains the chemical composition data of the soya bean meal that was used in the *in vivo* experiment. There were no clear differences between the mills or the collection months in the chemical composition of either the whole seeds or the extracted meals, except that the ether extract content of the rapeseed meal produced by Unitrition appeared to be higher than the meals produced by Cargill and ADM. Soyabean meal had a higher crude protein content and lower NDF and NSP content than the rapeseed meals. The concentration of ether extract was lower in the extracted meals than the whole seeds, and this was associated with an increase in the concentration of crude protein and NSP, although the concentration of NDF was lower in the extracted meals compared with the whole seeds.

The concentration of various indigestible or anti-nutritive factors in the whole seeds and meals are presented in Table 14. The concentration of erucic acid in the rapeseed meals was negligible. The sinapine content was also low, but processing had increased the concentration of acid detergent insoluble N. The concentration of all these factors was noticeably lower in the soyabean meal compared with the rapeseed meals. The total concentration of glucosinolates in the whole rapeseeds was between 17 and 28 μmol/g DM. In the rapeseed meal samples that were produced from these seeds, the total glucosinolate content was much lower, below 8 μmol/g DM. The 4-hydroxyglucobrassicin was the glucosinolate that proved to be most susceptible to heat treatment.

The diet digestibility and N balance of the chicks fed diets supplemented with one of the four rapeseed meals or the soyabean meal is presented in Table 15. There were no significant differences between treatments in terms of dry matter or gross energy digestibility. The N digestibility of the diet supplemented with rapeseed meal collected from Unitrition in June was significantly lower ($P<0.05$) than the N digestibility of the diet supplemented with soyabean meal, but there were no significant differences between the diets supplemented with rapeseed meal. There were also no significant differences between diets in the chicks' N balance. No significant differences between diets were observed in the dry matter intake by the birds, although this was low at 41 g/bird/d.

The concentration of total amino acids in the four rapeseed meal samples and the sample of soyabean meal is illustrated in Figure 1. The high concentration of essential amino acids in soyabean meal relative to rapeseed meal is evident in this figure, and this is mostly a reflection of the higher protein content of soyabean meal. The concentration of sulphur amino acids (methionine and cystine), however, was higher in rapeseed meal. Differences between the rapeseed meals taken from different mills were small. The true availability of the individual amino acids is presented in Figure 2. The low availability of amino acids in rapeseed meal

compared with soyabean meal is evident in this Figure, particularly lysine, cystine, threonine, tryptophan and isoleucine. Again, the differences between the different rapeseed meal samples were small. The concentration of available amino acids is presented in Figure 3, where again the superiority of soyabean meal over rapeseed meal as a supplier of essential amino acids (including the sulphur amino acids) may be clearly seen.

The effective rumen degradability (calculated at a rumen outflow rate of 0.06 h^{-1}) and the calculated concentrations of rumen degradable (ERDP) and digestible undegradable protein (DUP) in the samples of rapeseed and soyabean meal are presented in Table 16. The protein in soyabean meal was significantly ($P<0.001$) more degradable than the protein in rapeseed meal. The concentration of ERDP was 65% greater in soyabean meal ($P<0.001$) while that of DUP was 30% greater ($P<0.001$). The effective degradability of the rapeseed meal taken from Cargill in October was significantly ($P<0.001$) greater than that of the other rapeseed meal samples. The ERDP content of the Cargill meal was significantly greater than the other meals, while that of the sample taken from Unitrition in June was significantly lower. The reverse was true for DUP content, with the Unitrition/ June sample having the highest DUP content and the Cargill/ October sample the lowest.

Development of treatments

The solubility of rapeseed meal N in potassium hydroxide solution following treatment with different enzymes is summarised in Table 17. The relationship between N solubility and enzyme concentration is summarised in Table 18. The highest solubilities (corresponding to the highest predicted protein digestibilities in monogastric animals) were observed when the rapeseed meal was incubated with 0.4 and 0.6 g cell wall degrading enzyme/kg rapeseed meal DM. No relationship between N solubility and phytase concentration was observed, but there was a relationship between N solubility and cell wall degrading enzyme concentration (R^2=62.8%). There was no evidence that N digestibility was improved if the cell wall degrading enzyme was mixed with phytase. The treatments selected for further investigation in the next experiment, therefore, for monogastric animals were the application of 0.4 and 0.6 g cell wall degrading enzyme/ kg rapeseed meal dry matter.

The predicted digestible undegraded N (DUN) contents of the treated rapeseed meals are presented in Table 19. The application of pressure and the addition of water did not increase DUN content compared with the control. The result obtained by heating rapeseed meal to 134^0C, 228 kPa pressure for 30 min in the absence of water appeared to be aberrant. However, the other treatments in this group did not suggest that this approach would increase protein quality for ruminant animals. The two treatments that produced the highest estimates of DUN content were heating rapeseed meal (in the absence of water) in an oven set at 80^0C for 80 min., or in an oven set at 130^0C for 20 min. These two treatments were therefore selected for further investigation.

Effect of treatment

Treating rapeseed meal had little effect on its chemical composition (Table 20) or its amino acid profile (Table 21) although the addition of cell wall degrading enzyme (POU1 and POU2) increased the concentration of cystine, threonine, valine, isoleucine, leucine and phenylalanine slightly. Lysine availability was significantly ($P<0.001$) lower in rapeseed meal compared with soyabean meal, and treating rapeseed meal with cell wall degrading enzyme did not reverse this effect. Indeed, treatment with 0.4 g cell wall degrading enzyme/kg feed dry matter (POU1) reduced ($P<0.01$) the availability of methionine, cystine, threonine, tryptophan, leucine, phenylalanine and histidine. Treatment with 0.6 g cell wall degrading enayme (POU2), however, did not affect amino acid availability compared with UT. Apart from the lower lysine availability in rapeseed meal, there were no significant differences between soyabean meal and untreated rapeseed meal in terms of their amino acid availability. However, the available amino acid content of soyabean meal compared with rapeseed meal was significantly greater ($P<0.001$) for all amino acids except cystine and methionine. The available methionine content of UT was greater than that of soyabean meal and POU1 ($P<0.01$). There was no significant difference ($P>0.05$) between the four oilseed meals in terms of their available cystine content.

The rate of rumen degradation of protein was much slower when rapeseed meal was first heated to 130^0C for 20 min (Figure 6). The effective rumen degradability of rapeseed meal (calculated at an outflow rate of 0.06 h^{-1}) was significantly ($P<0.001$) lower in rapeseed meal compared with soyabean (Table 22). The effectively rumen degradable protein contents of UT, RUM1 and RUM2 were significantly ($P<0.001$) lower than that of soyabean meal, although there were no significant differences between the treated and untreated rapeseed meals in this parameter. The rumen undegradable protein content of RUM2, however, was significantly greater ($P<0.01$) than that of UT, RUM1 and soyabean meal. When the acid detergent insoluble N content was taken into account, however, RUM2 maintained a higher digestible, undegradable protein content than UT and RUM1 ($P<0.01$) but there was no significant difference ($P>0.05$) between RUM2 and soyabean meal, or between soyabean meal and UT and RUM1.

Effect of replacing soyabean meal with a mixture of maize gluten 60, rapeseed meal, field peas and field beans on the fatty acid composition of broiler lipid.

The lipid content and fatty acid composition of the carcase tissue taken from birds fed diets supplemented with either soya or a non-soya protein mix is presented in Table 23. The fatty acids 18:3 and 22:1 were undetectable in these tissues. There was no significant difference ($P>0.05$) between treatments in the total lipid content of the edible tissues, but a quadratic effect was observed in the concentration of total fatty acids ($P<0.01$), 16:0 ($P<0.01$), 18:0 ($P<0.001$), 18:1 ($P<0.05$) and 18:2 ($P<0.01$) with the 50% soya/non soya protein mix having a higher concentration of these fatty acids than the 100% soya or 100% non soya protein treatments. The proportion of saturated fatty acids in edible tissue was also significantly affected by diet

($P<0.01$) with the 50% non soya protein mix having a significantly lower proportion than was observed in the birds fed the other two diets. These effects of treatment cannot be directly ascribed to the effect of substituting soyabean meal and oil with rapeseed products, however, as the non soya protein mix contained field peas, field beans and maize gluten 60 as well as rapeseed meal and whole rapeseed.

Discussion

Effect of genotype

The crude protein contents of the rapeseed meals prepared from the five different varieties were within the range observed by MAFF (1990) in their analysis of 17 different samples of rapeseed meal. The neutral detergent fibre contents were generally higher than, and the water soluble carbohydrate contents generally lower than, those observed by MAFF (1990). This could be an artefact of the extraction process, as the samples analysed by MAFF (1990) were the products of commercial mills that had also applied heat treatment to the meals in their preparation. In this experiment, the seeds were subjected to a laboratory scale extraction that did not include some of the conditioning stages that form part of the commercial process.

The sinapine content of rapeseed meal was at the lower end of the range quoted by Smithard (1993), suggesting that the concentration of this anti-nutritive factor has declined over the last ten years. Although there were differences between varieties in sinapine concentration, these differences were small and unlikely to make any appreciable difference to the acceptability of rapeseed meal as a feed for brown egg laying hens. Effort either needs to be made to further reduce the sinapine content of rapeseed through breeding (as was the case with glucosinolates and erucic acid), or an effective means of reducing the sinapine content in the processed meal needs to be developed if rapeseed is to be fed to the laying flock to any great extent. This is a topic that is receiving attention by the processing mills in the UK. The erucic acid content of rapeseed meal is very low, partly because the varieties commonly used are 'double zero', with low erucic acid contents in the whole seed, and partly because this is a fatty acid that is extracted with the oil during processing. There is therefore no reason to suppose the erucic acid content of rapeseed meal is acting as a constraint to the use of rapeseed meal in livestock diets. The glucosinolate contents of the conventional varieties were lower than those of the hybrid varieties investigated in this experiment. However, although two of the hybrid varieties (Toccata and Royal) on the HGCA Recommended Lists (2004/05) have noticeably higher glucosinolate contents than other recommended varieties, the HGCA (2004) data do not suggest a consistent difference between conventional varieties and hybrids in terms of their glucosinolate content. In reality, the glucosinolate contents of rapeseed meals produced commercially from these varieties are likely to be lower as heat generated during processing is likely to be greater than the heat produced during the laboratory extraction of the meals, and the heat will denature many of the glucosinolates. Mills do not segregate oilseed rape on the basis of variety, and so the glucosinolate contents of the rapeseed meals produced will reflect the glucosinolate content of the incoming seed and the relative importance of different

varieties of rapeseed in the UK market. However, if UK-produced rapeseed meals typically contain 10-14 μmol glucosinolate/g meal (I. Mayers, pers. comm.), then it should be possible to include rapeseed meal in pig diets at rates of 140-200 g/kg and maintain glucosinolate contents below 2 mmol/kg diet, as recommended by Schöne *et al.* (2002).

Such differences as were observed between varieties in the total and available amino acid content were so small as to have no nutritional significance, and thus no significant difference in the ideal protein content was observed between the five varieties. The availability of lysine and threonine was much lower than the other amino acids, and this may indicate that some heat damage occurred during the extraction process, as the ε-amino group in lysine is particularly vulnerable to Maillard type reactions when subjected to heat and moisture (Newkirk and Classen, 2002). The reduction in lysine availability following processing has been observed before, and it has been noted that modifications to the extraction procedure would be necessary to substantially reduce this loss in lysine availability (Newkirk and Classen, 2002).

No differences between predicted rumen degradability and whole tract digestibility were observed. Although the absolute values obtained from these estimates are probably low, the relative values are likely to be accurate and indicate that variety has no substantial effect on the availability of rapeseed meal protein to ruminant animals.

The variety of rapeseed, therefore, has little if any effect on either the chemical composition or the nutritive value of the rapeseed meal. If improving the nutritive value of rapeseed meal were to be a particular breeding goal then this situation may change. However, the current market structure of rapeseed mitigates against this as the processing mills have no means of segregating incoming rapeseed by variety or even by supplier. There is therefore no mechanism for rewarding growers for producing particular varieties of rapeseed that might generate meals with a higher than average nutritive value.

Effect of processing mill

The processing of rapeseed to produce oil and rapeseed meal first involves the material being sifted to remove large foreign material. The seed is then warmed to 60^0C in a steam jacketed conditioner to make the seed plastic, and it is then flaked. It is then cooked for approximately 15 min at 100-105^0C to reduce the oil's viscosity and agglomerate the protein. The seed is then pressed to expel half the oil. The oil is transferred to a decanter to separate off fines and phosphatides that are then added to the expelled cake stream. The cake is then extracted. Cargill and ADM adopt a continuous extraction process with a counter current extractor that uses increasingly pure solvent to extract the oil. Unitrition, on the other hand, use a batch extraction process. This latter process may be less efficient at extracting oil from residues with a low oil content, and this may explain the slightly higher ether extract contents of the rapeseed meals collected from Unitrition compared with the samples taken from Cargill and ADM. After extraction, the solvent is

driven off by steam (in the Unitrition process) or in a desolventiser/ toaster (in the Cargill/ ADM process) that agitates the meal at 110^0C in a humid environment for 15 min. The solvent (food grade hexane) maintains the temperature of the meal below 65^0C until the solvent has been removed. After this, the humid environment will to some extent protect the protein by preventing the temperature of the meal rising above 100^0C. However, the very presence of the moisture combined with the heat will allow Maillard reactions to occur that will have a particularly marked effect on the availability of lysine. This is because of the ε-amino group in lysine that reacts with carbohydrate moieties to produce indigestible Maillard products (Newkirk and Classen, 2002).

The extraction of oil increases the concentration of the residual matter, particularly the crude protein and ADIN fractions. The NDF content of the meal was lower than the whole seed, however, and this may suggest that although complete dehulling of the rapeseed is not practical, processing does remove some of the seed coat. The production of rapeseed meal significantly reduces the total glucosinolate content of the material, and all of the rapeseed meals that were investigated in this experiment had glucosinolate contents below 8 μmol/g. This low concentration would suggest that, as far as glucosinolates are concerned, inclusion rates of up to 250 kg/t in pig feeds would be acceptable (Schöne *et al.* (2002).

Differences between mills in their extraction process did not affect the digestibility of diets supplemented with rapeseed meal. However, the N digestibility of the diet supplemented with rapeseed meal taken from Unitrition in June was lower than that of the diet supplemented with soyabean meal. This particular sample of rapeseed meal had the highest concentration of sinapine, and the lower N digestibility may be associated with that. In general though, diet digestibility and feed intake were as good with the diets supplemented with rapeseed meal as they were with the diet supplemented with soyabean meal. However, feed intakes were low with all diets. The fact that feed intake was also low with the diet supplemented with soyabean meal might suggest an environmental constraint rather than a problem with the rapeseed meal. In order to collect the excreta to perform the digestibility trial, it was necessary to maintain the chicks on a mesh floor, and this may have contributed to the low feed intakes that were observed.

The available amino acid, ERDP and DUP contents of soyabean meal were significantly greater than those of the rapeseed meal samples. This is primarily a function of the higher protein content of soyabean meal. However, the degradability and digestibility of rapeseed meal protein was lower than that of soyabean meal. This may indicate that the protein in rapeseed meal is subjected to more heat damage during processing than is the case with soyabean meal. Heating generally reduces the degradability of protein in the rumen (Mustafa *et al.*, 2000). Heating in the presence of moisture encourages Maillard-type reactions to occur, and this reduces both protein digestibility and amino acid availability (Newkirk and Classen, 2002; Newkirk *et al.*, 2003). The use of heat and moisture to remove solvent at the end of the extraction process reduces amino acid (particularly lysine) availability (Newkirk and Classen, 2002). It is possible to remove the solvent without the addition of moisture, and it was observed that this did not have a significant impact on the rate at which the solvent was removed (Newkirk and Classen, 2002). Broiler performance was improved

when this was done, even though the glucosinolate content of the rapeseed meal was higher when steam was removed (Newkirk and Classen, 2002). Removing the steam from this stage would increase the availability of amino acids to monogastric animals, which would increase the protein quality of rapeseed meal in pigs and poultry. However, it would increase the rumen degradability of protein and therefore reduce protein quality for ruminants. Despite the different extraction processes that are adopted by the different mills in this study, the effect on the protein quality of rapeseed meal was relatively small. Altering the processing conditions may make a significant impact on composition and digestibility of rapeseed meal, but with the processes that are currently adopted by the major processors there appears to be no significant effect of processing mill on the protein quality of rapeseed meal.

Effect of treatment

None of the treatments investigated resulted in a marked reduction in the glucosinolate content of the rapeseed meal, but even in the untreated meal, the concentration of glucosinolates was low. The addition of cell wall degrading enzyme to aid the digestion of the NDF fraction of rapeseed meal and thereby potentially increase the digestibility of cell contents was not effective at increasing amino acid (particularly lysine) availability. Indeed, if anything, the addition of digestive enzymes decreased amino acid availability. This is in contrast to the observations of Hoare *et* al. (2003), who reported increased nutrient digestibility and digestible energy concentration in rapeseed meal supplemented with non-starch polysaccharide degrading enzymes when fed to pigs. However, these authors used a combination of two enzymes, and did observe that when the enzymes were used alone there was no effect on nutrient digestibility. These authors also noted that the increased digestibility was not reflected in any improvement in animal performance. The use of pectinase did enable canola meal to perform as well as soyabean meal in terms of broiler carcase yield (Kocher *et al.*, 2001) and more detailed work in characterising enzymes may produce one that was more effective at increasing the protein quality of rapeseed meal. The low availability of lysine, that is characteristic of rapeseed meal, arises from the heat damage that occurs during the desolventisation of the meal (Newkirk and Classen, 2002). An enzyme that was capable of hydrolysing Maillard products may therefore increase the lysine availability of rapeseed meal.

Heating rapeseed meal to 130^0C for 20 min increased its undegradable protein content such that it was a better supplier of undegradable protein than soyabean meal. The rapeseed meal product Rapepro that is available on the market also has its protein fraction protected from rumen degradation by heat, although pressure is applied as well in the production of Rapepro. Mustafa *et al.* (2000) observed that heating rapeseed meal to 125^0C (in the absence of water) decreased its rumen degradability without adversely affecting its intestinal digestibility, and they further noted that when applying dry heat the important factor in determining the effect on the rapeseed meal was the temperature to which the meal was heated rather than the length of time that the meal was subjected to heating. However, it was also noted by Mustafa *et al.* (2000) that while there are many reports in the literature of procedures that have reduced the protein

degradability of rapeseed meal, few if any have confirmed whether this also results in improved performance in terms of milk yield and composition.

Technical feasibility and financial implications of treating rapeseed meal

Processing rapeseed produces both rapeseed meal and rape oil, and the value of the oil is approximately twice that of the meal. Altering the processing and treatment of rapeseed meal to increase its nutritive (and hopefully market) value must therefore not be at the detriment of oil production. It is certainly technically feasible to treat rapeseed meal within the processing mill to increase its nutritive value, as the mills are investigating means of doing just that. Indeed, one of the processing mills is already producing rapeseed meals with a higher proportion of rumen undegradable protein for the dairy cow market (Rapepro). To improve the nutritive value of rapeseed meal (particularly its protein quality), however, requires different approaches depending on the market that is being targeted since different constraints apply in the monogastric and ruminant sector. For both ruminant and monogastric markets, the low protein and high fibre content of rapeseed meal is a limitation when it is being used (as it generally is) to replace soyabean meal. For pigs and poultry however, the relatively low availability of amino acids (particularly lysine) further limits the protein quality of rapeseed meal and the presence of anti-nutritional factors also reduce its acceptability. Glucosinolates, sinapine and tannins are still perceived as the anti-nutritional factors of importance, although much of the literature evidence would suggest that glucosinolates are no longer a threat to livestock production except perhaps for their negative effect on intake with monogastrics (Rymer and Short, 2003). For ruminant animals, the low protein content of rapeseed meal relative to soyabean meal is further compounded by the high rumen degradability of rapeseed meal protein.

When developing treatments to improve the nutritive value of rapeseed meal for pigs and poultry, heat treatment may be considered as this denatures the glucosinolates in the meal, although this may result in products that are at least as problematic as the glucosinolates themselves (Rymer and Short, 2003). Extruding rapeseed reduced the glucosinolate content from 4 to 1 μmol/g oil-free dry matter (Keady and O'Doherty, 2000) and resulted in the feeding value (to pigs) of rapeseed meal and soyabean meal being similar. These authors also cited evidence that glucosinolate contents of 1-10 μmol/g oil-free dry matter would not affect diet digestibility in pigs. All of the commercially produced rapeseed meals that were analysed in this study had total glucosinolate contents within this range, and so no problems (as far as glucosinolates are concerned) should be encountered when feeding these products to pigs. While extrusion generates heat in the product being extruded, it should be noted that rapeseed meal is already heat-treated as it undergoes a toasting stage at the end of production, and this reduces the glucosinolate content significantly (Jensen *et al.*, 1995; Newkirk and Classen, 2002). However, Newkirk and Classen (2002) observed that if the toasting stage was omitted, broiler performance was improved even though the glucosinolate content of the rapeseed meal was increased from 9.7 to 21.9 μmol/g DM as a consequence of not toasting the meal. This would suggest that the glucosinolates are not the first limiting constraints in rapeseed meal utilisation by

broilers and that other factors (such as essential amino acid availability) may have a greater impact on the protein quality of rapeseed meal. For monogastrics, therefore, producing rapeseed meal that has not been heat damaged may well have a greater effect on rapeseed meal quality than the introduction of other physical means of reducing the glucosinolate content. With regard to sinapine and tannins, treatments or breeding programmes to reduce their concentration would increase the acceptability of rapeseed meal. For sinapine, this is only really necessary to enable its inclusion in layers' diets but this would potentially open up a large market as there are currently approximately 25 m layers in the UK, all of which are consuming either no, or only very small amounts of rapeseed meal. Hydrothermal treatment of rapeseed meal does reduce its sinapine content, and it was observed (Jeroch *et al.*, 1999) that this resulted in a marked reduction in the trimethylamine content of eggs (this is the component that taints eggs in birds fed rapeseed meal). For laying hens, therefore, the cost in reduced amino acid availability may need to be weighed against the benefit of reduced sinapine content unless an alternative means of reducing the sinapine content of rapeseed meal can be developed.

The addition of cell wall degrading enzymes in this project did not increase amino acid availability. Coupled with the lower protein content of rapeseed meal, this resulted in available amino acids contents being approximately 60% that of soyabean meal, with the exception of the sulphur amino acids in which the supply by rapeseed meal and soyabean meal was about equal. Although in this project the addition of enzymes did not improve the protein quality of rapeseed meal the use of enzymes such as proteases and α-galactosidases have been observed to increase the nutritive value of oilseed meal (Ghazi *et al.*, 2003). Kocher *et al.* (2001) observed that while bird performance was not affected by the replacement of soyabean meal with canola meal, carcase yield was reduced. This effect was overcome when an enzyme product with pectinase activity was added to the diet. Such a treatment would have no implications on rapeseed meal production, as the enzymes are likely to be added at a feed mill rather than the processing mill. They may even be added on farm rather than at the mill.

The value of rapeseed meal as a protein source for pigs and poultry would be greatly increased if the fibre content of the meal could be reduced, as this would increase the protein content of the meal. Using the MAFF (1990) estimates of the crude protein and NDF contents of rapeseed and soyabean meal, the protein content of fibre-free soyabean meal is approximately 563 g/kg DM, whereas that of rapeseed meal is 570 g/kg DM. On this basis, dehulled rapeseed meal would be able to completely replace soyabean meal in livestock diets although constraints because of the lower palatability of rapeseed meal may still apply. Dehulling rapeseed meal is currently not viable either technically or financially, although work is being done to try and develop a means of doing this commercially. The relatively low digestibility of rapeseed meal is still an issue even when rapeseed hulls have been removed (Danielsen *et al.*, 1994) suggesting that some form of insoluble dietary fibre remains after dehulling. The triple low varieties of rapeseed, which have lower fibre and tannin contents than the traditional double low varieties, were not observed to be any more digestible in either pigs (Agunbiade *et al.*, 1991) or cows (Vanhatalo *et al.*, 1995). Dehulling, were it to become technically feasible, would address the lower protein content of rapeseed meal compared with

soyabean meal, but some constraints (lower palatability and digestibility) are likely to remain. The nutritive value of the rapeseed hulls that would be produced is likely to be very low and finding a market for them may be a challenge, although it is possible there may be a niche for them as a ruminant feed or possibly as a prebiotic in monogastric diets.

An opportunity for increasing the protein quality of rapeseed meal for pigs and poultry in the short term may come from altering the desolventising stage of processing so that the meal is not subjected to moist heat. This can be done without extending the time taken to desolventise the meal (Newkirk and Classen, 2002) and so should have little effect on the throughput of rapeseed meal in the mill. In the longer term, developing a commercially viable means of dehulling the seed would increase its protein content, although its digestibility may still be lower than that of soyabean meal. The development of appropriate enzyme technology to increase the digestibility of rapeseed meal for pigs and poultry might increase the amino acid availability in rapeseed meal. This may be done in addition to, or instead of, the dehulling process.

With the varieties of double zero rapeseed that are currently available, there appears to be little consistent difference in the composition of the rapeseed meals that are produced. Plant breeding could in theory produce a variety with a protein content comparable to that of soyabean meal, a virtual absence of anti-nutritive factors and a seed coat that was easily removed during processing. To be attractive to growers, such a variety would also have to yield well, with acceptable agronomic characteristics and a high oil content. At present, this variety does not exist. It is not clear whether the rapeseed market as it is currently structured would be able to sufficiently reward growers for producing such a plant to ensure that it dominated the market and hence brought about a consistent improvement in the feeding value of UK-produced rapeseed meal.

For ruminant animals, the low protein content of rapeseed meal relative to soyabean meal is an issue, but a further constraint is the high rumen degradability of the protein. At an outflow rate from the rumen of 0.06 h^{-1}, rapeseed meal protein is about 58% degradable, compared with 73% for soyabean meal. Heating the rapeseed meal to 130^{0}C decreased its degradability to 53% and the two commercially available rapeseed products that have been treated to increase protein quality for ruminant animals have advertised rumen degradabilities of 48 and 42%. Both products have undergone an autoclave process, but one (Rapetec 1652) is a rape expeller product while the other (Rapepro) is made from extracted rapeseed meal. It is clearly technically feasible to apply heat and pressure to rapeseed meal to improve its protein quality for ruminant animals, and it is reasonable to suppose that other treatments could be applied at the mill as well if there were sufficient demand for the resulting product.

The treatment of rapeseed meal to improve its nutritive value would increase its market value, and the cost of any treatment would need to be recouped in the increased price that the product could attract. The price of rapeseed meal (July-October 2004) is £81-98/t, compared with £150-156/t for Brazilian soya and £152-156/t for Hipro soya. These price differences reflect differences in the protein content of the different feedstuffs, which for these feeds would average 26.7 p/kg crude protein. Rapeseed meal would then be somewhat

underpriced (21.1-25.6 p/kg crude protein). The two treated rapeseed products that are on the market (Rapetec 1652 and Rapepro) are priced at £144-149/t and £122-132/t respectively. Rapepro has a higher digestible undegraded protein content compared with Brazilian soya (157 compared with 136 g/kg DM), but its lower energy content reduces its price to £26/t less than that of Brazilian soya. However, the high energy content of Rapetec 1652 (the treated rape expeller product) results in a price only slightly lower than that of Brazilian soyabean meal. The prices and nutritive values of these feedstuffs are summarised in Table 25. When price was regressed with these descriptors, the best relationship was obtained between price and the ME and DUP content of the feeds. The relationship between these predicted and actual prices is illustrated in Figure 7. From these data it would suggest that any treatments that might increase the ME and DUP content of rapeseed meal should result in an increased market price of the product. Although somewhat volatile, this should assist in determining whether the development of any treatment is likely to be financially viable.

Conclusions

The different varieties of double low rapeseed that are currently available have little effect on the protein quality of rapeseed meal. The high throughput of rapeseed in the processing mills also means that it is not possible to segregate meals on the basis of variety. Although in theory it would be possible to breed a variety of rapeseed meal with a higher protein content and lower concentration of anti-nutritive factors such as sinapine and tannins, this is not a feasible option in the short to medium term. There is therefore little that growers can do themselves to increase the acceptability and market value of rapeseed meal.

With the processing techniques that are currently employed, there is also little difference in the protein quality of rapeseed meals produced by different mills. However, there is potential for the mills to differentiate their product by altering the processing technique, or by applying treatments to the meal after it has been produced. This is already being done at one mill, where an autoclave treatment is applied to either rape expeller or extracted rapeseed to make two different products with lower rumen protein degradability than that of conventional rapeseed meal. These higher value products are aimed at the dairy cow market. Other opportunities for increasing the protein quality of rapeseed meal for pigs and poultry could arise from altering the desolventising stage of the process to remove the use of moist heat as this toasts the meal and reduces the availability of lysine. However, the main opportunity in the future would be the development of a means of dehulling rapeseed so that its protein content became comparable to that of soyabean meal. This would also increase its digestibility (although soluble fibres in rapeseed meal may still render it less digestible than soyabean meal) and perhaps its palatability. The development of appropriate enzymes to increase nutrient availability in rapeseed meal would also enhance its market value, and other work has demonstrated that the use of a pectinase increased the carcase yield in broilers.

Future research should concentrate on the monogastric sector, as this is where the greatest constraints to rapeseed meal utilisation are encountered, and where a year-round market for the product exists. This work should focus on developing a commercially viable means of dehulling rapeseed and on the development of appropriate enzyme technology to supplement rapeseed meal so that its full potential as a valuable protein source for all classes of livestock may be realised.

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TABLES

Table 1. The composition of diets fed to broiler chicks to evaluate the effect of processing mill on rapeseed meal protein quality.

Feed ingredient	Diet composition (g/kg fresh weight)	
	SBM	RSM[1]
Maize grain	600.0	537.0
Poultry fat blend	30.4	30.4
Vegetable oil	16.6	16.6
Soyabean meal	243.8	
Rapeseed meal[1]		307.0
Fishmeal 66	80.0	80.0
Mineral/Vitamin supplement[2]	5.0	5.0
Synthetic methionine	3.1	3.1
Synthetic lysine	8.7	8.7
Limestone	5.9	5.9
Dicalcium Phosphate 18	4.8	4.8
Salt	0.1	0.1
Sodium Bicarbonate	1.6	1.6

[1]This was one of the four rapeseed meals used in this part of the experiment.

Table 2. A summary of the treatments investigated to improve the protein quality of rapeseed meal for ruminant animals.

Treatment code	Temp. (^{0}C)	Time (mins)	Treatment code	Temp. (^{0}C)	Pressure (kPa)	Water (l/kg DM)	Time (mins)
T0	Control		TP0	Control			
T80/10	80	10	TPH	134	228	0	30
T80/20	80	20	TPHW	134	228	2	30
T80/40	80	40	TPL	115	69	0	30
T80/60	80	60	TPLW	115	69	2	30
T80/80	80	80					
T130/10	130	10					
T130/20	130	20					
T130/40	130	40					
T130/60	130	60					
T130/80	130	80					

Table 3. A summary of the treatments investigated to improve the protein quality of rapeseed meal for monogastric animals.

Treatment	Rate of Ronozyme P (g/kg DM)	Rate of Depol 740L (ml/kg DM)	Treatment code
Control	0	0	C
Phytase (PHY)	0.2	0	P1
PHY	0.5	0	P2
PHY	1	0	P3
Cell wall degrading enzyme (CELL)	0	0.2	D1
CELL	0	0.4	D2
CELL	0	0.6	D3
PHY+CELL	0.2	0.2	P1+D1
PHY+CELL	0.5	0.4	P2+D2
PHY+CELL	1	0.6	P3+D3

Table 4. The effect of variety on the chemical composition of whole rapeseed.

	Variety					SEM	Sig.[1]
	Canberra	Fortress	Gemini	Royal	Winner		
Dry matter (g/kg fresh)	937	937	922	931	931	6.2	ns
Chemical composition (g/kg DM)							
Organic matter	964	963	959	959	963	0.9	**
Crude protein	183	180	194	180	175	5.7	ns
Ether extract	497	484	454	467	486	7.8	*
Neutral detergent fibre	326	359	347	369	339	11.8	ns
Water soluble carbohydrates	37.7	44.2	47.1	46.1	44.5	2.73	ns
Non-starch polysaccharides	107	117	126	126	121	5.6	ns
Neutral detergent cellulase + gammanase digestibility (%)	83.1	82.2	81.0	82.3	80.0	1.26	ns

Table 5. The effect of variety on the chemical composition of laboratory-extracted rapeseed meal.

	Variety					SEM	Sig.[1]
	Canberra	Fortress	Gemini	Royal	Winner		
Dry matter (g/kg fresh)	920	921	921	921	915	2.1	ns
Chemical composition (g/kg DM)							
Organic matter	946	950	942	946	947	1.8	ns
Crude protein	356	337	330	348	337	15.5	ns
Neutral detergent fibre	479	504	497	486	486	10.7	ns
Water soluble carbohydrates	71.4	81.5	82.7	82.6	82.5	5.35	ns
Non-starch polysaccharides	214	227	230	237	236	8.7	ns
Neutral detergent cellulase + gammanase digestibility (%)	73.0	78.9	76.4	77.2	76.3	1.45	ns

[1]ns: not significant (P>0.05).

Table 6. The effect of variety on the concentration of various anti-nutritive factors in whole rapeseed

Anti-nutritive factor	Variety					SEM	Sig.[1]
(g/kg DM)	Canberra	Fortress	Gemini	Royal	Winner		
Sinapine	10.0	8.6	9.6	8.8	7.6	0.46	*
Erucic acid	0.0	0.0	1.5	0.0	0.2	0.18	**
Glucosinolates (μmol/gDM)							
Progoitrin	8.71	10.5	11.2	22.9	9.9	1.24	***
Gluconapin	4.59	3.65	5.47	8.03	3.37	0.512	**
4-HGB[2]	3.95	4.14	5.49	5.89	5.44	0.276	**
Total glucosinolates	33.2	28.1	33.1	50.2	27.9	2.52	**

[1]*: P<0.05, **: P<0.01, ***: P<0.001

[2]4-HGB: 4-hydroxyglucobrassicin

Table 7. The effect of variety on the concentration of various anti-nutritive factors in the rapeseed meal

Anti-nutritive factor	Variety					SEM	Sig.[1]
(g/kg DM)	Canberra	Fortress	Gemini	Royal	Winner		
Sinapine	11.4	9.9	10.9	10.0	8.6	0.52	*
Erucic acid	0.0	0.0	0.1	0.0	0.0	0.01	**
Glucosinolates (μmol/g DM)							
Progoitrin	4.40	5.10	5.33	10.31	2.89	0.651	***
Gluconapin	2.47	1.87	2.75	3.75	1.41	0.167	***
4-HGB[2]	2.63	2.46	3.76	3.36	3.03	0.509	ns
Total glucosinolates	11.2	12.3	16.0	21.1	10.4	1.19	**

[1]*: P<0.05, **: P<0.01, ***:P<0.001.

[2]4-HGB: 4-hydroxyglucobrassicin.

Table 8. The effect of variety on the concentrations of total essential amino acids in rapeseed meal.

Amino acid	Variety					SEM	Sig.[1]
	Canberra	Fortress	Gemini	Royal	Winner		
Total amino acid concentration (g/kg dry matter)							
Lysine	21.7	21.8	20.8	20.7	21.1	0.38	ns
Methionine	6.7	6.2	6.4	5.9	6.2	0.12	*
Cysteine	5.9	5.7	6.6	5.9	5.8	0.34	ns
Threonine	16.0	15.7	15.3	14.7	15.2	0.20	*
Tryptophan	3.5	3.3	3.4	3.0	3.1	0.09	ns
Valine	17.3	17.0	17.2	15.8	16.5	0.30	ns
Isoleucine	13.3	13.3	12.9	11.9	12.4	0.21	*
Leucine	22.8	22.7	21.9	20.3	21.5	0.29	**
Phenylalanine	10.8	10.8	10.4	9.6	9.9	0.20	*
Histidine	9.6	9.5	9.2	8.9	9.1	0.12	*

[1]ns: not significant; *: $P<0.05$; **: $P<0.01$.

Table 9. The effect of variety on the availability of essential amino acids in rapeseed meal.

Amino acid	Variety					SEM	Sig.[1]
	Canberra	Fortress	Gemini	Royal	Winner		
Amino acid availability (%)							
Lysine	61.1	61.0	65.0	58.0	58.4	2.24	ns
Methionine	85.0	84.0	85.2	81.7	83.0	0.76	ns
Cysteine	77.4	84.5	80.4	77.5	77.2	1.46	ns
Threonine	62.1	63.0	65.7	62.6	62.0	1.11	ns
Tryptophan	92.8	93.4	92.6	91.6	93.0	0.83	ns
Valine	73.4	71.4	70.7	69.4	70.3	0.53	*
Isoleucine	71.5	72.7	72.7	70.9	70.9	1.03	ns
Leucine	78.7	79.8	79.5	78.6	77.9	0.78	ns
Phenylalanine	103	97.4	95.6	91.3	98.3	1.94	*
Histidine	80.7	76.5	77.0	73.5	75.3	1.00	*

[1]ns: not significant; *: P<0.05; **: P<0.01.

Table 10. The effect of variety on the concentration of available essential amino acids in rapeseed meal.

Amino acid	Variety					SEM	Sig.[1]
	Canberra	Fortress	Gemini	Royal	Winner		
Available amino acid concentration (g/kg dry matter)							
Lysine	13.3	13.4	13.5	12.0	12.3	0.42	ns
Methionine	5.7	5.2	5.4	4.8	5.1	0.10	**
Cysteine	4.6	4.8	5.3	4.6	4.4	0.29	ns
Threonine	9.9	9.9	10.1	9.2	9.4	0.21	ns
Tryptophan	3.2	3.1	3.2	2.8	2.9	0.08	*
Valine	12.7	12.1	12.2	11.0	11.6	0.17	**
Isoleucine	9.5	9.7	9.4	8.4	8.8	0.25	ns
Leucine	17.9	18.1	17.4	16.0	16.8	0.35	*
Phenylalanine	11.1	10.5	10.0	8.8	9.7	0.21	**
Histidine	7.7	7.3	7.1	6.5	6.9	0.16	**

[1]ns: not significant; *: P<0.05; **: P<0.01.

Table 11. The effect of variety on *in vitro* nitrogen degradability and digestibility.

	Predicted rumen degradability or intestinal digestibility (%)	
Variety	Rumen degradability	Intestinal digestibility
Canberra	55.3	78.9
Fortress	50.1	76.2
Gemini	49.6	74.6
Royal	48.9	75.3
Winner	46.4	72.3
SEM	1.85	1.70
Significance[1]	ns	ns

[1]ns: not significant

Table 12. The chemical composition of the whole rapeseed processed by mills at different times of the year.

	Mill/ month			
	Unitrition/ Jun	Unitrition/ Oct	Cargill/ Oct	ADM/ Dec
Dry matter (g/kg fresh weight)	929	930	920	930
Chemical composition (g/kg DM)				
Organic matter	960	955	960	962
Ether extract	475	429	396	411
Crude protein	194	226	198	199
Neutral detergent fibre	532	446	496	533
Water soluble carbohydrates	43.9	40.4	49.9	38.7
Non-starch polysaccharides	125	99.8	128	123

Table 13. The chemical composition of the rapeseed meals produced by mills at different times of the year.

	Mill/ month				Soya bean
	Unitrition/ Jun	Unitrition/ Oct	Cargill/ Oct	ADM/ Dec	meal
Dry matter (g/kg fresh weight)	894	884	879	889	870
Chemical composition (g/kg DM)					
Organic matter	924	925	924	923	933
Ether extract	28.1	26.7	15.	19.	17.8
Crude protein	366	383	381	382	544
Neutral detergent fibre	306	283	290	296	80
Water soluble carbohydrates	96.8	96.6	104	101	104
Non-starch polysaccharides	273	216	221	202	141

Table 14. The concentration of various indigestible or anti-nutritive factors in the whole seeds and extracted meals collected from mills at different times of the year.

Factor (g/kg DM)	Mill/ month				Soya bean
	Unitrition/ Jun	Unitrition/ Oct	Cargill/ Oct	ADM/ Dec	meal
Whole seeds					
Acid detergent insoluble N	1.98	2.31	2.24	2.38	
Sinapine	8.04	6.59	8.53	7.48	
Erucic acid	0.50	1.04	0.03	0.11	
Glucosinolates (μmol/g DM)					
Progoitrin	7.13	6.33	8.01	2.83	
Gluconapin	2.64	2.27	2.89	1.26	
4-HGB[1]	3.81	5.20	2.51	4.16	
Total	17.7	27.5	17.5	12.9	
Extracted meal					
Acid detergent insoluble N	4.35	3.85	3.90	4.02	1.92
Sinapine	9.54	8.61	8.41	7.86	0.23
Erucic acid	0.00	0.09	0.00	0.11	0.00
Glucosinolates (μmol/g DM)					
Progoitrin	4.05	3.85	4.25	3.13	nd[2]
Gluconapin	1.26	0.56	0.37	0.65	nd[2]
4-HGB[1]	0.30	0.39	0.23	0.10	nd[2]
Total	7.84	7.36	7.41	5.87	nd[2]

[1]4-HGB: 4-hydroxyglucobrassicin.

[2]nd: not determined

Table 15. The digestibility and N balance with chicks fed diets supplemented with soyabean meal or rapeseed meal collected from different mills at different times of the year.

Diet supplemented with rapeseed meal	Digestibility			N balance
from (mill/month)	Dry matter	Gross energy	N	(g/d)
Unitrition/Jun	0.787	0.828	0.522	3.25
Unitrition/ Oct	0.794	0.829	0.643	5.05
Cargill/ Oct	0.783	0.820	0.629	4.67
ADM/Dec	0.791	0.826	0.624	4.18
Soyabean meal	0.812	0.846	0.689	4.58
SEM	0.0167	0.0130	0.033	0.706
Significance[1]	ns	ns	*	ns

[1]ns: not significant (P>0.05), *: P<0.05.

Table 16. The effective rumen degradability, effective rumen degradable protein content and digestible undegraded protein content of the samples of rapeseed meal taken from different mills, and a sample of soyabean meal.

	Mill/ month				Soyabean meal	SEM	Sig.[1]
	Unitrition /Jun	Unitrition /Oct	Cargill/ Oct	ADM/Dec			
Effective degradability[2] (%)	59.7	59.2	63.4	58.8	68.0	0.53	***
Effective rumen degradable protein content (g/kg DM)	182	191	200	191	314	1.3	***
Digestible undegraded protein content (g/kg DM)	94	103	88	104	125	1.8	***

[1]Significance, ***: P<0.001

[2]Calculated at a rumen outflow rate of 0.06 h^{-1}.

Table 17. The effect of different enzyme treatments on the nitrogen solubility of rapeseed meal in potassium hydroxide solution.

Sample code	Enzyme concentration (g/kg rapeseed meal DM)		N solubility in potassium hydroxide solution (%)
	Phytase	Cell wall degrading enzyme	
C	0.0	0.0	18.2
P1	0.2	0.0	10.9
P2	0.5	0.0	11.2
P3	1.0	0.0	10.3
D1	0.0	0.2	16.5
D2	0.0	0.4	22.7
D3	0.0	0.6	23.9
P1+D1	0.2	0.2	23.5
P2+D2	0.5	0.4	21.3
P3+D3	1.0	0.6	21.3

Table 18. The regression of N solubility in rapeseed meal subjected to different enzyme treatments on the concentration of those enzymes.

Regression equation	R^2 (%)	P	s
N sol % = 19.5 – 4.45(Phytase concentration, g/kg)	10.5	0.360	5.46
N sol % = 13.8 + 17.6 (Cell wall degrading enzyme concentration, g/kg DM)	62.8	0.006	3.52

Table 19. The effect of different treatments on the predicted digestible, undegraded N content of rapeseed meal.

Sample code	Summary description of treatment applied				Predicted digestible undegraded N content (g/kg DM)
	Temperature (^{0}C)	Pressure (kPa)	Water (l/kg DM)	Time (min)	
T0	-				35.5
T80/10	80			10	36.6
T80/20	80			20	33.4
T80/40	80			40	32.5
T80/60	80			60	34.8
T80/80	80			80	37.0
T130/10	130			10	34.9
T130/20	130			20	36.6
T130/40	130			40	36.2
T130/60	130			60	31.8
T130/80	130			80	25.0
TP0	-	-	-	-	35.3
TPH	134	228	0	30	-6.6
TPHW	134	228	2	30	34.3
TPL	115	69	0	30	33.5
TPLW	115	69	2	30	25.5

Table 20. The chemical composition of the samples of treated and untreated rapeseed meal and soyabean meal.

	Rapeseed meal sample[1]					Soyabean
	UT	POU1	POU2	RUM1	RUM2	meal
Dry matter (g/kg fresh weight)	921	968	969	939	932	892
Chemical composition (g/kg dry matter)						
Organic matter	926	910	919	927	927	933
Crude protein	373	366	361	370	376	533
Glucosinolates (μmol/g DM)						
Progoitrin	2.30	1.44	1.86	2.62	2.10	nd[2]
Gluconapin	1.07	0.78	0.68	2.10	1.15	nd[2]
4-HGB[3]	0.17	0.02	0.11	0.25	0.12	nd[2]
Total	5.09	4.17	4.36	6.79	4.98	nd[2]

[1]UT: untreated, POU1: UT treated with 0.4 g cell wall degrading enzyme/kg feed DM, POU2: UT treated with 0.6 g cell wall degrading enzyme/kg feed DM, RUM1: UT heated to 80^0C for 80 min, RUM2: UT heated to 130^0C for 20 min.

[2]nd: not determined

[3]4-HGB: 4-hydroxyglucobrassicin.

Table 21. The total concentrations of essential amino acids (g/kg DM) in the samples of treated and untreated rapeseed meal and soyabean meal.

	Soyabean	Rapeseed meal[1]				
	meal	UT	POU1	POU2	RUM1	RUM2
Lysine	32.1	19.9	21.1	20.7	18.6	18.7
Methionine	6.4	6.8	6.9	7.1	7.5	7.6
Cystine	6.8	8.1	9.0	9.1	8.2	8.4
Threonoine	20.0	15.5	16.7	16.6	16.3	15.9
Tryptophan	7.5	5.3	5.4	5.3	5.4	5.0
Valine	26.1	19.4	22.3	21.9	19.5	19.2
Isoleucine	25.6	15.0	16.7	16.5	14.3	14.5
Leucine	41.6	26.0	28.8	28.3	24.4	25.3
Phenylalanine	27.4	14.8	16.0	15.7	14.4	14.4
Histidine	13.6	9.7	10.7	10.4	8.9	9.2
Arginine	38.7	21.6	22.6	22.8	20.6	21.9

[1]UT: untreated, POU1: UT treated with 0.4 g cell wall degrading enzyme/kg feed DM, POU2: UT treated with 0.6 g cell wall degrading enzyme/kg feed DM, RUM1: UT heated to 80^0C for 80 min, RUM2: UT heated to 130^0C for 20 min.

Table 22. The effective rumen degradability, effective rumen degradable protein content and digestible undegraded protein content of the samples of treated and untreated rapeseed meal, and a sample of soyabean meal.

	Rapeseed meal[1]			**Soyabean**	SEM	Sig.[2]
	UT	RUM1	RUM2	meal		
Effective degradability[3] (%)	58.2	56.7	53.0	72.5	0.64	***
Protein content (g/kg DM):						
Effectively rumen degraded	204	198	188	394	2.6	***
Rumen undegraded	172	171	188	168	2.6	**
Digestible undegraded	131	130	145	141	2.3	**

[1]UT: untreated rapeseed meal, RUM1: UT heated to 80^0c for 80 min, RUM2: UT heated to 130^0C for 20 min.

[2]Significance, **: P<0.01, ***: P<0.001

[3]Calculated at a rumen outflow rate of 0.06 h^{-1}

Table 23. The nutritive value of oilseed by-products and their market price.

Feed	Market price (£/t)	Crude protein content (CP), g/kg DM	ME (ruminants), MJ/kg DM	Digestible undegraded protein content (DUP), g/kg DM
Hipro soya	152-165	568	13.8	189
Brazilian soya	150-156	530	13.4	136
Rapeseed meal	81-98	383	12.0	100
Rapetec 1652	144-149	300	16.0	120
Rapepro	122-132	340	12.0	157

Table 24. The fatty acid composition (g/kg fresh tissue) of broilers fed different proportions of soya or non-soya protein.

Fatty acid	Proportion of non-soya protein in diet[1]			SEM	Significance[2]
	0.0	0.5	1.0		
Total lipid	17.1	18.7	18.5	2.14	ns
16:0	2.94	3.87	2.73	0.329	**
16:1	0.19	0.28	0.23	0.038	ns
18:0	1.01	1.40	0.86	0.103	***
18:1	3.02	4.60	3.37	0.475	*
18:2	4.05	5.42	3.28	0.496	**
18:3	nd	nd	nd		
20:1	0.07	0.09	0.06	0.011	ns
22:1	nd	nd	nd		
Total fatty acids	11.3	15.7	10.5	1.43	**
% saturated fatty acids	56.4	45.7	60.2	3.73	**

[1]Source of dietary protein was either soyabean meal, or a mixture of rapeseed meal, peas, field beans and synthetic lysine formulated to be equivalent to soyabean meal in terms of crude protein and available essential amino acid content.

[2]ns: not significant (P>0.05), *: P<0.05, **: P<0.01, ***: P<0.001.

nd: not detectable.

FIGURES

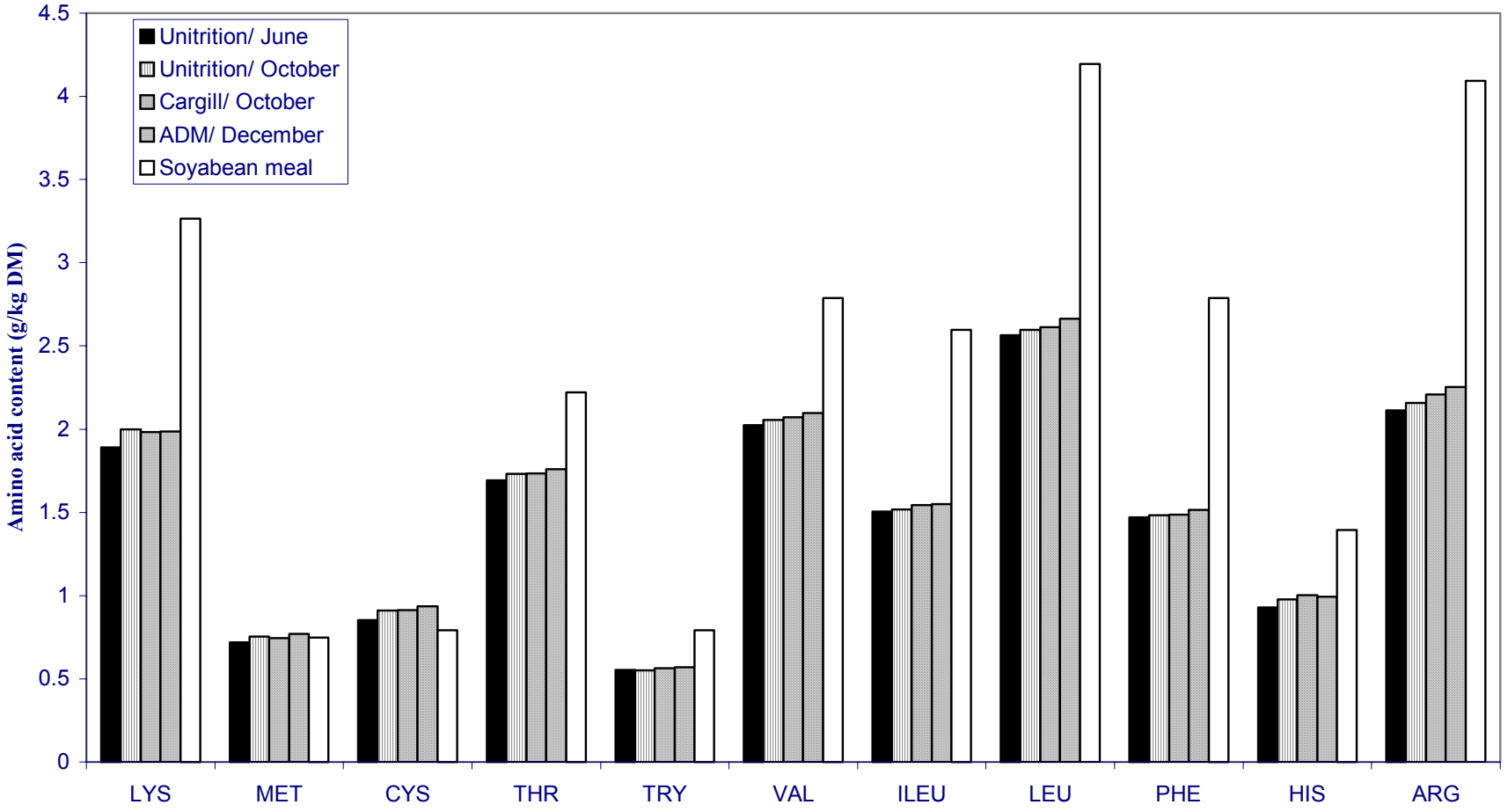

Figure 1. Total concentration ofamino acids in the rapeseed meal and soyabean meal samples taken from different processing mills

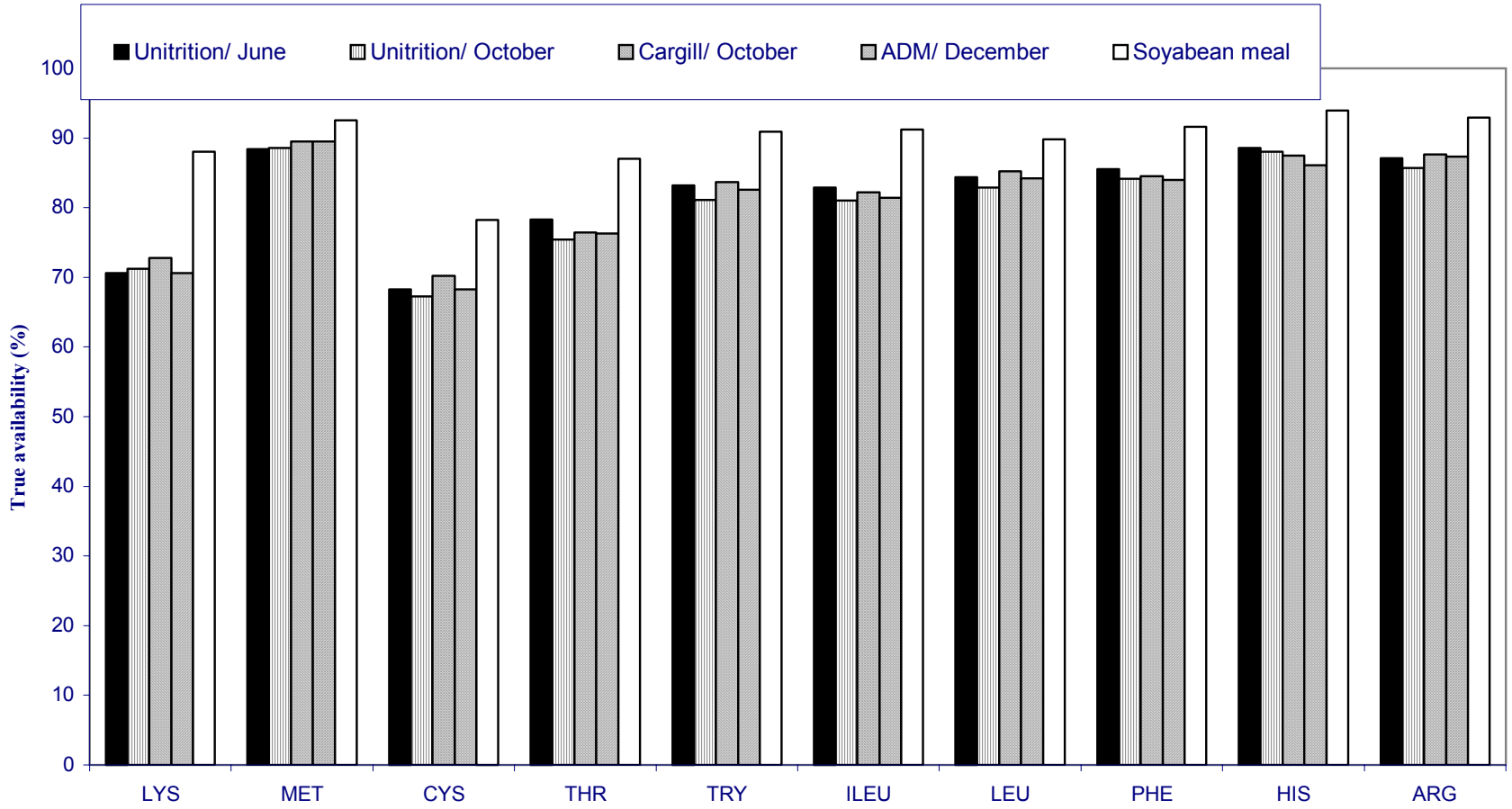

Figure 2. True availability of the individual amino acids in the rapeseed meals taken from different mills and a sample of soyabean meal

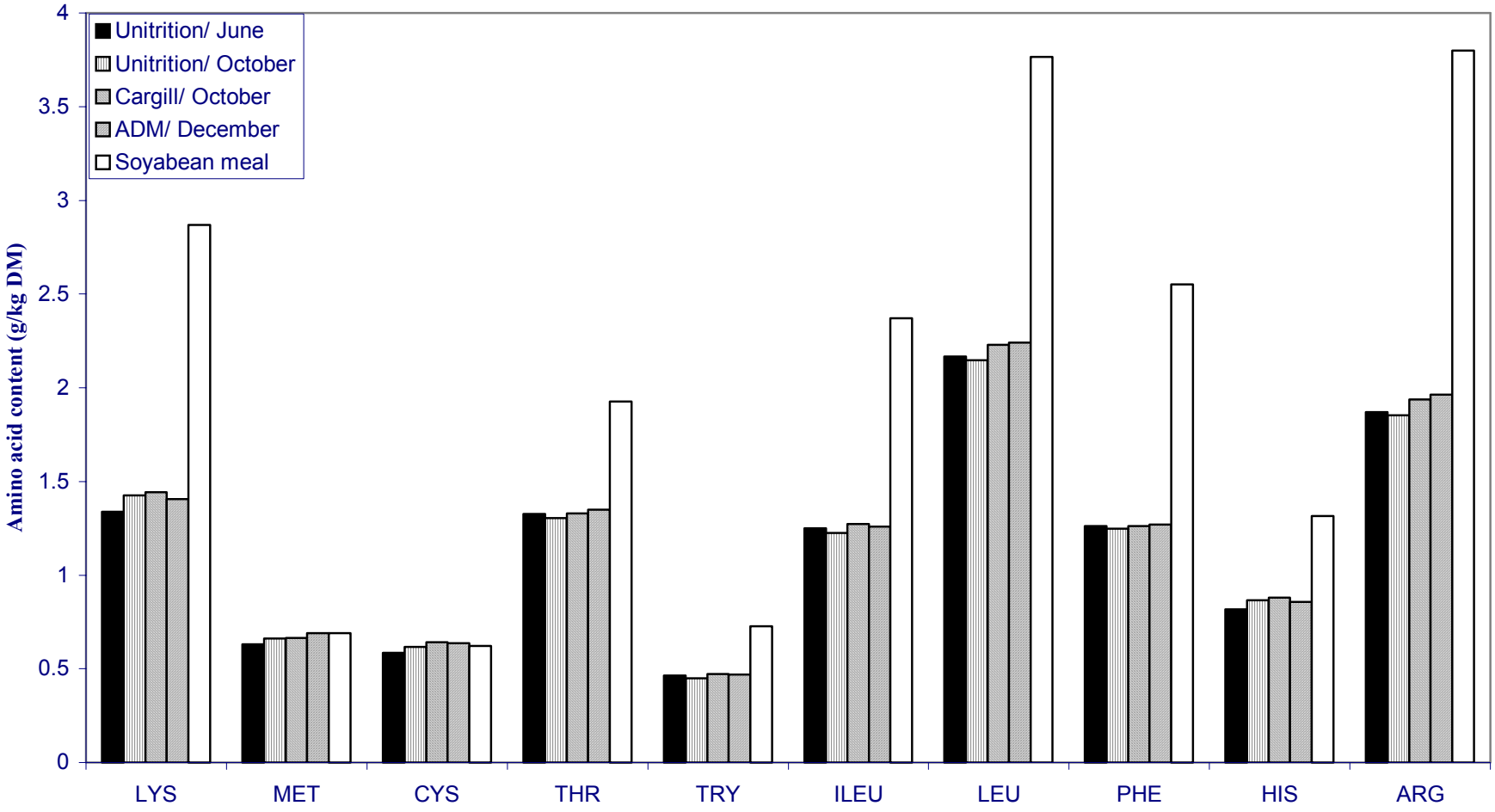

Figure 3. The available amino acid content of rapeseed meals taken from different mills and a sample of soyabean meal.

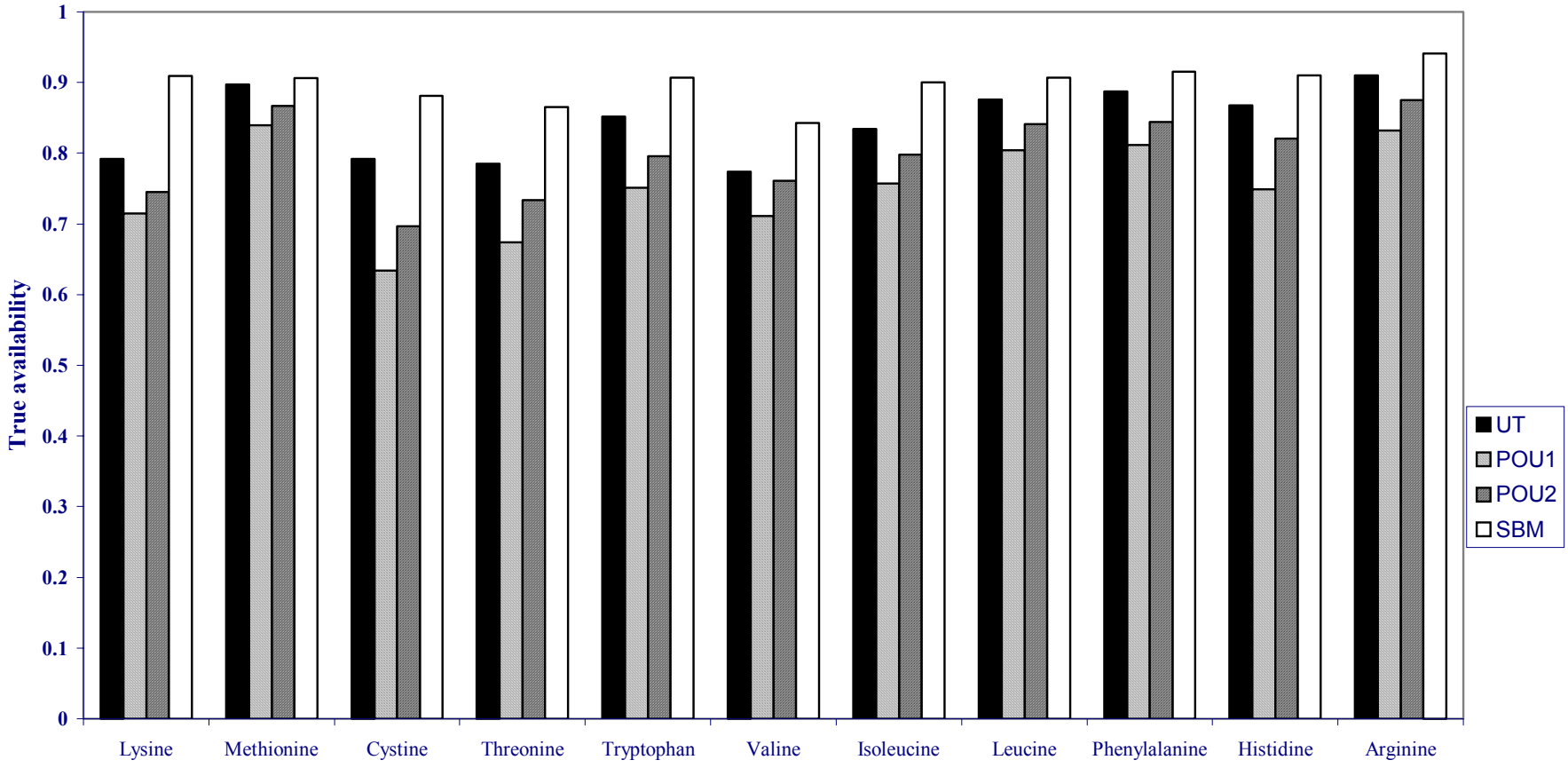

Figure 4. Effect of treating rapeseed meal on the true availability of its amino acids

UT: untreated rapeseed meal, POU1: UT treated with 0.4 g cell wall degrading enzymes/kg DM UT, POU2: UT treated with 0.6 g cell wall degrading enzymes/kg DM UT.

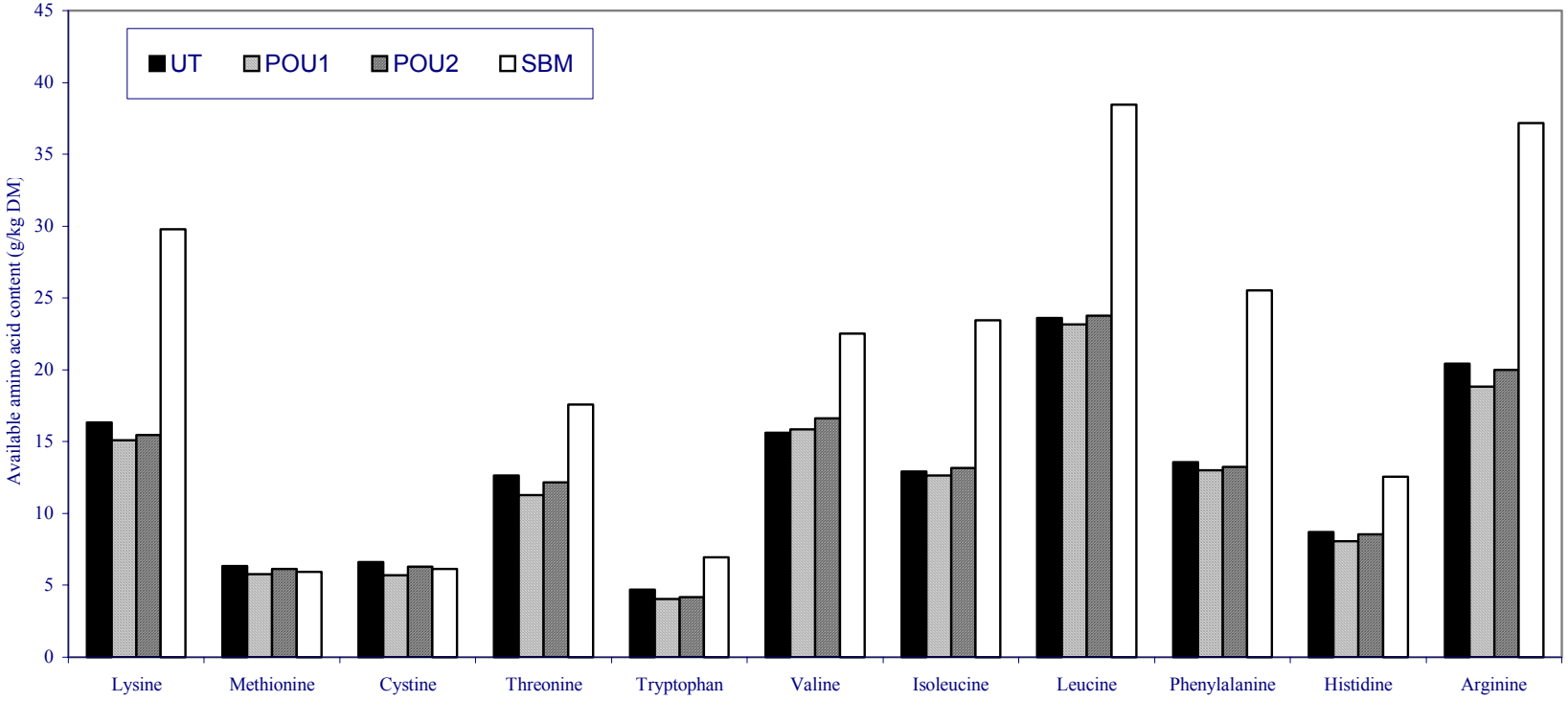

Figure 5. Effect of treatment on the available amino acid content of rapeseed meal and soyabean meal

UT: untreated rapeseed meal, POU1: UT treated with 0.4 g cell wall degrading enzymes/kg DM UT, POU2: UT treated with 0.6 g cell wall degrading enzymes/kg DM UT.

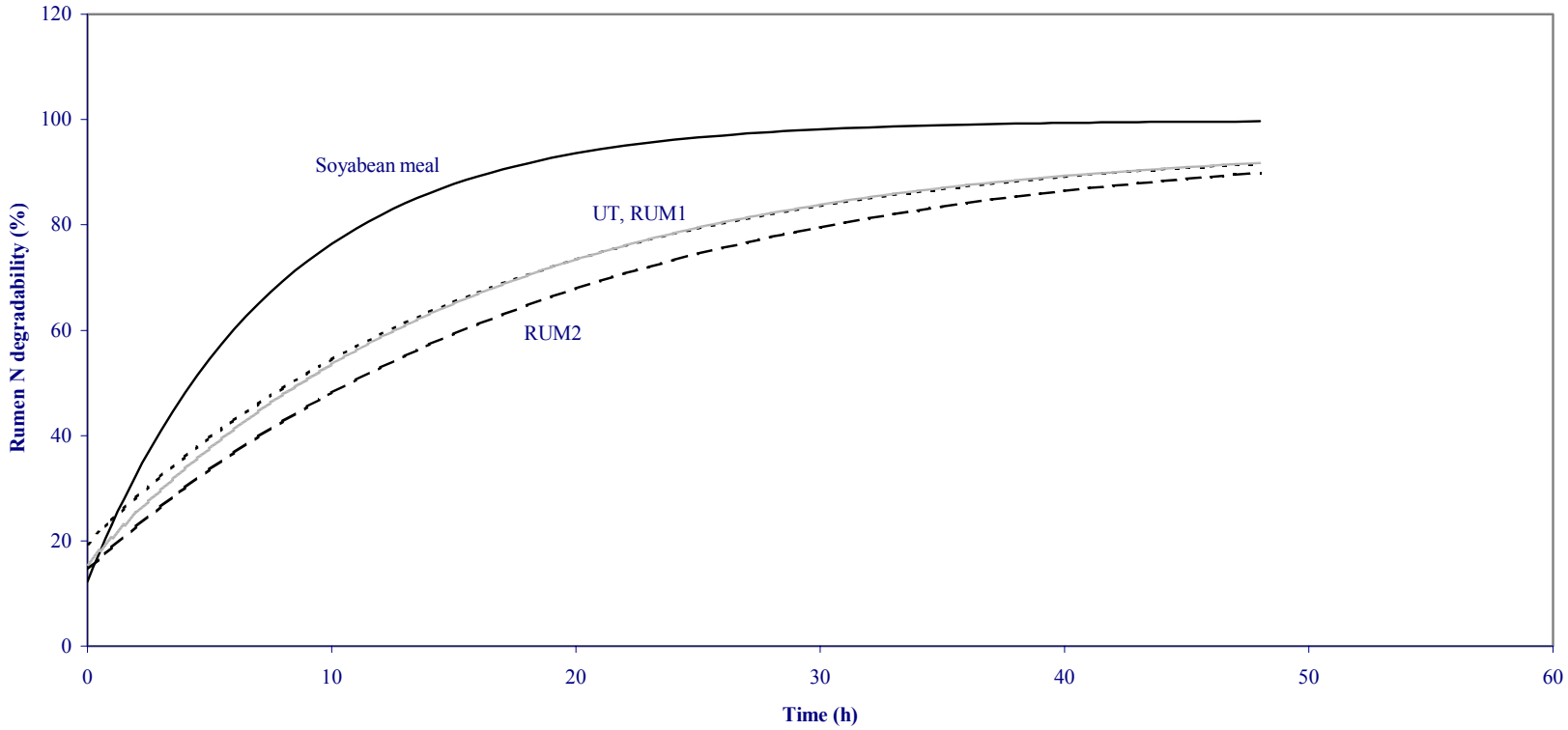

Figure 6. Effect of treatment on the rumen degradability of rapeseed meal

UT: untreated rapeseed meal, RUM1: UT heated to 80^0C for 80 min, RUM2: UT heated to 130^0C for 20 min.

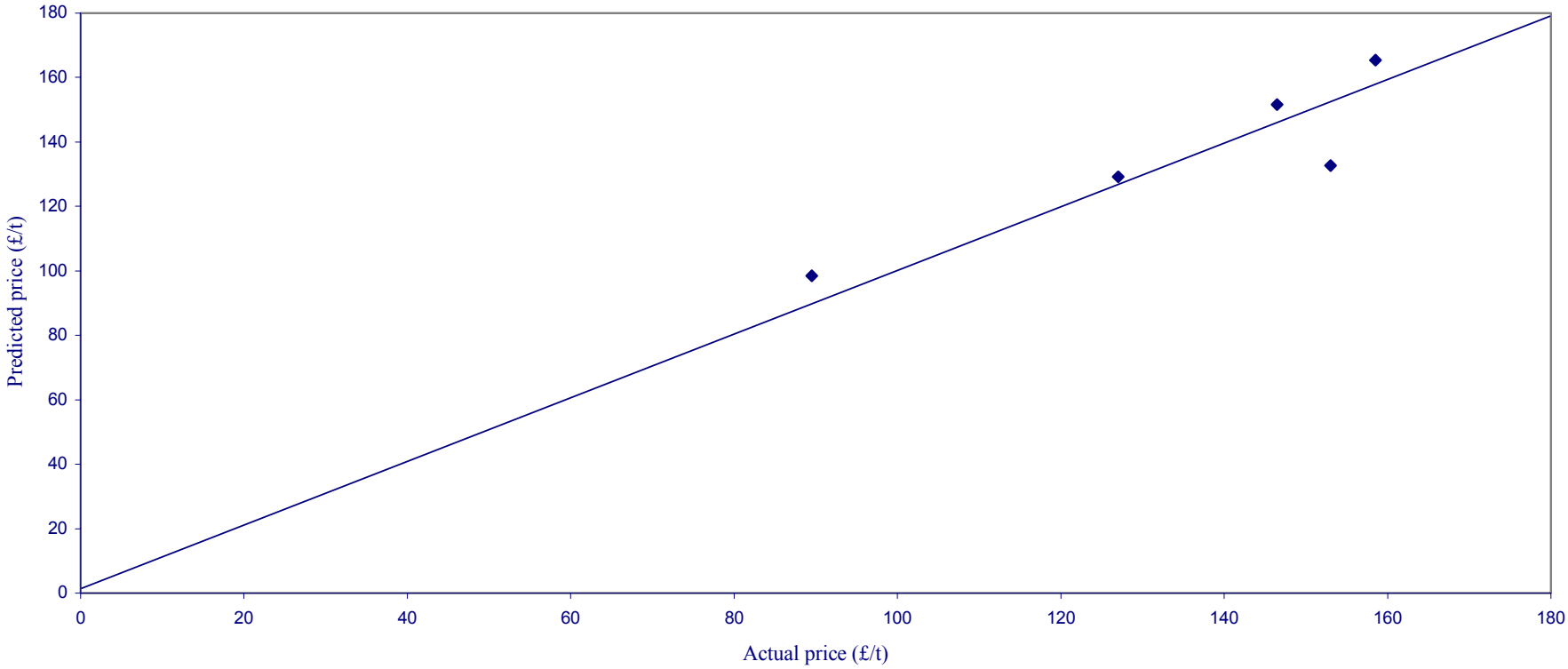

Figure 7. Relationship between actual and predicted price of different oilseed products