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Alternative protein sources

Grain legumes as alternative protein sources in monogastric animal feeding

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Introduction

Research on the utilisation of legume seeds (pea, faba bean, lupin) began thirty years ago in order to reduce European dependence upon American soybean meal (SBM) and the share of imported protein sources in animal feeding. Maximal extension of legume grain crops was recorded in 1993. However, with the readjustment of subsidies between grain legumes and cereals and other events such as current spreading of crop diseases, surfaces devoted to the former have been decreasing over the last ten years. The future of these crops depends on plant research in order to get acceptable yields, compared to those of cereals, and (or) the improvement of nutritional values so that, at given price, they can compete with soybean meal. This is even truer since the ban on meat meals in the EU tended to favour the use of soybean meal (SBM), rather than legume seeds particularly in poultry and ruminants feeds. At the same time, socio-economic constraints regarding the preservation of the environment lead to reduced protein contents in diets for pigs and poultry and use of highly digestible and well-balanced protein sources, while legume grains often display low digestibility and amino acid deficiencies. Furthermore, we know that low nutrient digestibility partly caused by anti-nutritional factors (ANF) may affect not only energy and protein values but also the health of animals particularly at gut level, while users pay more attention to negative impacts of feedstuffs since the addition of antibiotics as growth factors in animal feeds has been strongly restricted. Within this context, it is important to know if it is still possible and how we could promote the use of legume grains as alternative protein sources in Europe.

In this paper, we review recent information on the advantages and drawbacks of legume grains in diets for monogastric animals and particularly pigs. We examine first general aspects of nutritional value in terms of energy and protein, with particular attention to the new concepts of net energy and ileal digestible or available amino acids. Then we consider the opportunities offered by plant genetics, recently developed additives, technological treatments or new concepts in feed evaluation to improve the competitivity of legume grains in monogastric animals feed industry.

General aspects of the nutitive value of legume grains

Energy value

Competition between legume and cereal grains in diets for pigs and poultry

Cereals are the basal energy supply in diets for monogastric animals (pigs and poultry). However, total nitrogen and essential amino acid (EAA) supplies must be completed through the incorporation of protein sources providing lysine, the most limiting amino acid as well as some other EAA (oil-meals, fishmeals, legume grains). Digestible energy is positively influenced by starch and protein contents. Furthermore, it was shown in growing pigs that energy from amino acids is less efficiently utilised than the energy from starch or lipids regardless of whether they may be incorporated into body protein or metabolised into ATP (Noblet, 1996). Most legumes grains have intermediate protein and EAA contents between cereals and SBM. Therefore, at least in pigs, *cereal grains will always surpass legume grains in terms of net energy value due to their higher starch content, although legume grains surpass soybean meal.* This is not necessarily true for poultry (J. Noblet and B. Carré, personal communication). Consequently, if cereal-legume grain price differential is not high enough, low-protein grains such as pea will tend to be replaced by cereals plus industrial EAA when their energy value is low. In the recent years, two simultaneous events have emphasised this trend. First the development of industrial amino acids, particularly L-threonine after L-lysine-HCl, allowed limitation of the incorporation of protein, hence of soybean meal, and better valorisation of the energy of cereals. At the same time, this practice was encouraged by directions in each country as well as at EU level, in order to minimise environment pollution by nitrates(Dourmad et al., 1995). Therefore a high energy value is essential for the use of alternative proteins such as legume grains in diets for monogastric animals. Recently we investigated what would be in France the shift in the utilisation of peas in compound feeds if pea energy value increased by as much as 23 % (Lemoignier, Dronne and Sève, unpublished). As expected, pea could represent in 2000 more than 20 % of French pig feeds and were virtually absent in broiler feeds. The consequence of an increase in energy value was favourable to an increase in the use of peas, but more in chicken than in pig diets. A limited effect on the incorporation of pea in pig diets could be explained by the opportunity offered through the increase in diet energy value to replace wheat with less energetic cereals and to increase the incorporation of low energy oil-meals such as rapeseed (RSM) or sunflower (SFM) meal. Finally, it appears that energy was probably the first factor limiting the opportunity to replace the wheat or maize-SBM association in poultry feeding.

Energy value according to animal species and legume grain composition

Energy value for birds is lower than energy values for pigs, and differences between cereals and legume grains are higher for the former than for the latter. Regardless of the animal species, fibre from cell walls constitutes a barrier limiting the access of enzymes to protein or starch. But, fibre is responsible for a high viscosity of intestinal contents in birds, which does not seem to be the case in mammals, at least in pigs. Therefore starch and protein digestibility in the small intestine (ileal digestibility) will be more negatively influenced by fibre, i.e., non-starch polysaccharides (NSP) in broilers than in pigs, although viscosity is much more a problem with cereals than with legume grains (Carré et al 1994). Furthermore, fibre may be fermented already at ileal level and, to a much larger extent, in the large intestine of mammals than in the caeca of birds. Even though the positive effect of fermentability is more limited in net energy due to lower energy efficiency of volatile fatty acids than glucose, it will positively affect digestible energy. Legume grain are more easily fermented than cereal grains in vitro (van Laar et al., 2000) and in vivo, in the gastro-intestinal tract of pigs. According to Canibe and Knudsen (2002) total tract fibre digestibility was 26 and 82 % for barley and pea hulls respectively and 74 and 96 % for barley kernel and pea cotyledon fibre respectively. Therefore in the same way as viscosity in birds, fermentability will be more in favour of legume grains than cereal grains in pigs. On the other hand, birds are also more sensitive than pigs to the structure of starch granules and to amylose, the content of which is higher in peas than than in cereals such as wheat or barley. This is well illustrated by the low digestibility of starch in wrinkled pea compared to smooth peas (Carré et al., 1998; Grosjean et al., 1999). Respectively higher and lower in legume than in cereal grains, fibre and starch contents are negatively correlated in peas (Bastianelli et al., 1995). Accordingly, this is true of other legume grains as compared with pea: faba beans with higher protein and lower starch contents and lupins in the quasi-absence of starch contain more fibre and are less energetic than peas. Finally, the fermentability of fibre and the lower impact on gut content viscosity tend to compensate for the higher fibre and lower starch content in legume than in cereal grains but these features are more in favour of high energy content for pigs than for poultry.

Protein value

Competition between legume and cereal grains in diets for pigs and poultry

In the same way as legume grains are in competition with cereal grains as energy sources they should be in competition with soybean meal as protein sources. We investigated also the impact of an increase in protein content of as much as 23 % on the incorporation of peas in pig and poultry feeding (Lemoignier, Dronne and Sève, unpublished). Compared with the 23 % increase in energy value, there was surprisingly no major shift in pea *vs*. SBM utilisation. Again, the increase in pea utilisation was higher in poultry than in pig feeding. The benefit of higher protein content was rather limited with a shift toward use of less energetic cereals with higher protein content such as barley. Taking into account the industrial practice which tends to limit the incorporation of barley in diets for broilers, the potential increase in pea utilisation is probably underestimated. However, the results obtained with pigs indicate that there are other limitations than energy or protein content for the use of legume grains. The price ratio of pea to SBM is quite stable due to the high correlation between the two protein sources and this determines a plateau of pea utilisation over a large range of SBM price (Lemoignier et al., unpublished). Therefore, the primary limiting factor for pea utilisation in France is certainly the availabity of pea on the market and, hence the attractivity of pea crops to producers.

Protein value according to animal species and legume grain protein composition

On the other hand, the chance of legume grains to be incorporated in diets for monogastric animals is dependent on both the balance and the bioavailability of their amino acids. In terms of balance of amino acid composition, legume grain proteins appear less valuable than soybean meal. As regards lysine, pea protein is richer, faba bean protein is similar and lupin is poorer than soybean protein. But, due to their lower content in threonine legume grain proteins are less interesting than soya proteins as a complement of cereal proteins. Furthermore, they are very deficient in sulphur amino acids and to a lesser extent in tryptophan. This drawback is emphasised by the relatively low digestibility of protein, compared to soybean meal, which particularly affects those amino acids, particularly cystine and tryptophan. DL-methionine supplements are required for high incorporation rate of pea in diets for growing pigs (Wachenheim and Mattson, 2002) and broilers (Reddy et al., 1979). Until recently, although high levels of peas could be used (e.g. Grosjean et al 1997) it was not possible to formulate diets for pigs rich in legume grains without maintaining soyabean meal at quite high level in order to meet the requirement for tryptophan. The appearance of industrial L-tryptophan on the market technically allows formulation of diets based on pea-wheat blend, but the cost of this supplement is still prohibitive for growing-finishing pig diets. Alternatively, rapeseed meal from “double-low” cultivars, the protein of which is quite rich in tryptophan can be used (Pastuszewska et al, 2001). Despite the low digestibility of amino acids in RSM (Buracewska et al, 1998), a number of experimental data from Poland are reporting such strategies, including the use of by-products from rapeseed oil industry, to compensate for the low energy content of a pea-RSM blend (Florek et al., 1999; Sobotka and Tywonczuk, 2000; Hanczakowska and Urbanczyk, 2001; Krasucki et al., 2002).

Strategies for improving legume grains

Plant genetics: Removal of antinutritional factors

Tannins

The energy value of peas is clearly dependent on tannins which are present in seeds from coloured-flowered cultivars in pigs according to Perez et Bourdon (1992) (81.6 vs. 87.7, i.e., 3.62 vs. 3.89 kcal ED/kg MS, respectively) and Grosjean (1998). However, the most important effect of tannin removal is on protein digestibility, in pigs as well as in poultry. The lower value of energy digestibility in coloured-flowered compared to white-flowered faba beans also was ascribed to tannins. Nevertheless, due to lower digestibility of starch, the first tannin-free cultivar was found to be less energetic than its coloured flowered counterpart for young chicks (Lacassagne et al 1988). In fact, comparing several cultivars, Grosjean et al (1999) could not show any significant negative effect of tannins on the metabolisable energy (ME) value for poultry. Similarly, testing white- and coloured-flowered near-isogenic faba beans cultivars Wareham et al. (1993) et al concluded that a negative effect of tannins could be observed only with a maximum daily intake of .52g per day and bird (Brufau et al., 1998), corresponding to at least 40% incorporation in the diet. Accordingly, they demonstrated a negative effect of tannoins with 60% faba beans in the diet. Nevertheless, as regards protein an important and significant effect of tannins on digestibility was consistently reported with tannins associated to faba bean hulls in pigs on fecal digestibility (Bourdon and Perez, 1984: 75.4 vs. 81.9; Grosjean et al., 1998: 76.0 vs. 84.0). This was confirmed by Jansman et al. (1993) on ileal digestibility. Contrary to energy, protein digestibility was more affected by tannins in poultry than in pigs (Jeroch et al., 1996; Grosjean et al., 1999). It was shown that tannins directly inhibited the enzyme activities in vitro (Ortiz Vera, 1994) and induce atrophy and shortening of villi at ileal levels in chicks (Ortiz et al., 1994). According to Longstaff and Mcnab (1991) the in vivo inhibition of enzymes was maximum for trypsin, intermediate for alpha-amylase and least for lipase.

Trypsin inhibitors

It is difficult to find a significant correlation between fecal digestibility of protein in pigs and the trypsin inhibitor (TI) content of pea (Gdala et al., 1992; Grosjean et al., 1998). *Nevertheless there is clear evidence of a depressive effect of this ANF, on the ileal digestibility of amino acids such as lysine, but even more of the most limiting ones, such as sulphur amino acids and tryptophan* (Leterme et al., 1990; Grosjean et al., 2000). In the latter studies only low-tannin peas were considered, and the correlation of protein digestibility with fibre was not significant. This was not the case in the study of Gdala et al. (1992), which included tannin-rich peas, and where there was a significant correlation of digestibility with NDF content, suggesting combined actions of different ANF. In the work of Grosjean et al (2000), we notice that high TI content may not only affect winter but also spring pea cultivars. Indirect evidence of a depressive effect of the trypsin inhibitor on pea protein digestibility was obtained in chickens as prevented by autoclaving or steam pelleting (Conan and Carré, 1989). This was recently confirmed (Wiseman et al., 2003) namely in near-isogenic lines differing in TI activity, particularly for the apparent ileal digestibility of cystine (high TI: 73; low TI: 81).

Other factors.

The above observations led to the development of new cultivars low in tannin for both faba beans and peas and low in trypsin inhibitor for peas. Among potentially toxic factors a particular attention was paid to production of low vicine and convicine cultivars of faba beans in order to avoid favism or a decrease in egg weight or production in laying hens (Duc et al., 1999). The incorporation of the new cultivar Divine up to 30% in the diet of laying hens did not affect egg production, but it was in an experiment where a conventional faba bean did not cause any trouble (Danner, 2003). Therefore more validation studies are probably needed. Regarding the protein value of the best cultivars from Grosjean's last study in pigs (Baccara cultivar), the ileal digestibilities of amino acids remained 7 to 8 points percentage units lower than those from a regular SBM. Similarly, low digestibility of white-flowered cultivars was far to be explained by NDF content in Gdala's study (Gdala et al., 1992). The same observation held when more appropriate criteria such as WICW (Grosjean et al 1998; 1999) were used. Similarly, the proportion of different protein classes (11S legumin, 7S vicilin, albumins) (Crevieu et al., 1997b; Salgado et al., 2003) was difficult to evoke since the most resistant proteins, 7S-globulins, PA2 albumin and lectins, were detected only in low amounts at ileal ilevel. In fact, proteins of high and medium molecular weight found at ileal level are likely of endogenous origin (Le Gall et al., 2003, and unpublished) and nitrogen loss from pea proteins is probably mainly composed of small peptides (Crevieu-Gabriel, 1999)

The particular case of lupin seeds

Lupin seeds contain 28 to 42 % protein, very low amounts of starch and high amounts of NSP. The latter features make them difficult to be used in diets for monogastric animals. Two species of lupin have been considered in France, white lupin (*Lupinus Albus*) due to development of high-yield cultivars, blue lupin (*Lupinus Angustifolius*), less productive but adapted to dry areas (Australia), for its great interest in animal production. Yellow lupin (*Lupinus Luteus*) with both highest protein and NSP content, is grown in Eastern Europe (Poland). Gdala et al (1996), showed that blue lupin was better utilised than white lupin and reported the highest digestibility for yellow lupin cultivars which could replace SBM in the same way as blue lupin at about 40 % in pig diet. Earlier Hungarian work had shown this potential for SBM replacement but did not report such an advantage of yellow lupin over white lupin (Szelenyine Galantai et al., 1985) while good results were repeatedly found with Polish cultivars (Kotarbinska et al., 1990; Flis, 1993). The high value of blue lupin confirmed data of Barnett and Batterham (1981) on piglets while less optimistic recommendations were made with white lupin for growing pigs (Bourdon et al., 1980) or piglets (Bourdon et al., 1980; Quemere et al., 1984). In poultry, a depressive effect on growth rate also was reported (Hamilton et al., 1999) from low levels in diets while older chicken could tolerate 20%. Although the above quoted species are supposed to provide « sweet » lupins cultivars, alkaloid contents may still be a problem which will affect feed intake and growth performance at levels of 200-300 mg per kg diet (Pearson and Carr, 1977; Godfrey et al., 1985). In hens reduced egg production was observed (Tarasewicz et al., 1995) although the effect was not clearly significant at 148 mg alkaloid per kg diet (Cubillos et al., 1996). However this also depends on the type of alkaloids since lupinine, the major alkaloid in yellow lupin is less toxic than lupanine which represents about 70 % of total alkaloids in white lupin (Ruiz et al., 1977). Generally speaking, measurements of nutritional values have shown high nutritional values for blue lupin (Batterham, 1978; Batterham et al., 1986a; Batterham et al., 1986b) with an advantage on white lupin both in terms of ileal digestibility of amino acids (Mariscal-Landin et al., 2002b) and net energy value (King et al., 2000). Interestingly blue lupin (cv Gungurru) hulls were shown to increase the empty body weight gain of pigs and the efficiency of ileal digestible lysine utilisation (Fernandez and Batterham, 1995) and of ME into NE (J. Mancuso, D. Bourdon and J. Noblet, unpublished data). Due to reports of bloat accidents resulting from flatulence (Bourdon et al., 1980; Mariscal-Landin et al., 2002a), the higher oligosaccharide content in lupin seeds than in other legume grains, is another feature generally put forward to explain the lower value of white lupin. But, in the same way as for alkaloids no clear differences in alpha-galactoside contents were reported. On the contrary, recent results in poultry seemed to indicate that an ethanol extract from lupin, rich in alpha-galactosides was important for its nutritive value even improving performance of chicken when added to a a maize-SBM diet (Brenes et al., 2003)

Use of enzymes

The higher NSP content in legume than in ceral grains limit their energy value and even more their protein value. Attempts to improve nutritive value of legume grains with enzyme supplements were generally not very successful in pigs, as previously reported for cereal grains or brans. Nevertheless, improvements in ileal digestibility were reported with a mixture of cellulase and driselase (Dierick and Decuyper, 1998). According to Owusu-Asiedu et al. (2002a) a mixture of xylanase plus amylase provided a better response of early-weaned piglets than the same mixture plus protease. Accordingly, protease did not increase digestibility, although an improvement in feed conversion was reported (O'Doherty and Forde, 1999). The addition of xylanase and amylase to raw and extruded or micronised pea did not prevent an important positive response of amino acids ileal digestibility to the technological teatments, suggesting quite limited effects of the enzyme (Owusu-Asiedu et al., 2002a). Gdala et al., (1997b) also reported limited effects of a mixture of three enzymes (alpha-galactosidase, protease and xlanase) on the ileal digestibility of dry matter in which part of a cereal-soybean mixture was replaced by a RSM-pea blend. However in another study they found that alpha-galactosidase addition to a lupin-casein diet improved ileal digestibility not only of the alpha-galactosides but also of the amino acids (Gdala et al., 1997a). Nevertheless, this beneficial effect is still questionable since alpha-galactosidase was also found to improve digestibility of a cereal-SBM-pea diet as well as growth performance in growing-finishing pigs in a further Spanish study (Baucells et al., 2000), but not in Irish experiments (O'Doherty and Forde, 1999). In poultry, supplements of a mix of hemicellulase, pectinase, beta-glucanase and endoglucanase were inefficient to increase performance of chicken fed peas (Brenes et al., 1993). The same authors later reported improvements when enzymes were added to a lupin containing diet, preventing the enlargement of the digestive tract (Brenes et al., 2002; Brenes et al., 2003). The relative inefficiency of enzyme supplementation of pea-containing diets was recently confirmed (Keller and Jeroch, 1997; Richter et al., 1999; Richter et al., 2001; Cowieson et al., 2003), although combination of a multienyme preparation with alpha-galactosidase improved AME by 2-4% (Keller and Jeroch, 1997). Similarly, pectinase and alpha-galactosidase as supplements either of whole pea (Igbasan et al., 1997) or of pea cotyledons (Daveby et al., 1998), also were relatively inefficient to increase nutritive value parameters although slight improvements were shown in growth rate of young chicken.

Technological treatments

Grinding

The low energy value and the low digestibility of amino acids also encouraged studies on technological, namely thermomechanical, treatments applied to raw materials or used in feed manufacturing industry. Grinding is the first and simplest treatment, primarily affecting the accessibility of enzyme to substrate (Carré et al., 1998). In vitro data showed that protein digestibility was linearly increasing when particle size decreased from 1000 to 500 and 200 µm (Lahaye, 2004) while there was no further improvement at 200 µm for wheat. Similarly, it was shown in pigs that the ileal digestibility of energy and amino acids increased by 5 percentage points when particle size decreased from 500 to 200 µm (Lahaye et al., 2003a). This seems particularly important for piglets fed high levels of pea, responding to a decrease in particle size down to 400 µm with significantly higher growth performance (Albar et al., 2000). Nutrient and particularly amino acid digestibilities could be considerably increased with very fine grinding (particle size 50-60 µm) both in chicken (Crevieu et al., 1997a) and in pigs (Hess et al., 1998). However, in chicken as well as in piglets (LeGall et al, unpublished) the accumulation of small peptides at ileal level probably limits the magnitude of the improvement. Moistening of peas decreased the efficiency of the grinding process to decrease particle size, but improved pea starch digestibility in diets for chicken (Carré et al., 1998). This interesting effect can be explained by the increase in mechanical energy used in the grinding process, this energy, called the specific energy of grinding, being absorbed by the product.

Heat treatments

Heat is already a parameter involved in grinding. But there is a considerable amount of literature on the effects of more sophisticated heat treatments. These treatments were primarily applied in order to reduced the contents of antinutritional factors and their harmful effects (Bertrand et al., 1982; van der Poel, 1989; Bengala-Freire et al., 1991). Favourable effects were mainly ascribed to neutralisation of trypsin inhibitor or lectins. However, simple steam processing or extrusion of whole tannin-containing faba beans were ineffective to improve ileal or fecal digestibility in pigs (Poel et al., 1992). In contrast, Brufau et al. (1998) recently reported that autoclaving faba bean and incorporation at 60 % in diets for poultry improved AME, and they claimed that half the effect was associated with the inactivation of tannins. However, it is clear that heat treatments may be used to improve low ANF legume grains, in the same way as other feedstuffs. Indeed, the effect of extrusion was shown by Bengala-Freire et al (1991) and Mariscal-landin et al. (2002) only on winter peas with high content in trypsin inhibitor, but the ileal digestibility of treated peas largely exceeded that of low ANF white-flowered pea. Similar improvements were recently reported in early-weaned pigs fed diets with raw, extruded or micronised pea as sole protein source (Owusu-Asiedu et al., 2002b). It was also shown that a depressive effect of 40% vs. 20% raw pea on growth performance of growing-finishing pigs could be overcome with extruded pea. On the other hand extrusion of a pea-canola seed blend was not successful in improving nutrient digestibility and growth performance of pigs(Thacker and Qiao, 2002). Heat treatment effect on cell wall components is not well documented. For example toasting of pea did not improved the NSP ileal digestibility (Canibe et al., 1997). The positive effect of heating on pea protein was probably explained by an optimal action on pea protein itself, improving its accessibility to enzymes through denaturation. Accordingly, we have recently shown in growing pigs that the ileal digestibility of amino acids of a pea-wheat blend and the overall nitrogen balance could be improved by a moderate steam heat treatment ("thermisation"), commonly used to neutralise salmonella (Lahaye et al., 2003a)

Pelleting

Pelleting was shown to increase the energy value of tannin-containing faba beans (Lacassagne et al., 1988). Farrell et al., (1999) reported similar data on faba beans and other legumes. This effect was confirmed by Grosjean et al (1999), even in white-flowered peas, the ME value of which increased by more than 12 % with a noticeable decrease in variability from 4.3 à 2.2 %. In contrast, the improvement in DE value with pelleting was less important (Grosjean et al., 1989), probably due to the efficient digestion observed in the large intestine. Pelleting undoubtedly improved the ileal digestibility of amino acids from other protein sources of low digestibility such as sunflower meal (Lahaye et al., 2003b), rapeseed meal (Lahaye, 2004), but the impact of the regular industrial steam pelleting process on protein value needs to be assessed or reassessed. On the other hand, different pelleting processes were compared showing that the association of expansion to pelleting did not improve digestibility or performance of pigs fed a high amount of pea in their diet (van der Poel et al., 1997; O'Doherty et al., 2000).

Impact of new concepts in energy and protein nutrition

Until now, the ME energy system was used in poultry feeding, while the NE system has been largely developed in pigs. An important difference between the two systems is related to the relatively low efficiency of energy utilisation from protein, which gives relatively lower NE values to protein-rich sources. This system is more favourable to the use of legume grains with low protein contents such as pea. It is probably one reason for the important development of pea incorporation in diets for pigs, at least in France. In contrast, measurements of low digestibilities for most amino acids, whichever digestibility system is used, apparent or standardised, were not really in favour of an increase in the utilisation of legume grains. Nevertheless, an objective knowledge of the nutritive value is always better than the use of empirical constraints to reduce the incorporation level of a particular feedstuff when least-cost diets are calculated. Peas can be used at quite high levels in diets for growing-finishing pigs in the U S., on basis of standardised amino acid digestibility from new NRC tables (Wachenheim and Mattson, 2002), as well as in France on basis of new INRA tables. The equivalence of protein sources in diets formulated on basis of similar apparent ileal amino acid, and especially lysine, digestibility could recently be shown in a Dutch experiment (Szabo et al., 2001).

However, there are still some uncertainties that need to be overcome for a better approach of the true availability of amino acids. Batterham et al. (1986a) pointed out a low availability of lysine from lupin and concluded that it could not be due to a heat sensitive factor. On contrary, a decrease in amino acid availability may also be related to excessive heat treatment (Barneveld et al., 1995). This drawback may be overcome for example through measurement of the digestibility of reactive lysine as proposed by (Moughan, 2003). Another cause for reduced availability of ileal digestible amino acids is the propensity of a protein source to stimulate digestive endogenous losses beyond the basal level that may be measured with a protein free diet. We could show that legume grains tend to enhance endogenous losses along the same linear regression on fibre content as RSM (Sève and Lahaye, 2003). Pea cotyledon rather than hull fibre could be responsible for enhancing endogenous nitrogen losses due to their water retention capacity (Leterme et al., 1996). On the other hand, quite important differences in ileal endogenous losses could be shown between different cultivars of peas or faba beans, not necessarily in relation to their cotyledon NSP. The important point is the metabolic cost of these endogenous losses in energy but also in amino acids which was shown, to be at least equal to the ileal loss of digestible amino acids (Hess et al., 2000). The impact of technological treatments on these losses also should be considered for a better approach of their benefical effects on the availability of amino acids (Lahaye et al., 2004).

Conclusions

We have reviewed different ways of improving legume grains in order to promote their competitivity with imported SBM. We have seen that the availability on the market is probably the most limiting factor for extensive use of legume grains in diets for monogastric animals. Certainly, research aiming at creating new cultivars more attractive in terms of crop yield is a priority. In addition, new varieties of pea and faba beans must be developed from low-tannin, low trypsin inhibitor genotypes to be incorporated in diets for monogastric animals. New varieties of lupin also could be developed from low alkaloid blue or yellow lupin genotypes, but with little chance to be used in poultry diets due to excess fibre. It is not easy to decide if the improvement in protein content should be preferred to improvement in energy content. Whatever choice is made, attention should be paid to maintaining and, as far as possible, to improving the level of limiting amino acid in protein, sulphur amino acids, but even more crucially tryptophan. More research on the interactions between nutrition and health is needed to document advantages and drawbacks associated with this choice. In any case, particular attention should be paid to factors allowing higher digestibility of protein and amino acids, and particularly the limitation of the propensity to enhance endogenous protein losses. In this respect, we need better knowledge of the interaction between fibre and protein in the digestive process, regarding the rate of passage and the fermentability of legume grain fibre from the hull or from the cotyledons. Lastly, although albumins seem clearly undesirable, although rich limiting amino acids, the nutritional and pathophysiological properties of 7- and 11S-globulins should be investigated further.

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