

The Use of Lupins in Feeding Systems - Review -

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ABSTRACT : The seed, or grain, of modern cultivars of *Lupinus angustifolius*, commonly known as Australian sweet lupins (ASL), is an established feed resource for the intensive animal industries of Australia, Japan, Korea and several other countries in Asia and Europe. Since the introduction of ASL to the world marketplace about 25 years ago, researchers in many countries have found them to be a valuable component of the diet of beef and dairy cattle, sheep, pigs, poultry, finfish and crustaceans. The seed of ASL contains ~32% crude protein (CP) (~35% DM basis) and 5% oil. The main storage carbohydrates in the seed are the β -galactans that comprise most of the cell-wall material of the kernel and the cellulose and hemicellulose of the thick seed coats. ASL seeds contain about 40% non-starch polysaccharides (NSP) and a negligible amount of starch. This makes them an excellent ingredient for ruminant diets, as the risk of acidosis is very low. The seed of modern cultivars of domesticated *Lupinus* species contain negligible amounts of lectins and trypsin inhibitors so they do not require preheating before being used as an ingredient in feeds for monogastric species. They have a high digestibility coefficient for protein, >90% for most species, but a low energy digestibility, ~60%, which is mostly due to the high content of NSP. The low content of methionine (0.22%) and of lysine (1.46%) is typical of the legumes. The lysine availability for pigs is >70%. Lupin kernels contain ~39% CP (~42% DM basis), 6% oil and 30% NSP. They have a higher digestible energy for pigs and finfish and a higher metabolisable energy for poultry than whole seed. Commercial operations rarely achieve complete separation of kernel from hull and it is more likely that the kernel fraction, called splits or meats, will contain ~36% CP. The replacement of soybean meal or peas with ASL in cereal-based diets for most intensively reared animals, birds and fish is possible provided lysine, methionine and digestible energy levels are kept constant. This makes ASL economically competitive in many, but not all, circumstances. (*Asian-Aus. J. Anim. Sci.* 2000, Vol. 13, No. 6 : 861-882)

Key Words : Lupins, Composition, Nutrition, Pigs, Poultry, Ruminants, Aquaculture, Humans

INTRODUCTION

The terms lupin and lupins are widely used to describe the seed or grain of domesticated *Lupinus* species, either of *L. albus*, *L. angustifolius*, *L. cosentinii*, *L. luteus* or *L. mutabilis*.

Lupinus albus, the European white lupin, or lupine, has flowers that are white to violet-blue. The seed is flat, has a whitish seed coat and typically weighs about 350 mg, although seed of some European varieties, often called lupini beans, can weigh about 500 to 600 mg. The greatest production of *L. albus* is in Australia, ~100,000 tonnes annually. This seed has a very low alkaloid content and it is often referred to as Albus lupin to differentiate it from the larger-seeded, bitter lupini beans grown elsewhere. *L. albus* is also cultivated in Poland, around the Mediterranean basin, and in several south American countries: altogether these countries produce less than 200,000 tonnes.

Lupinus angustifolius, the narrow-leafed lupin, has flowers that are normally blue, and it is sometimes

referred to as blue lupin in the literature. To this day the bitter varieties that are grown in some countries have a blue flower. However, in the breeding program started in the 1960s the *leucospermus* gene for white-flowered and white-seeded sweet, low-alkaloid, types was successfully introduced as an unlinked marker for sweetness allowing ready identification of the desired trait (Gladstones, 1998). This led many earlier researchers in Australia to inadvertently refer to it as white lupin and sweet white lupin, and some did not discriminate between it and the true white lupin leaving some confusing data in the literature.

Stringent measures are taken to ensure that the alkaloid content of the seed remains low. Pedigree seed is monitored and all breeding material is carefully checked to cull out any rogue seed. There is also a monitoring program for all commercial seed. At present about 12 varieties of *L. angustifolius* are available for use, each having some particular agronomic advantage or disease resistance profile, so farmers can choose the variety most likely to grow best on their property each year. This all helps to ensure continuity of supply to the animal feeds industry. To minimise confusion and to differentiate this seed from that grown elsewhere it is often referred to as Australian sweet lupin (ASL). Over 1.2

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million tonnes of ASL seeds are produced in Australia each year and over 800,000 tonnes are available for export. A typical seed weight is about 150 mg, and they are similar in shape and size to soybeans and field peas.

Lupinus luteus, yellow lupin (YL), has golden yellow flowers. A typical seed weight is ~120 mg, and they are more ellipsoid in shape than seed of *L. angustifolius*. It is more agronomically suited to some areas where it out-yields ASL. About 2,000 tonnes were produced in Australia in 1999 and production is expected to rapidly increase in future.

Other *Lupinus* species in the process of domestication are *L. atlanticus*, Atlas lupin, *L. cosentinii*, sandplain lupin, *L. hispanicus*, *L. mutabilis*, Andean lupin, and *L. pilosus*.

This review will cover the composition of lupins under the headings of protein and amino acids, carbohydrates and lipids, minerals and vitamins, and biologically active compounds. The nutritive value of lupins for intensive animal industries will be discussed under the headings: beef and dairy cattle, sheep, pigs, poultry, finfish and crustaceans, and other species.

The review will concentrate on ASL, as it comprises over 95% of the seed available to the feed industries of Australasia, but reference will be made to other domesticated lupins where appropriate. It will also cover the potential for improving the feed value of lupins by biotechnology and industrial technology, and some food and industrial uses of lupins.

THE CHEMICAL COMPOSITION OF AUSTRALIAN SWEET LUPINS

The seeds, or grains, of ASL have a thick testa, or

seed coat, comprising about 22% of the seed weight. They contain very little starch, with carbohydrate stored in the form of complex polysaccharides in the thick cell walls of the cotyledons, and as cellulose and hemicellulose in the testa. The crude protein (CP) content is typically 32% (35% DM), with only small seasonal variations, and oil content is usually between 5 and 6%. Typical proximate analyses for ASL and other major lupin species are shown in table 1.

The composition of ASL kernels is shown in table 2. The content of CP in the kernels approaches that of soybean meal (SBM), and the crude fibre content is close to that of most other vegetable protein sources.

Proteins and amino acids

About 85% of the total protein of lupins consists of a group of globulins called conglutins (Blagrove and Gillespie, 1975), which are normally soluble in buffers at about pH 7.5. This globulin fraction contains three major proteins conglutin δ , conglutin β , and a lupin-specific protein called conglutin. They have similar size and physical properties to the storage proteins of the field pea, soybean and other legumes. The largest protein, conglutin δ , which has a molecular weight (MW) of about 315,000 daltons (315 kDa), is analogous to legumin of peas and glycinin of soybeans. Conglutin β (MW ~185 kDa) is analogous to the vicilin of peas and conglycinin α and β in soybeans. Conglutin δ (MW ~17 kDa) is sulphur-rich and is analogous to the conglycinin of soybeans (Lilley and Inglis, 1986). The remaining proteins are albumins which are insoluble in buffers at pH 7.5: they vary in size from ~6 to ~117 kDa.

The amino acid profile for ASL and other domesticated lupins is shown in table 3. The low

Table 1. Chemical composition of the major lupin species (g/kg as received)

Botanical name	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>
Common name(s)	Albus lupin White lupin	Australian sweet lupin Narrow-leafed lupin	Yellow lupin
Dry matter	914.2	910.8	915.0
Protein (N × 6.25)	357.6	320.1	382.8
Ash	32.8	27.1	34.8
Crude fat	94.9	59.0	56.4
Crude fibre	105.7	153.5	162.5
Acid detergent fibre	146.3	196.5	248.7
Neutral detergent fibre	176.3	235.3	343.0
Lignin	7.0	8.6	7.3
Starch	ND ^A	ND	ND
Calcium	2.0	2.2	2.2
Phosphorus	3.6	3.0	4.3
Sulphur	2.5	2.3	4.6
Gross energy (MJ)	18.7	18.4	19.6 ^B

Sources: Petterson et al. (1997) and ^B B. P. Mullan (unpubl.).

^A ND: Not detected.

Table 2. Chemical composition of the kernels of lupin species (g/kg as received)

Botanical name	<i>L. albus</i>	<i>L. angustifolius</i>	ASL splits ^A	<i>L. luteus</i>
Moisture	^B	100.1	100	83.0
Protein (N × 6.25)	400.9	400.3	350	525.7
Ash	33.0	26.9	-	43.4
Crude fat	114.0	65.5	-	71.6
Crude fibre	18.0	87.1	32	17.1
Acid detergent fibre	-	70.2	108	31.2
Neutral detergent fibre	-	71.2	121	47.9
Lignin	-	6.7	-	-
Calcium	-	1.0	-	1.2
Phosphorus	-	5.1	-	9.7
Sulphur	-	2.5	-	5.0
Gross energy (MJ)	20.4	18.0	18.0	10.7

Sources: A. C. Edwards (unpubl.), Petterson et al. (1997), and Zdunczyk et al. (1994).

^A ASL splits are commercial preparation of kernels: the data for these are similar to what industry can expect from large-scale operations.

^B No value reported.

Table 3. Essential amino acid profile for major lupin species

	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>
	g amino acid/16 g N			% amino acid in seed		
Arginine	12.2	11.62	11.3	4.50	3.59	4.37
Cysteine	1.34	1.36	2.28	0.50	0.42	0.88
Histidine	1.86	2.57	3.3	0.68	0.79	1.05
Isoleucine	3.80	3.91	2.70	1.40	1.22	1.42
Leucine	6.90	6.61	7.89	2.30	2.12	3.06
Lysine	4.75	4.66	5.35	1.58	1.46	2.07
Methionine	0.66	0.72	0.70	0.24	0.20	0.27
Phenylalanine	3.85	3.65	4.04	1.24	1.18	1.56
Threonine	3.29	3.54	3.51	1.20	1.09	1.36
Tryptophan	0.97	1.00	^A	0.36	0.31	-
Tyrosine	4.26	3.66	3.1	1.46	1.13	1.12

Adapted from Petterson et al. (1997).

^A No value reported.

content of methionine (~0.2% of the seed, 0.66 g/16 g N), cysteine (~0.4% of the seed, 1.36 g/16 g N) and lysine (1.46% of the seed, 4.75 g/16 g N) is typical of legumes while the content of arginine (~3.6% of the seed, 11.6 g/16 g N) is higher than for most other legumes.

The relationships between the content of lysine, methionine and threonine and that of CP in ASL seed were calculated to be: lysine (g/kg)=0.041 CP (g/kg)+0.210; methionine (g/kg)=0.007 CP (g/kg)+0.004; threonine (g/kg)=0.035 CP (g/kg)+0.146 (S. Sipsas, unpubl.).

There are limited data for tryptophan in ASL seed. Ravindran et al. (1999) recently developed an improved assay and reported values of 2.76 g/kg in ASL, compared to 6.05 g/kg in SBM, 1.85 g/kg in

peas and 4.51 g/kg in canola meal.

The Protein Efficiency Ratio (PER) in rats, i.e. the bodyweight gain per unit of protein ingested, is low for all lupin species but the addition of 0.2% DL-methionine is generally sufficient to bring the PER value up to that of casein or egg albumin (Zdunczyk et al., 1998; Petterson, 1998). PER values for *L. albus* meal (0.8) are similar to those of soybeans (0.9) but lower than rapeseed meal (1.9) (Rozaan et al., 1997).

Non-protein nitrogen

In preparations of amino acid extracts from ASL and some other *Lupinus species*, the sum of amino acids was about 90% of the value of N × 6.25 (A. J. Evans, unpubl.). This approximates to a conversion factor of 5.6, so about 10% of the nitrogen present in

Table 4a. The carbohydrates in *L. angustifolius* (% dry weight)

Fraction	Cell wall content	Cellulose	Lignin	Starch	Sucrose	Oligosaccharides
Hulls	90	51	1.2	0.4	1.0	0.4
Kernels	28	1.2	0.9	0.6	3.5	7.7

Adapted from Evans (1994) with permission from the publishers.

Table 4b. Individual sugars in total, soluble and insoluble NSP from hull and cotyledon of *L. angustifolius* (monosaccharide, as % total polysaccharides)

	Hull			Cotyledon		
	Total	Soluble	Insoluble	Total	Soluble	Insoluble
Araginose	8.7	11.8	8.5	13.0	10.0	13.8
Galactose	2.2	10.0	1.4	67.0	67.7	64.6
Glucose	59.4	4.0	62.9	4.6	2.9	4.5
Mannose	2.5	13.9	1.7	0.7	3.5	0.3
Rhamnose	n.d. ^A	1.3	n.d.	2.6	3.7	2.9
Uronic acids	12.3	17.9	12.8	9.9	10.2	10.8
Xylose	14.9	41.2	12.5	2.3	1.9	3.2

Adapted from Evans et al. (1993).

^A n.d. - not detected.

lupin seed is likely to be of non-protein origin. This is similar to the value suggested by Mosse (1990) and Sosulski and Imafidon (1990) for *L. albus*.

Carbohydrates

Lupin hulls are predominantly composed of cellulose, hemicelluloses and pectins (Brillouet and Riochet, 1983; Evans et al., 1993), while the main carbohydrates in the cotyledons are the non-structural polysaccharides (NSP) of the cell walls. There is no significant amount of starch in lupin seed. The ratios of the monosaccharides that comprise the NSP of hull and cotyledon of some lupin species are summarised in table 4. Farrell and Mannion (1997) and van Barneveld (1999) gave similar values. The oligosaccharides are discussed later as bioactive compounds, although they do contribute to the net energy content of lupin seed for some species.

Lipids

The lipid content of lupin species ranges from about 1% in some cultivars of *L. luteus* to 21% in some of *L. mutabilis*. Seeds of *L. angustifolius* usually contain less than 6% oil. There is little variation in the composition of the oil fraction in seed of *L. angustifolius* grown in Australia with the major components being palmitic (11.0%), oleic (33.5%), linoleic (37.1%) and linolenic (5.3%) acids (Pettersen et al., 1997). The typical lipid profiles for the major species are shown in table 5.

Minerals

The range of values of calcium, magnesium,

phosphorus, potassium and sulphur for each of the main lupin species is up to about 30% of the mean and the sodium content is more variable, depending on soil type (table 6). The range for minor elements is greater with variations in the content of iron (31-150 mg/kg), manganese (6-76 mg/kg), cobalt (10-260 µg/kg) and selenium (18-240 µg/kg) in ASL related to rainfall zone, with seed from low rainfall areas generally having a higher mineral content. Soil type and growing conditions influence the concentrations of copper, molybdenum and zinc to a lesser degree. These concentrations can be below minimal maintenance and growth requirements of animals (Underwood, 1971), however this is not of concern for feed formulators because crops from many areas are mixed at grain handling facilities and mineral mixes are commonly added to compounded feeds.

Vitamins

R. Fountain (unpubl.) reported the following values for ASL in mg/kg: β -carotene 3.5, thiamin 5.3, riboflavin 2.8, biotin 0.04, folic acid 0.4, choline 3035, niacin 36, pantothenic acid 1.6 and α -tocopherol 2.2. Higher concentrations of α -tocopherol were found in later cultivars of ASL (Merrit, 2.3-4.6 mg/kg; Gungurru, 3.0-4.2 mg/kg) (G. M. Smith, unpubl.).

Biologically active compounds

Legumes are well known for containing a range of compounds with apparent untoward effects on species ingesting them, traditionally known as anti-nutritional factors (ANF) or anti-nutrients. However, there is an increasing awareness that while these compounds may

Table 5. Fatty acid profile of major lupin species (% fatty acid in hexane extract)

Fatty acid	Common name	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>
14:0	Myristic acid	0.1	0.1	P
16:0	Palmitic acid	7.8	11.0	4.8
16:1	Palmitoleic acid	0.3	0.1	P
18:0	Stearic acid	1.6	3.8	2.5
18:1	Oleic acid	53.0	38.2	21.0
18:2	Linoleic acid	17.2	37.1	47.3
18:3	Linolenic acid	9.5	5.3	7.5
20:0	Arachidic acid	1.2	0.9	2.7
20:1	Hexeicosanoic	4.3	0.3	1.8
20:4	Arachidonic acid	0.4	P*	P
22:0	Behenic acid	3.9	1.9	7.1
22:1	Erucic acid	1.9	P	0.8
24:0	Lignoceric	0.7	0.4	0.8
Sterols		P	2.2	P

Adapted from Petterson et al. (1997).

* P-Present, not quantified.

Table 6. Minerals content of major lupin species - mean with range of data set in parentheses

	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>
	g/kg		
Calcium	2.0 (1.2-2.5)	2.2 (1.5-2.9)	2.2 (1.8-2.6)
Magnesium	1.3 (0.9-1.6)	1.6 (1.1-2.0)	2.1 (2.2-3.2)
Phosphorus	3.6 (2.5-9.0)	3.0 (2.1-4.3)	5.1 (3.4-6.0)
Potassium	8.8 (2.8-11.1)	8.0 (6.6-9.1)	9.7 (8.8-10.0)
Sodium	0.3 (<0.1-0.3)	0.4 (0.3-1.1)	<0.1
Sulphur	2.5 (2.1-2.7)	2.3 (1.5-2.9)	4.6 (4.0-4.9)
	mg/kg		
Copper	5 (3-8)	5 (3-7)	8 (6-12)
Iron	27 (21-44)	68 (31-150)	59 (52-70)
Manganese	896 (23-3772)	19 (7-76)	35 (25-50)
Molybdenum	2 (1-3)	2 (1-3)	^A
Zinc	30 (22-38)	34 (25-45)	53 (39-82)
	μ g/kg		
Cobalt	206 (10-430)	78 (10-260)	-
Selenium	85 (20-360)	89 (18-240)	-

Adapted from Petterson et al. (1997).

^A No value reported.

have a negative effect on feed utilisation, which is important for animals and birds raised for food production, they may also have beneficial effects. For example, phytate and protease inhibitors are antioxidants and have anti-cancer properties in rats (Wang and McIntosh, 1995). Therefore, it is probably more correct to regard these as bioactive or biologically active compounds (G. R. Fenwick, pers. comm.), a view supported by the recent conference of the European Grain Legumes Association (Muzquiz, 1999). A summary of data for the content of bioactive compounds in lupins is shown in table 7.

1) Phytate

Phytate, inositol hexaphosphate and lower substituted homologues and their salts, forms insoluble complexes with divalent cations, particularly Ca²⁺ and Zn²⁺, rendering them less available for absorption and utilisation. The net effect depends on the overall protein content and characteristics and the total mineral content of the feed. The phytate content of lupins (~0.5%), which is similar to that of peas and soybeans, is not likely to be of concern under any conditions of intensive animal production.

Table 7. Bioactive compounds in the major domesticated lupin species

Botanical name		<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. luteus</i>
Total alkaloids	mg/kg	<100	<200	500
Oligosaccharides	%	6.6	4.1	8.9
Saponins	mg/kg	n.d. ^A	573	- ^B
Condensed tannins	%	0.02	0.01	0.03
Lectins	titre	n.d.	n.d.	-
Trypsin inhibitors	mg/g	0.08	0.12	0.16
Phytate	%	0.57	0.50	0.93

Adapted from Petterson et al. (1997).

^A n.d.=not detected.; ^B No value reported.

2) Tannins

Tannins are complex compounds with molecular weights ranging from 500 to 2,000 daltons that can form cross-linkages between proteins and other macromolecules and make them unavailable for digestion (Griffiths, 1991). Of the two tannin sub-groups, hydrolysable and condensed (non-hydrolysable), it is the condensed tannins that are best able to precipitate proteins, especially the gut enzymes. This property and their astringent taste give the tannins their anti-nutritional role. The tannins are concentrated in the seed coats (hulls) so dehulling will minimise any adverse effects, however the concentration of condensed tannins is so low in lupins (~0.01%) that it is unlikely to impair protein utilisation by any animal species. Higher concentrations occur in some varieties of field pea and faba beans.

3) Saponins

Saponins are plant glycosides with a steroid or a triterpenoid compound as the non-sugar. They have a bitter taste, which acts as a feeding deterrent, and their anti-nutritional effect seems due to an increase in the permeability of the small intestinal mucosa cells. Only traces of saponins are present in *L. albus*, while concentrations in *L. angustifolius* range from 480 to 730 mg/kg (Ruiz et al., 1996; Frokiaer et al. 1998), and in *L. luteus* 55 mg/kg were detected by Cuadrado et al. (1995). These concentrations are about one-tenth that in SBM and one-half that in field peas (Fenwick et al., 1991). There is no evidence that these concentrations of saponins have any effect on feed intake or gut absorption.

4) Protease inhibitors

Trypsin inhibitor activity is less than 0.3 mg/kg and chymotrypsin inhibitor activity is less than 0.6 mg/kg in *L. albus*, *L. angustifolius*, *L. cosentinii* and *L. luteus* (Petterson et al., 1997; Salmanowicz and Weder, 1997). These are less than one-tenth of the

activity in most other grain legume crops.

5) Lectins

There is no lectin activity in extracts from *L. albus* or *L. angustifolius* in standard tests (Liener, 1989; B. N. Greirson and D. S. Petterson, unpubl.). Slight agglutinating activity can be induced if the red cells are specially treated, but this is not considered biologically significant (A. Pustzai, pers. comm.; M. Duranti, pers. comm.). This offers an advantage over soybeans and SBM, which need heat treatment to inactivate lectins.

6) Oligosaccharides

The oligosaccharides of *Lupinus* species are α -galactosyl homologues of sucrose. Raffinose has one galactose moiety linked to a sucrose molecule through an α -1,4 bond, while stachyose has two, verbascose three and ajugose four. These compounds cannot be metabolised by monogastric animals, and they undergo bacterial digestion in the colon to produce carbon dioxide, methane and hydrogen. This causes abdominal discomfort, cramps, gut distension and flatulence. The oligosaccharides may have a beneficial role in osmotic regulation in the gastrointestinal tract of poultry and other species. They have no adverse effect in ruminants.

There is a wide range of values in the literature for the content of oligosaccharides in the various lupin species, which can be mostly accounted for by differences in analytical procedures. The values of ~5% in the seed quoted by Macrae and Zand-Moghaddam (1978), Quemener (1988) and Petterson et al. (1997) are considered the most reliable. Sucrose is sometimes reported as an oligosaccharide, however it is metabolised by the upper digestive tract of monogastrics. Soybeans and field peas contain similar amounts of these oligosaccharides (Petterson et al., 1997).

7) Isoflavones

Isoflavones are regarded as antinutritional factors because in high concentrations they have negative effects on fertility in ruminants grazing pasture medics and subterranean clovers. However, at lower concentrations, the anti-cancer effects of genistein and daidzein make them a desirable component of human foods. Kaufman et al. (1997) surveyed over 80 agriculturally important legumes and found that *L. angustifolius*, *L. albus*, faba beans and soybeans were excellent sources of both compounds. Serad (1999) reported a similar content of isoflavones in ASL seed and soybeans.

8) Alkaloids

The alkaloids in ASL are bicyclic, tricyclic or

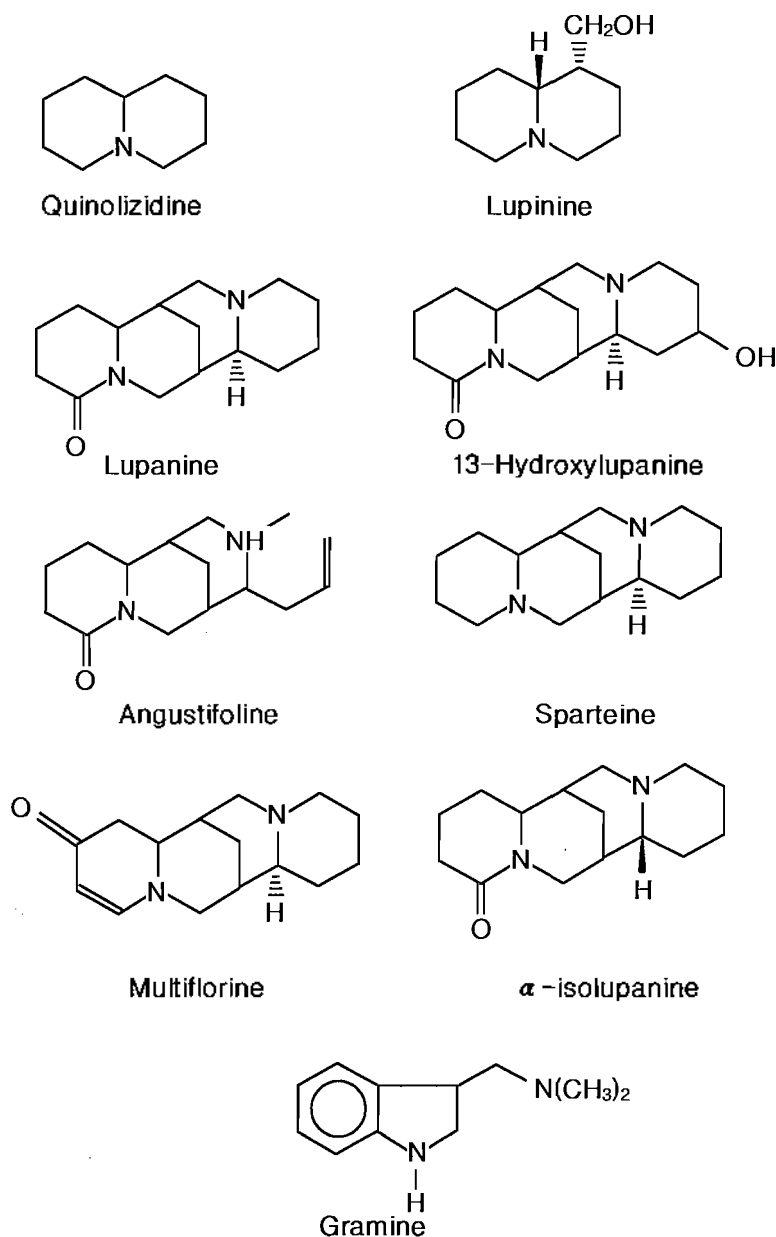


Figure 1. Structure of lupin alkaloids

tetracyclic derivatives of quinolizidine (figure 1). Seed of modern cultivars of *L. angustifolius* grown in Australia typically contain less than 200 mg/kg alkaloids (Harris and Jago, 1984) whereas the bitter wild types that still exist in many countries may contain from 5,000 to 40,000 mg/kg alkaloids. The typical alkaloid profile of ASL is lupanine 42-59%, 13-hydroxylupanine 24-45%, angustifoline 7-15%, α -isolupanine 1-1.5% and traces of other alkaloids. The concentration of alkaloids in commercial crops from Western Australia for the period from 1990 to 1992 ranged from 30 to 150 mg/kg (Pettersson, 1998) and similar values were found in samples from grain

receival points between 1994 and 1998 (D. J. Harris, pers. comm.). These concentrations are less than one-tenth of that shown to cause inappetance in pigs, the species most sensitive to the lupin alkaloids.

9) Mycotoxins

The only mycotoxins reported on ASL seed are the phomopsins, a group of toxic secondary metabolites produced by the weakly parasitic and saprophytic fungus *Diaporthe toxica*. Only obviously discoloured seeds contain significant amounts of these toxins (Wood and Pettersson, 1986; Wood et al., 1987). These discoloured seeds can be easily removed by grading

(Wood and Petterson, 1986) or colour sorting (K. H. Than, pers. comm.). Modern cultivars of *L. angustifolius* are strongly resistant to *D. toxica* invasion (W. A. Cowling, pers. comm.), so the risk of phomopsins being present is minimal.

No other toxigenic fungi have been detected in ASL from Western Australia (P. McR. Wood, pers. comm.). The Mediterranean climate does not favour fungal activity, and the moisture content of seed is almost invariably below 10%.

NUTRITIVE VALUE OF LUPINS FOR RUMINANT ANIMALS

Protein

Rumen degradation of ASL protein ranges from ~73 to ~95% (Hume, 1974; Jarrige, 1989; Cros et al., 1991). The variation seems to be influenced by the nature of other feed ingredients and how well the matrix supports an active rumen flora. Particle size is also important as Freer and Dove (1984) found that 85% of the nitrogen from finely milled seed and 10% from coarsely milled seed escaped from nylon bags inside the rumen within 2 hr of ingestion. After 24 hr the losses were 97 and 91% respectively. Nevertheless ASL has proven to be a valuable source of protein for ruminants under a wide range of conditions in several countries.

Energy

The carbohydrates of lupin are highly, but not rapidly, fermentable in the rumen so the risk of a lactic acidosis is low. This makes it easy to introduce ruminants to lupins under intensive feeding conditions.

A digestible energy (DE) value for sheep of 16.5 MJ/kg was estimated by Mackintosh et al. (1985), and conservative estimates for metabolisable energy (ME) of 12.2 MJ/kg (13.4 MJ/kg DM) were given by Petterson and Mackintosh (1994) after reviewing several *in vivo* studies. The AFRC (1993) reported a ME value of 14.2 MJ/kg DM and a fermentable ME of 10.2 MJ/kg DM based on the work of van Straalen and Tamminga (1990). A study with adult wethers fed only ASL reported ME values from 13.5 to 13.9 MJ/kg (Margan, 1994). In this study there was a high retention of energy and low retention of nitrogen relative to that which occurs with oats, suggesting deposition of fat rather than lean meat when ASL is the sole feed source. This may have implications for using seed of any species of lupin to finish ruminants for certain markets. Moss et al. (1997) estimated a ME value of 16.9 MJ/kg DM for *L. albus* seed.

Grinding or cracking ASL seed appears to be cost-effective for cattle. Valentine and Bartsch (1986) reported that ~24% of whole seed ingested passed through cattle fed a diet based on oaten hay and

~31% through those fed a pasture based diet. Rolling the seed, to crack it, increased milk yield by ~3% in high-producing cows fed a pasture-based diet (Hough, 1991) and mechanical disruption of ASL improved their acceptance and intake by dairy cows and calves (Hough and Jacobs, 1994). Results with beef cattle have been less conclusive, with Axelsen et al. (1979) and May and Barker (1984) reporting a benefit of cracking the seed to steers. Emile et al. (1991) reported no benefit of cracking *L. albus* seed for bulls.

Ferguson (1975) treated a diet containing ASL seed with formaldehyde and reported a 25% increase in wool growth. However, no increase in wool growth is observed when only the lupin component is treated, despite a reduction in protein degradation in the rumen (Fortune et al., 1980; Hynd and Allden, 1986; White et al., 1998a). This lack of response to protected lupin protein may be due to the low content of methionine and cysteine. Rodehutsord et al. (1999) reported a 35% increase in wool growth when sheep were fed formaldehyde-treated ASL or ASL heated to 115°C both with protected methionine added, but only a 17% increase when fed protected methionine alone.

Extrusion of ASL at 130 or 140°C resulted in increased nitrogen retention by penned sheep but had no effect on their wool growth (Dunn, 1992). In studies with *L. albus* protein degradation in the rumen decreased with increasing heat treatment, up to extrusion at 190°C, and the heat did not affect protein breakdown in the digestive tract (Cros et al., 1991). Flame roasted *L. albus* seed had an estimated extra 26% of protein passing through the rumen undegraded (Robinson and McNiven, 1993).

Feed companies in Japan and the Republic of Korea roll and steam ASL to make a flake for beef and dairy cattle. This has been common practice for over 10 years and since each country imports over 100,000 tonnes of ASL each year (Cox, 1998) it is presumed to be economically viable.

Lupins in feedlot and dairy rations

Fukamachi (1986) used flaked ASL (at 12.5 or 13.0% of the diet) as isonitrogenous replacements for SBM in diets of Holstein steers grown from 250 to 700 kg. Feed intakes averaged 1 to 4% higher for the ASL diets across the trial period, resulting in a 3% advantage in average daily gain (ADG) in bodyweight and a 2% better efficiency of feed conversion. Similar results were obtained in several studies with *L. albus* seed as part or total replacement of SBM in diets of bulls and steers (Emile et al., 1991; Moss et al., 1997).

Rowe et al. (1994) found no significant advantage in feeding ASL compared with cereal grains in the diets of 300 kg steers fed a basal ration of hay,

provided there was sufficient nitrogen in the diet. Jacobs and Tudor (1994) found no difference in performance between 300 kg steers fed a basal ration of silage supplemented with either 3.0-3.5 kg cereals plus urea or isoenergetic amounts of ASL.

At even a modest discount to the price of SBM one could expect an advantage in using ASL under most intensive feeding circumstances, depending on the other components that make up the diet. Anyone intending to use ASL will need to carefully consider their intended feed matrix for optimum use.

In studies on milk production with diets based on maize silage (Lemerle et al., 1985) or pasture-based silage (Hough and Jacobs, 1994) yields were higher with ASL as a concentrate than cereal grain, but lower from ASL than from canola meal or cottonseed meal. However in studies with different roughages (Fukamachi, 1986; May et al., 1990) ASL proved equivalent to SBM for milk yield and protein content, and in one study replacing 75% of the SBM with ASL gave increases in both protein and yield (May et al., 1993). Where the base diet was deficient in protein, adding ASL improved milk yield (Bartsch and Wickes, 1984; Hough and Jacobs, 1994). This reconfirms the need to consider the impact of rumen activity, and balancing for amino acids, when using ASL as supplement to diets of differing basal quality.

Kenney (1986) reported variable effects of including ASL in grain-based diets of lambs. Adding ASL increased voluntary feed intake, provided extra nitrogen for rumen function and increased the total dietary DE. The greatest effects were with the poorest quality diets. No effect on the ratio of lean meat to fat was noted.

Lupins as a supplementary feed for grazing ruminants

1) Survival feeding

One distinct advantage of using any lupin species for grazing sheep is the low risk of acidosis, so farmers generally do not need to gradually phase in any supplementary feeding. The nutritive value of ASL to grazing sheep is affected by the quality of the roughage and of any other basal feed being offered (Berge and Dulphy, 1985), as well as the total feeding regime, and the physiological status of the sheep (Dove and Freer, 1986; Egan et al., 1987; Holst et al., 1994; Paduano et al., 1995). While these factors make it difficult to accurately quantify the true nutritive value of ASL for grazing sheep the widespread practice of supplementing with 50 to 250 g per head per day appears to be economical for most Australian farmers. For example, Krebs et al. (1997) compared supplementing sheep grazing cereal stubbles with 100 or 150 g ASL/day and found increments in weight

gain of 31 and 59 g/hd/day, with a small increment in wool growth. At present prices in Australia, excluding labour, transport costs and commissions, this represents about a 3-fold return on the cost of the supplement. An alternative approach in the study by Warner et al. (1998) showed a return of A\$641 per hectare by grazing prime lambs on a lupin crop in Western Australia, compared to A\$368 for harvesting the grain.

2) Enhancing reproduction

Feeding ASL to ewes for a few days prior to mating can increase ovulation rate (Oldham and Lindsay, 1984; Stewart and Oldham, 1986). The response may be due to an increased energy intake (Teleni et al., 1989a, b) or to an increase in undegraded protein (UDP) reaching the small intestine (Nottle et al., 1988). Supplementing the diet of rams with ASL increases testis size and serving capability (Martin et al., 1987; Murray et al., 1990). The reasons for this are also unclear (Murray et al., 1991).

NUTRITIVE VALUE OF LUPINS FOR PIGS

Protein and amino acids

The best estimates of the quality of lupin protein for pigs come from the availability of its constituent amino acids, particularly lysine, methionine and threonine. This is normally assessed as an apparent ileal digestibility, assuming that amino acid presence in the ileum quantitatively equates to its availability. These values are shown in table 8. However, Edwards and van Barneveld (1998) suggest that this measurement significantly overestimates the true amino

Table 8. Apparent ileal digestibility^A for pigs of essential amino acids from whole seed and kernel of *L. angustifolius* (proportion of total)

Amino acid	Whole seed	Kernel
Arginine	0.88	0.96
Cystine	0.84	0.92
Histidine	0.84	0.86
Isoleucine	0.79	0.90
Leucine	0.81	0.91
Lysine	0.82	0.92
Methionine	0.68	0.86
Phenylalanine	0.82	0.92
Threonine	0.72	0.86
Tryptophan ^B	0.78	n.a.
Tyrosine	0.79	0.91
Valine	0.78	0.91

^A The proportion of amino acid assumed to be digested by the time the digesta has reached the terminal ileum—uncorrected for any endogenous secretion.

^B Source: Ravindran et al. (1999).

Adapted from Edwards and Van Barneveld (1998).

acid availability from ASL, and probably from all other lupin species. Van Barneveld et al. (1997a) used a modified slope-ratio assay to estimate the lysine availability at 0.73 from whole seed (1.07% of the seed) and 0.79 from the kernel (1.46%). These values are much higher than the value of 0.55 predicted by Batterham et al. (1984) using a slope-ratio assay, but are in agreement with the value of greater than 0.7 suggested by Godfrey and Payne (1987) and with commercial experience (A. C. Edwards, pers. comm.).

There is some variation reported for the digestible energy (DE) content of ASL: 12.3 to 15.3 MJ/kg for whole seed and 15.4 to 16.6 MJ/kg for kernels (Wigan et al., 1995). This may be due to different degrees of fineness of the meals used, as Edwards and van Barneveld (1998) suggest an inverse relationship between particle size and digestibility for lupins. In addition, van Barneveld et al. (1995) demonstrated that DE does not change as the proportion of lupins increases in the diet, but the proportion of energy digested by the end of the small intestine (which will influence net energy) decreases significantly.

Digestible energy is commonly used to describe the available energy content of feed ingredients for pigs. However DE measurements can overestimate the true net energy (NE) content of ingredients, such as lupins, that contain a high proportion of carbohydrates that are fermented in the hindgut (Taverner et al., 1983). Noblet (1997) found the NE content of whole seed and kernel to be approximately 10.5 and 10.6 MJ/kg DM respectively for growing pigs and adult sows when measured under controlled conditions. In this study there was no difference between the NE content of ASL and soybeans (10.6 MJ/kg DM).

The sow has a higher capacity than growing pigs for hindgut fermentation of ASL kernel and hulls and consequently can extract a significant amount of energy from lupins. Noblet (1997) reported that sows could extract 14.0 MJ/kg DM of metabolisable energy from ASL hulls compared to 7.4 MJ/kg DM by growing pigs. High levels of gas production accompany high fermentation levels, and when ASL are included at >20% in their diets this can compromise their health. This demonstrates the need for care when feeding lupins to sows.

The maximum recommended inclusion levels of ASL in pig diets based on existing data (King, 1990; SCA, 1997) and commercial experience are; 100-150 g/kg for starter diets, 200-250 g/kg for grower diets, 300-350 g/kg for finisher diets and 200 g/kg for dry and lactating sows (Edwards and van Barneveld, 1998). These are conservative recommendations as much higher inclusion levels are possible without affecting feed intake and subsequent performance. For example, Barnett and Batterham (1981) replaced SBM in wheat-based diets with ASL, while maintaining

lysine and energy levels, for 6 to 20 kg pigs and found they could tolerate dietary levels of 430 g/kg without depressing growth. Pearson and Carr (1976) used up to 370 g/kg in diets of growers and finishers with no reduction in growth, and Taverner (1975) and Batterham (1979) reported similar results.

Kwak et al. (2000) replaced SBM in corn-based diets for grower (25 to 50 kg liveweight) and finisher (60 to 90 kg) pigs with ASL kernel meal (ASLK meal) while maintaining lysine and energy levels. They found no loss of performance of growers with a 10 or 20% inclusion, but did not test any higher levels. There was no loss in performance of finishers with a 15% or 30% inclusion; but at 30% there was a 5% reduction in chilled carcass weight. At both levels there was an improvement in carcass grade, which may well have covered any yield loss.

A. C. Edwards (pers. comm.) reported on a commercial-scale study in which SBM was replaced with ASLK meal to a crude protein equivalent in pig weaner diets that were balanced for lysine, but not methionine. There were incremental increases in growth rate, ranging from 330 g/day to 368 g/day, as the ASLK meal content increased from 0 to 21%, and the best feed conversion ratio (FCR) was achieved by the pigs fed a 21% ASLK meal diet.

Some earlier literature referred to an adverse effect of lupin alkaloids on the performance of pigs due to inappetence. Godfrey et al. (1985) concluded from feeding alkaloids at different levels that pigs could tolerate up to 0.2 g alkaloids/kg diet, with no loss of performance. Since current cultivars of ASL usually contain ~0.1 g alkaloids/kg and will not comprise more than 30% of the diet there is a very wide safety margin.

Improving the nutritional value of lupins for pigs

There is evidence for several ways of improving the nutritional value of ASL for pigs. The viability of any of these methods will need to be evaluated under specific circumstances.

1) Role of oligosaccharides

An ethanol extraction process (Coon et al., 1990) removed 73% of the oligosaccharides from ASL and improved their DE content for growing pigs (van Barneveld et al., 1996), but did not change the gross energy content. Ethanol extraction improved the DE of diets containing *L. angustifolius* and *L. albus* by 0.5 and 0.7 MJ/kg respectively. The ethanol extraction of lupins improved the digestibility coefficients of all amino acids in ASL by 0.05-0.10 MJ/kg and in *L. albus* by 0.05-0.08 MJ/kg (van Barneveld et al., 1997b). This suggests that the galactose oligosaccharides hinder the digestion of amino acids in the small intestine of pigs. This is in contrast to the

findings of Gabert et al. (1995) and Zuo et al. (1996) who found no effect on amino acid digestibility after extracting oligosaccharides from SBM, or with the addition of oligosaccharide isolates to the diet. The results suggest that the increase in lupin DE consistent with oligosaccharide extraction reported by van Barneveld et al. (1996, 1997b) was due to more than just DE dilution when oligosaccharides were present.

Gdala et al. (1997) added 5g α -galactosidase/kg to diets containing YL as the main protein source and found a significant improvement ($p < 0.05$) in digestibility of oligosaccharides and most amino acids.

2) Treating lupins to enhance performance

The nutritional value of lupins for pigs should be improved by the removal of the hull since this contains most of the fermentable NSP. Godfrey and Payne (1987) reported ASLK meal to be a superior protein and energy source to ASL meal, while Wigan et al. (1995) reported that dehulling led to a significant improvement in gross energy digestibility and an observed improvement in apparent ileal digestibility of lysine. However, Noblet (1997) reported that the NE content of ASLK was no higher than in the whole seed.

Steam flaking and extrusion can improve the digestibility of nutrients in many grain feeds, but there are no reports of any improvement in nutritional value of ASL for pigs. Batterham et al. (1986) showed that autoclaving ASL at 121°C for 5 min had no effect on pig growth.

The negative effects of lupin NSP and oligosaccharides on amino acid and energy digestion (van Barneveld et al., 1996, 1997b) suggest a role for exogenous enzymes in pig diets containing ASL. However responses to exogenous enzyme supplementation in diets for pigs have been variable and they are rarely used commercially (van Barneveld, 1999). Flis et al. (1998) found no significant advantage in adding 1 g Porzyme 9,100 to diets based on *L. albus*. More specific enzymes than those currently available will be needed.

THE NUTRITIVE VALUE OF LUPINS FOR POULTRY

Lysine availability using slope-ratio analysis was reported at 0.91 (Batterham, 1992). A true protein digestibility coefficient of 0.95 was reported by Rhone Poulenc Animal Nutrition (1989), compared to 0.90 for peas and soybeans. Individual amino acids coefficients ranged from 0.91 to 0.97. Heartland Lysine Inc. (1992) reported similar values. Sickler et al. (1996) quote values of 0.90 and 0.89 for ASL and SBM respectively.

The low content of lysine and methionine in ASL

relative to requirements means that supplementation is necessary to optimise the use of this commodity. Lacassagne (1988) reported a tryptophan deficiency in poultry fed diets containing more than 10% *L. albus* meal. This observation should be viewed cautiously since none of the many other reports on using any of the *Lupinus* species in poultry diets noted any deficiencies in performance, even up to 40% in the diet. Estimates for the apparent metabolisable energy (AME) of ASL for chickens range from 6.5 to 11.0 MJ/kg DM (Johnson and Eason, 1991; Annison et al., 1994; Bryden et al., 1994; Petterson et al., 1997; Hughes et al., 1998; Perez-Maldonado et al., 1998). Factors contributing to this variation could be differences in experimental procedure, the use of different breeds of bird, variations in the NSP content of the lupins used, and source of the seed. A value of 10.0 MJ/kg DM (9.1 MJ/kg undried seed or meal) is recommended for practical use until more data are available. This value is lower than for peas (10.8 MJ/kg DM) and SBM (10.7 MJ/kg DM). One explanation for this lower value is a poor recovery of energy from hindgut fermentation.

Up to 36% ASL meal can replace other protein sources in broiler diets without affecting growth or feed conversion (Perez-Maldonado et al., 1998; Rubio et al., 1998). When 12 to 36% grain legumes were included in the diet of broiler starters, the birds on an ASL-based diet had an ADG (32.2g) about 4% less ($p > 0.05$) and FCR (1.29) about 4% poorer than those birds fed a pea-based diet (Perez-Maldonado et al., 1998). In a broiler finisher study there was no significant difference in ADG (49g) or FCR (1.98) between performances on the ASL- and pea-based diets (Perez-Maldonado et al., 1998). Overall, across the full grow-out of the birds, there was no loss of performance with up to 36% inclusion of ASL.

Most commercial growers in Australia use a maximum of 10% ASL meal in broiler diets because of the effect of the lupin NSP on digesta viscosity and the moisture content of excreta, and the consequent health and environmental problems associated with a high moisture litter.

Up to 25% *L. angustifolius* meal can be used in layer diets with no loss of production provided amino acid supplements are used (Francesch et al., 1993; Perez-Maldonado et al., 1998). In a 40-week layer study using diets containing 250g grain legume/kg there was no difference in hen-day egg production, egg mass or efficiency of converting feed to egg mass (2.6) between birds fed ASL- or pea-based diets (Perez-Maldonado et al., 1998). In a separate 48-week study with a total of 960 layers fed diets containing 7.5% or 15% ASL meal there was no difference in hen-day production, egg mass or feed efficiency (2.3) (R. J. Bishop, unpubl.).

It is common practice in the poultry industry in Australia to use up to 20% ASL meal in layer diets (A. C. Edwards, pers. comm.). The physical separation of the bird from its waste allows the higher level of inclusion before there are health and environmental problems.

1) Role of oligosaccharides

Marquardt (1993) suggested that the high concentration of oligosaccharides in all lupin species could lower productive performance of poultry, because of their inability to hydrolyse α -galactosides. However ethanol extraction of ASLK meal resulted in a reduction of AME by 0.4 MJ/kg DM, and a lower dry matter digestibility and chickens fed diets based on the extracted meal performed worse than those fed diets based on the original meal (Kocher et al., 1999). The oligosaccharides are presumed to have a role in maintaining osmotic balance.

2) Treating lupins to enhance performance

Removal of the hull improves the nutritional value of ASL for poultry since this contains most of the fermentable NSP. Kang et al. (1989) reported increases in the true metabolisable energy (TME), AME and protein digestibility of ASL through dehulling, and concluded it should improve productivity. Rubio et al. (1998) formulated diets to contain 12.55 MJ/kg and 210 g/kg protein and showed a 32% inclusion of ASLK meal in a casein-soybean diet had no adverse effect on feed intake or growth, yet a 40% inclusion of ASL lowered feed intake, but not FCR, and growth. While *Escherichia coli* counts were not affected, Lactobacilli numbers were increased in all sections of the gut of birds fed lupin-containing diets. In another study, this group showed that *E. coli* counts were reduced in the gut of rats fed ASL and suggested this might be due to the lupin fibre hindering attachment of the bacterium to the gut wall (Rubio et al., 1995). They postulated that this could be a simple way to reduce the numbers of potentially harmful organisms in the gut of intensively raised animals. Australian feed formulators prefer to use ASLK rather than ASL for increased productivity and fewer litter problems, but their usage depends on the price differential between the two commodities.

Supplementation with enzymes capable of degrading the cell wall material, or NSP, of ASL might be expected to improve its overall feed value for poultry, particularly if the problems associated with wet litter could be minimised. Supplementation of ASL meal with Avizyme 1300 (Finnfeeds International Ltd., U.K.) increased the TME from 9.7 to 11.7 MJ/kg DM (Wirawan et al., 1995), whereas the same treatment had no effect on the value of field pea, 13.0 MJ/kg DM. In a study across the starter and finisher stages

of growth Creswell et al. (1995) added Avizyme 1300 to wheat-based diets containing 25% ASLK meal. During the starter phase the Avizyme 1300 group had an 8% better ADG, a 5% better FCR and lower digesta viscosity than the unsupplemented group, and during the finisher stage there was a 3% better ADG, no improvement in FCR, and a drier litter. However when they repeated the experiment with 30% ASLK meal in a sorghum-based diet there were no benefits from adding the enzyme. It therefore seems probable that the beneficial effects of the Avizyme 1300 were mostly on improving the value of the wheat component. Annison et al. (1996) tested two enzyme mixtures (Biofeed Plus CT[®] and Energex MG[®]) in diets of broiler chickens fed sorghum- and casein-based diets, with and without 30% ASLK meal. There was no benefit of adding ASLK meal or enzymes on ADG or FCR. Naveed et al. (1998) reported that a xylanase and cellulase supplement to a diet containing 400 g/kg *L. albus* meal improved feed intake, growth and feed conversions, whereas the addition of a protease had no effect. This might explain some of the variable responses reported earlier.

THE NUTRITIVE VALUE OF LUPINS FOR FINFISH AND CRUSTACEANS

The nutritional requirements of aquaculture species have not been studied as much as for pigs and poultry. However, the results of protein substitution experiments across several finfish and crustacean species suggest that ASL protein has a similar nutritive value to that of SBM.

Gomes et al. (1995) reported an apparent digestibility coefficient (ADC) of 85% for protein, 61% for energy and 63% for dry matter from *L. angustifolius* meal for rainbow trout (*Oncorhynchus mykiss*). These were similar to those for pea meal (80, 59 and 66% respectively) but lower than for SBM (96, 91 and 86% respectively). For gilthead sea bream (*Sparus aurata*) Robaina et al. (1995) substituted 20% fishmeal in the diet with 34% *L. angustifolius* meal with no loss of performance, and reported a dietary ADC of 93% for protein and 95% for lipid. In a direct study, an ADC of 92% for protein, 68% for lipid and 54% for energy was estimated for ASLK meal (G. W. Kissil and I. Lupatsch, unpubl.). For silver perch (*Bidyanus bidyanus*) Allan (1997) reported an ADC for protein of 97%, energy of 59% and dry matter of 50% for ASLK meal.

Viola et al. (1988) fed diets containing 30% and 45% ASLK meal to carp (*Cyprinus carpio*) and found SGR (1.0) and FCR (3.2) values to match or exceed those of fish fed isonitrogenous and isocaloric diets based on SBM or sorghum. When carp fry were fed a 33% CP diet in which the plant protein source varied

from 0 to 100% ASLK meal, with the balance being SBM, the best SGR (2.0), FCR (3.5), ADC protein (63%) and ADC energy (72%) were achieved with the 100% ASLK diet. Performances fell away with each drop in ASLK content. The same levels of substitution were used in a 35% CP diet for milkfish (*Chanos chanos*) and similar performance rankings were recorded, and in another experiment a diet based on ASLK performed better than diets based on SBM or ASL (J. H. Hutabarat, unpubl.).

The inclusion of up to 40% ASL into the Australian Reference Diet (70% fishmeal - FM, 46% CP) for pink snapper (*Pagrus auratus*, sometimes referred to as red sea bream) with no attempt to balance for CP, lysine or methionine, did not affect the SGR (~1.7) or FCR (~1.3), of juveniles (Petterson et al., 1999). There was no difference in performance of fish fed isonitrogenous diets based on ASL, ASLK or a protein concentrate from ASLK (D. S. Petterson, G. I. Jenkins and A. J. Evans, unpubl.).

A 50% replacement of either the FM or SBM component of a commercial 30% CP diet with ASLK, when balanced for CP, lysine and methionine, had no effect on specific growth rate (SGR) (2.4) or FCR (1.5) of red tilapia (*Oreochromis niloticus*, Stirling) when grown from ~55g to ~230g (Petterson et al., 1998). When fish were grown from ~240g to ~540g on a commercial 25% CP diet there was also no effect of the same level of replacement (J. H. Hutabarat and D. S. Petterson, unpubl.).

For prawns (*Penaeus monodon*), digestibility coefficients were reported as 39% DM, 88% protein and 45% energy for ASL, and 73, 95 and 74% respectively for ASLK (Smith et al., 1998). In a 42-day grow-out study with juvenile prawns, Sudaryono et al. (1999) showed that ASLK meal had a nutritive value equal to that of SBM and better than for *L. albus* seed or kernel meals. A protein concentrate from ASLK had similar nutritive values to the ASLK meal suggesting no further advantage with fibre removal. A feeding preference study indicated that the ASLK diet was more attractive to the prawns than the SBM diet.

THE NUTRITIVE VALUE OF LUPINS FOR OTHER SPECIES

Lupins are commonly included in the diets of horses, rabbits, emus, goats, and many other domestic and laboratory animal species, but few reports involving these species have been published. Manufacturers of horse diets usually include ~15% ASL meal in the ration (M. J. Hoxey, pers. comm.). Home mixers frequently soak whole seed in water overnight to reduce the oligosaccharide content and soften the seed, but there are no reports of

comparisons between soaked and cracked grain.

L. albus is used as an alternative to SBM in horse diets (McMeniman et al., 1990) and the nutritive value of *L. albus* meal matches that of SBM for rabbits (Kelly et al., 1990).

FOOD AND INDUSTRIAL USES FOR LUPINS

Extensive studies have shown that ASL can be used to make tempe, miso and fermented sauces (for review see Petterson, 1998). Hung et al. (1990) found ASL to be a better substrate than soybeans for fermentation, due to a greater production of soluble nitrogen compounds and simple carbohydrates. Fudiyansyah et al. (1995) found ASL tempe was as acceptable as soy tempe to a group of Indonesian and Australian panellists. Fermentation lowered the content of bioactive compounds but there was also a reduction in protein quality. Although tempe made from ASL splits had a firmer texture than soy tempe it was still acceptable, but not as much as soy tempe, to regular consumers (Brady-Robbeau et al., 1997). Tempe made from a 50:50 blend of ASL splits and soybeans had intermediate acceptability. The use of splits had the added benefit of lowering labour costs and increasing yield of the end product. Coffey (1989) reported that an expert Japanese panel preferred the colour and appearance of ASL miso to the traditional soy product and the other attributes of the two to be similar. However a more recent study found the ASL miso to be less acceptable than soy miso (M. Tucek, pers. comm.). Lupins can be used to make sauces similar in appeal to the traditional soy sauces of China (Hung et al., 1990), Indonesia (Ir. Sutardi, pers. comm.), Japan (T. V. Hung, pers. comm.) and Korea (Lee et al., 1982; Oh and Lee, 1983).

About 5% ASL flour can be blended into most wheat flours without loss in loaf size. Higher inclusions are not possible because lupin proteins lack the strength and elasticity needed for bread making (Lucisano and Pompeii, 1981; Petterson and Crosbie, 1990). 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). Research into using flour from *L. albus* in traditional breads of many countries has generally shown an improvement in the nutritional value of the bread (Petterson, 1998). Its use is also restricted by the low dough strength of the lupin proteins (Dervas et al., 1999). In Australia, pasta containing about 15% ASLK flour is sold commercially, and some manufacturers use lupin hull flour in high fibre breads. A fibre supplement from finely ground hulls makes an acceptable supplement to elderly consumers, and has the added benefit of lowering blood cholesterol and, in some cases, body

weight (Bunger et al., 1999).

ASL is used as an alternative to full-fat soybeans to make a range of cooked snack foods in Europe. One company processed about 500 tonnes in 1998 and expected a six-fold increase in production in 1999 (M. Tucek, pers. comm.). Other uses for seed meal and fibre are under investigation as consumers express concerns about ingredients derived from genetically modified soybeans. The fibre can hold about eight times its weight of water and has a white colour and bland taste. It has potential for a wide range of applications (Pettersen, 1998).

The poor strength and elasticity of ASL protein means it is not possible to make a lupin tofu (bean curd), however it is possible to incorporate up to 30% ASL milk with soymilk before the coagulation stage and produce an acceptable product (Hung et al., 1990; Ho, 1996). It is also possible to make an acceptable lupin-based yoghurt (H. Zhang, pers. comm.).

Lupins can be germinated to make a big sprout suitable for vegetable or salad use. The lupin sprout compared favourably with soy and mung sprouts for taste and texture, although a slight beany and bitter after-taste makes it less acceptable to some (Kaur, 1994).

OTHER LUPIN SPECIES

The NSP profile of Albus, ASL, Atlas, Sandplain and Yellow lupins are similar, with galactose being the predominant monosaccharide (A. J. Evans, unpubl.). There is a high degree of similarity between the protein sub-units of Albus and ASL, and there is a gross similarity in the amino acid profiles for all but YL, which has a superior profile (table 9). Therefore a similar effect of most of these species on animal performance, depending on their specific gross energy and amino acid content, could be expected.

Lupinus albus-Albus lupin, white lupin

The Albus lupin has a higher content of CP and oil (table 1) and a higher proportion of indispensable amino acids (table 3) than ASL and generally has better nutritional indices. It has a similar NSP content and profile (Mohamed and Rayas-Duarte, 1995) and

content of bioactive compounds to ASL (Pettersen et al., 1997). The Albus lupin is sometimes used for animal feeds in Australia; however because it can attract a higher price for human food use in the Middle East it is unlikely to be traded in large quantities for animal feed purposes.

Several studies on the use of *L. albus* seed as a partial or total replacement for SBM in the diet of beef cattle found no significant differences in ADG or feed conversion (Huguet et al., 1983; Schwarz and Kirchgessner, 1989; Emile et al., 1991). However, Murphy and McNiven (1994) found it necessary to flame-roast the lupin seed to get the same benefit. The milk yield and milk protein from cows fed diets based on maize silage were lower when supplemented with *L. albus* than when fed isoenergetic and isocaloric diets containing SBM (Guillaume et al., 1987). However in studies where other base diets were fed there was no difference in performance (Huguet et al., 1983; Emile et al., 1991; Robinson and McNiven, 1993; Bayourthe et al., 1998). Robinson and McNiven (1993) found that flame-roasting of *L. albus* increased the amount of UDP and possibly gave protection to the oil as the process enabled the cow to increase the production of long chain fatty acids in the milk.

Although *L. albus* has good nutritional indices for pigs, its use in Australia is generally restricted to a maximum of 15% of the diet because of a depression in feed intake, and consequently growth, above those levels (Edwards and van Barneveld, 1998). The same factor seems to be present in European and Canadian cultivars of *L. albus* as Kelly et al. (1990) and Donovan et al. (1993) found reduced performance with similar amounts of lupin in their pig diets.

L. albus has a higher AME value for broilers than ASL (Hughes et al., 1988) and up to 25% *L. albus* meal can be used in broiler diets (Bekric et al., 1990; Castanon and Perez-Lanzac, 1990; Brenes et al., 1993) and up to 40% can be included if methionine is added (Watkins et al., 1988; Buraczewska et al., 1993). For layers, up to 30% seed meal could be used provided methionine was added (Prinsloo et al., 1992). Inclusion of up to 40% *L. albus* meal in isocaloric and isonitrogenous diets for Peking ducklings had no adverse effect on growth, feed conversion or carcass

Table 9. A comparison of some constituents of lupin seed (g/kg whole seed)

	<i>L. albus</i>	<i>L. angustifolius</i>	<i>L. atlanticus</i>	<i>L. cosentinii</i>	<i>L. luteus</i>	<i>L. pilosus</i>
Crude protein	360	320	279	321	383	257
Lysine	15.8	14.6	12.2	13.5	20.7	11
Methionine	2.4	2.0	1.8	2.3	2.7	1.7
Threonine	12.0	10.9	8.8	9.4	13.6	8.5
Oil	94	59	32	34	56	45
Oligosaccharides	65	41	32	- ^A	89	29

^A No value reported.

quality compared to a soybean based diet. AME for the lupin meal was 10.9 MJ/kg as received, compared to 9.4 MJ/kg for the soybean meal.

Several studies have found *L. albus* seed or kernel meal to be a valuable ingredient for finfish diets. Moyano et al. (1992) could substitute up to 70% of fishmeal protein with *L. albus* meal in the diet of juvenile rainbow trout (*Oncorhynchus mykiss*) without loss of performance. Other studies showed that *L. albus* meal could provide up to 30% of the dietary protein, i.e. about 35% meal, without loss of performance (Hughes, 1988; Higuera et al., 1988; Gomes and Kaushik, 1990; Gouveia et al., 1993). Burel et al. (1998) included up to 50% extruded kernel meal, 47% CP, without loss of performance while at 70% inclusion there was a marked drop in growth and feed conversion, although they considered this could still be economical.

Sudaryano et al. (1999) found that *L. albus* meal, while a useful ingredient, was less valuable than ASL or SBM for prawn diets.

Lupinus luteus yellow lupin

The YL has the highest content of CP (383 g/kg) and essential amino acids of these species (table 3). Mullan et al. (1999) replaced up to 100% of the SBM with YL kernel meal in the diet of pigs, from weaning to market weight, and found no significant difference across replacement levels at any growing stage for voluntary feed intake, ADG or FCR. These results encouraged a major pig producer in Australia to plan for a full-scale commercial trial when sufficient seed becomes available (B. P. Mullan, pers. comm.). YL is used in the pig industry in Poland (W. Swiecicki, pers. comm.). Roth Maier (1999) reported an ME value of 14.1 MJ/kg for pigs and an AME of 8.7 MJ/kg for poultry.

The results of an in-house pilot study with broiler chickens were sufficiently encouraging for one commercial enterprise in Australia to plan for a commercial scale trial once sufficient seed becomes available (M. Tucek, pers. comm.).

Replacement of ASL meal (30%) in the diet of pink snapper with a CP equivalent of YL meal (23.5%) had no impact on ADG or FCR (D. S. Petterson, G. I. Jenkins and A. J. Evans, unpubl.). Gacek et al. (1978) found a higher yield of carp (*Cyprinus carpio*) in ponds when fed a diet based on *L. luteus* than when fish were fed a barley-based diet, and Nowak and Wrona (1979) found similar results with penned carp in a river system.

FUTURE DEVELOPMENTS IN THE LUPIN INDUSTRY

To make ASL a more useful ingredient for the

animal feed industries as a whole improvements could be made in several areas. Firstly, the amino acid profile could be improved by selecting for a higher content of lysine and methionine, or by genetic intervention. The range of values for lysine and methionine is quite small and it seems unlikely that significant improvements can be made without the use of gene technology. A major advance has been achieved with the successful insertion of a gene encoding for sulphur-rich albumin from sunflower into the Warrah cultivar of ASL (Molvig et al., 1997). The transgenic seed contained 3.9 g methionine/kg DM compared to 1.7 g for the parent cultivar grown at the same site. Individually penned sheep fed a diet containing 35% transgenic (TG) seed had a 7% greater ADG and an 8.5% greater wool production than sheep fed a diet containing 35% Warrah seed (White et al., 1998b). Ravindran et al. (1998) found that the higher methionine in the TG seed was used efficiently by broilers fed a diet containing 250g lupin/kg and estimated this would save 600 g methionine per tonne of feed, thereby valuing the TG seed at ~\$7/tonne higher than ASL. The TG seed has a higher DE for gilthead sea bream (G. W. Kissil and I. Lupatsch, unpubl) and growth studies in pink snapper indicate this extra feed value is reflected by improved performance (D. S. Petterson, B. D. Glencross, G. W. Kissil and G. I. Jenkins, unpubl.).

Secondly, there is a need to increase the NE content for pigs and poultry. This could be achieved by selecting for thinner hulls and thinner cell walls within the cotyledons. One experimental line with 18% seed coat (c.f. ~22% in commercial cultivars) has been identified (M. Dracup, pers. comm.). It should be possible to divert some of the metabolic pathways for laying down energy storage in the form of the β -galactans in the cell walls of the cotyledon to making oil bodies or starch granules (C. A. Atkins, pers. comm.). Success in these areas would have the extra benefit of producing a 'softer' seed that would be easier for the feed manufacturer to process.

Thirdly, the net value of the seed for diet formulation could be enhanced if specific enzymes could be found to break down the NSP. The structure of the cell wall polysaccharides of ASL has been largely determined (Cheetham et al., 1993) so it ought to be possible for industrial enzyme producers to find a suitable product. Fourthly, more economically effective ways of grinding and milling the seed or splits are needed to get the full value out of the existing material. There is evidence for finer grinding giving better energy values for pigs and poultry (see earlier discussion).

Finally, there is a need for research into some of the procedures such as infrared cooking, micronising, cell implosion and expansion cooking to ascertain

whether any of these can economically improve the net feed value or ease of processing ASL seed and splits.

CONCLUSIONS

Whole seed and kernels of the ASL are a useful source of vegetable protein for the animal feed industries of Australia and Asia. When included in diets balanced for nitrogen, lysine, methionine and available energy they can have a nutritive value equal to or better than field peas and SBM in many circumstances. They appear to have a particular advantage for finfish although a lot more work by industry will be needed to confirm experimental results. Whether feed mills can use them will largely depend on their price and availability relative to other vegetable protein sources. In view of some of the characteristics of ASL seed and kernels any feed mill considering their use for the first time should seek expert advice.

While Albus lupins could also be gainfully used in the fed industry, the higher relative price of the seed would preclude its use in many instances.

Yellow lupin, with its higher content of CP and sulphur amino acids and high nutritional indices has considerable promise.

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