Lupins as a Raw Material for Human Foods and Animal Feeds

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ABSTRACT

The seeds or grain of lupins, a cool climate legume, are a rich source of protein and energy. They could prove a valuable alternative to soybean and dry peas for both human foods and animal feeds. One advantage would be that lupins have a lower content of antinutritional factors, particularly the protease inhibitors and lectins. Lupins are a good substrate for fermentation and can be used to make tempe and traditional fermented foods for Japan, Korea and China. Lupin flour can be added to wheat flour to make high protein breads, cakes and pastas of higher nutritional value. Lupins can also be processed to make a protein concentrate, and a dietary fibre fraction with excellent water-holding capacity. Lupins have been shown to be a useful ingredient in the diets of fish and crustaceans, pigs, poultry and dairy and beef cattle. Much work to adapt its use for Indonesian conditions will be needed before the respective industries can fully benefit from this new commodity.

INTRODUCTION

The seeds of various species of lupin are rich in protein and have been used as both a human food and livestock feed for over 2000 years (Gladstones, 1970). However, it was not until pioneering work was carried out in Western Australia in the 1950s and 1960s which concentrated on improving agronomic characteristics and overcoming their bitter flavour that lupins were brought up to the status of a crop plant (Gladstones, 1982). Lupin *(Lupinus angustifolius)* is now a major crop in Western Australia with an annual production of about 1 million tonnes. About 300,000 tonnes are produced in other states of Australia. The seed is frequently referred to as Australian Sweet Lupin (ASL) to distinguish it from bitter seed grown elsewhere. Most of the seed that is sold is used in compound feeds for intensive animal industries with only a few thousand tonnes being used for human consumption. There is increasing interest in the use of lupins in the food industry, where its most obvious use would be as an alternative to or substitute for soybeans, and other grain legumes (or pulses) such as field peas and chickpeas. One advantage that lupins have is the low content of biologically active non-nutrients known as antinutritional factors: typically they contain no detectable lectins (phytohemagglutinins), very low levels of trypsin inhibitors, and low levels of phytate, condensed tannins, saponins and oligosaccharides (Petterson and Mackintost, 1994). They do however contain very low levels of quinolizidine alkaloids; typically less than 200 mg total alkaloids per kg whole seeds, with some variation due to the cultivar grown and some to the environmental conditions during the growing season. Other species of lupin which grow well in Australia are the Albus lupin, or white lupin *(L. albus)* and the Yellow lupin *(L. luteus)*. Annual production of these is expected to reach 200,000 tonnes within a few years. Another species, the Atlas lupin *(L. atlanticus)* is now fully domesticated and will be grown commercially from 2001. The term lupins is commonly used to describe the whole seed (grain) of these species.

Chemical composition

Typical concentrations of the major nutrients in the three commercial species of lupins are given in Table 1, the essential amino acid profiles are given in Table 2, and mineral profiles in Table 3. In common with other legumes the seed (grain) contains a number of ANFs. Typical concentration of these in lupins are shown in Table 4. Soybean data are given for comparison. The protein content of lupins (30-42%) is higher than most pulses, e.g. dry peas (18-28%) and chickpeas (16-24%), whilst that of the de-hulled seed, or splits, (38-52%) is similar to that of soybean meal. In common with many legume seeds, the amino acid profiles show a deficiency in lysine and methionine for hummans (Table 2). The oil fractions vary in both profile and content between these species. The Albus lupin contains ~ 9% oil, of which 59% is monounsaturated (mostly oleic acid) and 28% polyunsaturated, the ASL contains ~ 6% oil, of which 34% is monounsaturated (oleic acid) and 44% is polyunsaturated, and the Yellow lupin contains ~5% oil, of which 32% is monounsaturated (oleic acid) and 51% is polyunsaturated. The oils appear to be very stable, possibly due to high levels of carotenoids and other antioxidants. The oil is more digestible for humans than soy oil (Romana *et al.,* 1983).

Table 1. **Nutrients profile of Australian sweet (ASL), Albus (AL) and Yellow lupins (YL), g/kg as received**

	ASL		AL		YL	
	Mean	Range	Mean	Range	Mean	Range
Moisture	84	64-101	86	77-98	108	89-137
Protein	322	272-376	361	291-403	379	311-435
Ash	28	23-33	33	28-42	41	34-47
Fat	58	45-72	91	64-115	50	34-64
ADF(1)	197	160-232	143	123-170		
NDF(2)	227	195-248	172	144-204		
Lignin	7.0	2.7-13.0	6.5	3.6-8.3		

ADF - acid detergent fibre.
NDF - neutral detergent fibre.

One important feature of lupins for ruminant livestock is the absence of starch in the grain. Carbohydrate storage in lupins comes in the form of complex polysaccharides that make up the thick cell walls of the cotyledons. Sheep, cattle and goats can be introduced to a diet with a high content of lupins with little risk of suffering from acidosis. They are able to break down the non-starch polysaccharides without any build up of lactic acid.

Nutritionally, lupind seed (grain) could offer some advantages as an alternative to soybeans. Lupin seeds have a lower content of phytic acid, which can bind to minerals such as calcium and zinc in the diet and reduce their bioavailability; and of saponins which can alter the permeability of the membranes of the gut wall and might change the uptake pattern of essential nutrients. The concentration of trypsin inhibitors (proteases) which can interfere with digestive processes and reduce protein uptake is also lower in lupins and they do not contain any of the lectins, which can act as gastric irritants. The simple act of cooking can reduce the activity of the proteinaceous non-nutrients in soy products and render them quite safe, however the level of protease inhibitors in cooked soybeans is higher than in raw lupin seed. Lupins

Table 2. **Essential amino acid profile of Australian sweet lupin (ASL), Albus lupin (AL) and Yellow lupin (YL), g/16 N as received**

Amino acid	ASL		AL		YL	
	Mean	Range	Mean	Range	Mean	Range
Histidine	2.41	2.05-2.85	1.72	1.61-1.84	2.68	2.54-2.83
Isoleucine	3.97	3.57-4.43	3.72	3.50-3.89	3.81	3.59-4.06
Leucine	6.61	5.84-7.40	6.06	5.58-6.53	7.56	5.72-8.10
Lysine	4.66	4.21-5.21	4.20	3.85-4.77	5.15	4.69-5.47
Methionine	0.72	0.59-0.87	0.65	0.54-0.72	0.70	0.65-0.75
Phenylalanine	3.65	3.15-4.19	3.27	3.05-3.61	3.95	3.70-4.10
Threonine	3.36	2.97-3.78	3.13	2.91-3.41	3.38	3.15-3.65
Tryptophan	1.06	0.81-1.16	0.97	0.86-1.08	-	
Valine	3.91	3.55-4.30	3.64	3.18-3.92	3.52	3.36-3.77
Cys+Met	2.19	1.78-2.47	1.96	1.73-2.19	3.13	2.94-3.45
Tyr+Phe	7.33	7.01-7.87	8.68	8.24-9.12	6.76	6.17-7.00

Table 3. **Mineral profile of Australian sweet lupin (ASL), Albus lupin (Al) and Yellow lupin (YL), per kg as received**

Mineral	ASL		AL		YL	
	Mean	Range	Mean	Range	Mean	Range
				g		g
Calcium	2.2	1.5-2.9	2.0	1.2-2.5	1.5	0.5-2.4
Magnesium	1.6	1.0-2.1	1.4	0.9-1.6	2.1	1.6-2.5
Phosphorus	3.0	2.1-4.1	3.6	2.8-4.9	5.1	3.1-7.1
Potassium	8.1	7.2-9.2	9.8	4.1-12.0	9.7	
Sulphur	2.3	1.5-3.0	2.4	1.9-2.7	4.7	4.6-4.9
Sodium	0.5	0.2-1.2	0.5	0.1-1.1	0.1	<0.1-0.2
				mg		
Cobalt	0.1	0.1-0.3	0.3	0.3-0.3	0.0	0.0-0.1
Copper	4.9	3.0-6.8	5.0	3.1-8.1	8.8	1.2-16.3
Iron	75.0	36.0-160.0	26.2	20.0-42.0	92.7	50.1-135.3
Manganese	16.9	6.5-63.0	835	19-3800	86	8.6-162.4
Molybdenum	1.6	1.2-2.8	2.3	0.8-3.8	6.5	0.9-12.0
Zinc	34.7	24.0-45.0	29.7	21.0-38.0	55.8	46.6-64.9
				ug		
Selenium	82	18-220		20-280		

do not need this additional step in processing, although the heat treatment will have the added benefit of destroying lipoxygenases, lipases and other enzymes which can cause detrimental changes to flavour.

Table 4. **Bioactive non-nutrients in grain of Australian sweet lupin (ASL), Albus lupin (AL) and Yellow lupin (YL)**

Faktor	Units	ASL		AL		YL	
		Mean	Range	Mean	Range	Mean	Range
Alkaloids	%	0.019	0.005-0.043	<0.01	<0.01-0.020	0.009	0.006-0.010
Oligosaccharides	%*	5.16	4.73-6.14	6.69	5.85-7.41	**	–
Phytate	%	0.58	0.37-0.91	0.79	0.58-0.92	0.95	0.86-1.01
Tannins (Total)	%	0.32	0.17-1.20	0.37	0.23-0.52	0.31	0.30-0.32
Tannins (Cond)	%	<0.01	<0.01-0.01	0.01	0.01-0.01	0.02	0.02-0.03
Saponins	mg/kg	573	442-740	Not Detected		–	–
TIA	mg/g	0.14	<0.01-0.28	0.13	0.10-0.20	0.12	0.11-0.12
CTIA	mg/g	0.08	<0.01-0.59	–	–	–	–
Lectins	HW	Not detected		Not detected		–	–

* Sum of raffinose, stachyose and verbascose
** Not assayed.

Human food uses for lupins

The use of lupins in traditional fermented foods

Lupins have been shown by a number of researchers to be an excellent substrate for both bacterial and fungal fermentations, used in making foods such as tempe, miso and traditional soy sauces.

Tempe. Lupins *(L. angustifolius)* were first reported to be suitable for tempe production by Kidby *et al.* (1977). Since then Hung *et al.* (1990) showed that they were a better substrate for fermentation because of the greater breakdown of proteins and complex carbohydrates into more digestible, simpler structures. Agosin *et al.* (1989) found that *L. albus* was also a good substrate for making tempe. More recent research has shown that lupin (ASL) tempe was equally acceptable as soy tempe to a group of Australian and Indonesian panellists (Fudiyansyah *et al.*, 1995); the fermentation process lowers the content of biologically active non-nutrients (Fudiyansyah *et al.*, 1995); lupin tempe made in Indonesia was considered quite tasty by local people but they found the product to be too firm when compared with soy tempe (Fairbrother, 1994); and it is not economical to cook lupins for a long enough time to soften the seed to the texture of cooked soybeans (Coorey, 1996).

Miso. Two groups showed that lupins could be used to make miso (a range of paste-like products made by the fermentation of cooked soybeans and rice) with sensory properties similar to that of the traditional products (Coffey, 1989; Cunha and Beira da Costa, 1990). Japanese miso is a fermented paste made from soybeans with or without the addition of barley or rice. The grains are soaked, cooked and inoculated with a range of organisms including the moulds *Aspergillus oryzae* or *A. soyae.* Fermentation occurs over varying periods and the addition of salt with further fermentation results in a thick paste. The paste is then used as a flavouring agent in products such as soups (Shurtleff and Aoyagi, 1976). A traditional process would involve preparing a rice koji by fermenting cooked rice with a culture of *Aspergillus oryzae* (tane-koji) then adding cooked soybeans and salt to the koji. This mixture is mashed (e.g. through a meat mincer) and inoculated with lactic acid bacteria and yeasts, frequently from a previous culture. Variations in the colour and flavour of miso can come from varying: the cereal used e.g. wheat or barley in lieu of rice; the proportions of salf and cereal in the mash; total cooking time for the soybeans; fermentation time and temperatures; and the inoculum used.

Coffey (1989) reported that an expert panel of Japanese found lupin *(L. angustifolius)* miso to be equally acceptable as soy miso for flavour and texture and more acceptable in colour and overall appearance. Cunha and Beira da Costa (1990) reported a satisfactory product from *L. luteus,* with the desired characteristics found in the traditional product.

Other pastes and sauces. Lupins could be used to make sauces similar in flavour and texture to the traditional soy sauces of Japan (Worm and Beira da Costa, 1990), and China (Hung *et al.,* 1990). Research at the Korean University, Department of Food Technology, using lupins instead of soybeans to manufacture traditional pastes and sauces found that the lupin was a better substrate for fermentation of *A. oryzae* to make both paste and sauce (Lee, Oh and Kim, 1982; Oh and Lee, 1983). However, in sensory evaluation the flavour score of the lupin products was slightly less acceptable.

There are no reports on the use of lupins to make tauco and kecap. The similarity between the manufacture of these and that of miso (Steinkraus, 1977) would suggest that suitable products could be made from lupins.

Milk products

Milk. Camacho and Sierra (1988) reported that lupin milk gave a yield 30% less than soy milk, and that for maximum solubilisation of the proteins it was necessary to extract at a pH of 8.5 (cf. around neutral pH for soybeans). These variations are due to the different protein profiles of the two raw materials (Cerleti, 1983, Oomah and Bushuk, 1983). A lupin milk packaged after UHT treatment was still satisfactory to drink - with no flavour, texture or microbiological breakdown - after two years (W.S.A. Kyle and D.S. Petterson, unpublished results). A lupin-based milk was used in the Chilean program for children's nutrition for several years (E. von Baer, pers. comm., 1996). It is still used by households in some parts of the country.

Tofu (tahu). Lupins cannot be a sole ingredient for tofu manufacture because the proteins lack the necessary tertiary structures to produce a satisfactory matrix. However Hung *et al.* (1990) showed it was possible to incorporate up to 30% lupin milk (*L. angustifolius*) with soymilk before the coagulation stage and produce an acceptable product, with the advantage of a lower unit cost of production. Ho (1996) worked with newer cultivars of this species and different solubilisation techniques but could not improve on yield. Sensory evaluations showed that there was no significant difference ($p > 0.05$) between tofu made from soy milk and a 30/70 lupin/soy blend (Ho, 1996).

Fermented milks. Yoghurt type products made from soy milk and are being called sogurts. Soy milk, calcium lactate, gelatine and lactose are fermented with the appropriate organisms and yield a product that is similar to, but yellower and firmer than, dairy yogurts. Preliminary results indicate it will be possible to make a lupin based yoghurt (H. Zhang, pers. comm., 1996).

Bread, cakes and pasta

Lupin seed (grain) flour has been incorporated into such products as bread, cakes and pasta. Up to about 10% lupin flour can be mixed in with wheat or wholemeal flours to make a more nutritious bread. The blend of cereal and legume helps to balance the amino acid profile and make it a more complete food. It is not possible to add more than about 5% into most wheat flours without a loss in loaf size, because lupin proteins lack the strength and elasticity of wheat gluten (Lucisano and Pompeii, 1981; Petterson and Crosbie, 1990). When stronger flours, e.g. hard red wheat from Canada, are used it is possible to add 15% lupin flour and still retain loaf integrity and a high quality product (L. Brown, Hybrida Grains, pers. comm. 1996). There is an increase in water-holding capacity and the texture, flavour and yellow colour of the lupin-wheat flour is appealing to many consumers (Petterson and Crosbie, 1990). In pasta goods it is possible to increase the lupin component to about 20% before losing the integrity of the product (Boothey, 1993).

Sprouts. Lupins can be germinated to make a big sprout suitable for vegetable or salad use (Dagnie *et al.*, 1992).

Allergenicity of lupins

There is a small percentage of people with a food sensitivity to lupins. We have evidence in Australia that less than 1% of the population that have eaten lupin-based foods show an allergic reaction (Petterson and Crosbie, 1990), which is less than that commonly found in Western societies towards most food groups. In this case all those who reacted to the lupins were known to react towards other foods such as peanuts and soybeans (D. Barnett, cited in Petterson and Crosbie, 1990). As with most food sensitivities, people tend to have a predisposition to this type of reaction and are sensitive to other foods. There is only one reference to an allergic response to the consumption of lupins in the literature. It described a typical histamine production in a young girl who consumed a lupin-fortified pasta (Hefle *et al.* 1994).

Lupins as an animal feed

Aquaculture species

Lupins have been shown to be a useful ingredient in the diet for marine finfish, estuarine and freshwater species, and for fresh and saltwater crustaceans. Hughes (1988) used *L. albus* seed in the diet of rainbow trout and reported feed efficiencies (the inverse of feed conversion ratios) of 84% for an 8.5% inclusion rate; and 79% for a 40% inclusion rate. The fish grew at a comparable rate to others fed an equivalent protein soy-based diet and those on a commercial diet for rainbow trout. In a later paper, Hughes (1991) extended the comparisons between lupin and soy and concluded that it was more economic to use lupin. Similar observations were made by de la Higuera *et al.* (1988), and other groups working with rainbow trout in Europe.

M. Hoxey (*pers. comm.* 1996) uses 20-30% lupin (*L. angustifolius)* seed in commercial diets for rainbow trout in Western Australia and claims it is economically viable.

Jenkins *et al.* (1994) showed that a seed meal from *L. angustifolius* (at 28% inclusion) could be successfully substituted for soybean meal (at 20% inclusion) in diets for juvenile snapper (red sea bream, *Pagras auratus*) with a feed conversion of about 1.7 (feed efficiency of about 59%). Petterson *et al.* (1996) found little difference between the growth rates and feed conversion of juvenile snapper fed the Australia Reference Diet for this species and those fed a mixture of up to 40% Australian Sweet Lupins mixed in with the reference diet. Feed conversions ranged from 1.2-1.37, with the fish growing from 30 g to nearly 80 g in eight weeks. It is common practice in Western Australia for farmers to feed whole or cracked lupin ASL seed to various crustaceans (marron, *Cherax tenuimanus;* yabbies, *C. albidus;* and koonacs, *C. plebejus*) kept in farm dams. Most believe that most of the seed is eaten directly and that any residue forms part of the biosystem at the base of the dam, serving to break down and supply ingredients for organisms lower down the food chain. There have been no formal studies on the economic viability of this practice. Sudaryono *et al.* (1995) showed that up to 50% of the fishmeal or soybean meal in the diet for prawns (*Penaeus monodon*) could be replaced by lupin (ASL) seed without any reduction in performance compared to mixed diets containing plant and animal product.

Pigs and poultry

At present the Australian Sweet Lupin is the preferred (lupin) species for use pig diets. From research results and commercial experience in Australia, the recommended maximum inclusion levels of Australian Sweet Lupins are: starter diets, 10-15%; grower diets, 20-25%; finisher diets, 30-35%; and for dry and lactating sows, 20%. The production responses to lupins can be variable, depending on the diet base. For example, pigs fed a lupin-wheat based diet perform much better than those on a lupin-sugar based diet (Wigan *et al.* 1993).

The Albus lupin is not recommended for use in pig diets. There is some sort of palatability problem and poor acceptance and growth rates can occur at greater than about 10% inclusion (King, 1981). Commercial nutritionists for large Australian piggeries say it is uneconomical to include Albus lupins in their diets (van Barneveld and Hughes, 1994). Supplementation of the lupin-based diets with lysine and methionine is essential to provide a balanced ration.

Both Australian Sweet and Albus Lupins support adequate growth and production in broiler and layer birds. Up to 25% lupin seed meal can be included in broiler diets provided they are supplemented with lysine and methionine (Brenes *et al.* 1993). In commercial practice the recommended maximum inclusion rate for either lupin in broiler diets is about 10%. This is not because of production limitations, but is due to the incidence of wet-sticky droppings that can pose a healts risk to the birds through respiratory stress in coping with high levels of ammonia in the atmosphere and to higher risk of coccidiosis. Laying hens do not have such a problem with these wet-sticky droppings and up to 25% lupins can be included in their diets without affecting performance (van Barneveld and Hughes, 1984).

The feeding value of lupins for pigs and poultry can be improved in two ways. Firstly, the seed coats (hulls), which are largely indigestible celluloses and hemicelluloses, can be removed by dehulling. The hulls (about 22% of the weight of ASL seeds and 15% of the Albus seeds) can be used as an energy supplement for dairy cattle, beef cattle and goats. The kernels have a much higher protein and digestible energy density and approach the net quality of soybean meal. Secondly, the use of commercial carbohydrate enzymes to the feed formulation can improve the apparent metabolisable energy (AME) of lupins for poultry by up to 15% (Brenes *et al.*, 1993).

Dairy and beef cattle

Lupin grain is a valuable supplement for dairy production due to the high energy (13 MJ of metabolisable energy, ME, per kg dry matter) and protein content. This is especially important for high-producing cows whose access to grain is restricted to milking times. Dairy cows prefer coarsely rolled or hammer-milled lupin grain to the whole grain. This much processing increases the digestibility by about 15% (Valentine and Bartsch, 1986) and the cost of the processing is less than the added return in milk production (Hough and Jacobs, 1994). There are less problems with changes in rumen fermentation with feeding lupins rather than other legumes or barley. Lupins are considered a much safer management tool. Production can be limited if lupin grain is the sole protein source and some form of supplementing with canola meal, cereal grains or maize silage might improve productivity (Hough and Jacobs, 1994; Lemerle *et al.* 1985). For beef cattle the advantages are not so great and the value of lupins will largely depend on the relative costs of alternative protein sources. They are nevertheless widely used in feed lot formulations in Europe, Japan and Korea.

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