Recent research has identified substantial potential for lupins for use in fish feeds as a protein source. Limitations in the supply of fishmeal and soybean meal have justified the use of lupins in routine feed formulations by some international feed companies. This article reviews the nutritional quality of lupins and their applications in aqua feeds.

Lupins

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Introduction

The demand for alternative protein resources to fish meal in aquaculture diets has stimulated substantial interest in the potential of lupins in Australia. Assessment and development of the locally produced, non-GM crops of lupins as an alternative protein have received much attention recently. There are three key commercial species of lupins: *Lupinus angustifolius* (Narrow-leafed or Sweet Lupin), *L. albus* (White Lupin) and *L. luteus* (Yellow Lupin). *L. angustifolius* dominates world lupin production, with the bulk of that production being produced in the Mediterranean climate of south-western Australia. Research in recent years has identified substantial potential for lupins for use in fish feeds. Some major international feed companies are now routinely using it in their formulations. So, it is timely to provide a review of the nutritional quality of lupins and their applications in aqua feeds.

Nutrient content

The level of protein in most plant meals varies according to whether the grain is whole or dehulled (seed coat removed), full-fat or fat-extracted and according to the method of oil extraction. Lupins are certainly no different in this regard (Table 1). Lupin kernel meals have high crude protein; some species have protein levels similar to that seen in high-protein soybean meals. The kernel meal is produced by dehulling the whole seeds and then milling the kernels. This process requires little to no heat input and therefore causes minimal damage to the protein quality of the meals.

The amino acid composition of the lupin kernel meals varies among varieties and is different from that of other plant protein meals (Table 1). Lupins are generally regarded as very low in their methionine content, but have a lysine level between that of soybeans and wheat gluten. The relatively low level of methionine in lupin protein can be compensated by the use of synthetic methionine when necessary.

Lupins are not renowned as oilseeds. However, white lupin kernel meal has a reasonably high lipid content of about 13-14% on dry matter basis. Although, both the sweet lupin and yellow lupin varieties have low levels of lipids (< 8% on a dry matter basis), the levels are higher than that seen in solvent extracted soybean meals (Table 1). Analysis of the crude lipid composition has identified that triacylglycerides made up the majority of the total lipids (71.1%), with phospholipids (14.9%), free sterols (5.2%), glycolipids (3.5%), sterol and wax esters (0.5%), free fatty acids (0.4%) and hydrocarbons and unidentified waxy material (0.4%) making up the remainder.

The carbohydrate content of meals like lupins is also quite different to that of many other feed grain resources in that the meals possess high levels of both soluble and non-soluble non-starch polysaccharides (NSP). This group of carbohydrates forms primarily the structural polysaccharides of the seed. Starch is essentially non-existent in lupin meals. The free sugar content of lupin whole-seed meals is dominated by both glucose and galactose, each at about 30 to 40 g/kg DM.

Anti-nutritional factors

Anti-nutritional factors (ANF), also referred to as biologically active substances, are essentially evolutionary adaptations by plants to enable some level of protection against being eaten. The variety of anti-nutrients found in the different plant species varies quite widely, both in diversity and relative concentration (Table 2).

Alkaloids are found in most plants of the leguminaceae family (peas and beans). High levels (>10,000 mg/kg) were traditionally found in lupins reducing their palatability when

Table 1 Chemical composition specifications of key lupin product resources in comparison to fishmeal and soybean meal (all values g/kg DM unless otherwise specified)

Nutrient	Chilean Fishmeal	Soybean meal	Yellow Lupin Kernel	White Lupin Kernel	Sweet Lupin Kernel	Sweet Lupin Seed	Lupin Protein Concentrate	Lupin Protein Isolate
Dry matter Content	917	909	903	922	885	911	942	926
Crude protein	770	518	547	455	415	351	690	810
Digestible protein	673	477	485	402	354	n.d.	679	770
Crude fat	68	47	87	137	53	65	93	125
Ash	142	69	44	36	33	30	31	30
Phosphorus	22	8	6	5	4	3	5	5
Organic matter	858	931	956	964	967	970	969	970
Gross energy (MJ/kg DM)	21.3	19.6	20.9	21.3	20.4	20	22.2	22.6
Digestible energy (MJ/kg DM)	21.1	14.1	13.4	14.8	10.8	n.d.	18.7	20.6
Lysine	57	34	23	20	18	18	25	25
Threonine	34	23	16	16	14	14	23	23
Methionine	21	8	4	3	3	3	5	4
Isoleucine	32	25	16	19	16	15	27	28
Leucine	56	42	35	31	28	27	51	51
Valine	39	27	17	18	16	15	23	24
Phynylalanine	30	28	18	17	16	15	28	28
Histidine	31	16	14	11	12	10	15	16
Arginine	43	40	47	52	44	45	78	81

[a] L. angustifolius, [b] L. luteus, [c] L. albus, *SE: solvent-extracted. n.d.: not determined.*

Table 2 Anti-nutrient levels in the key plant protein resources

	Soybean[a]	Lupin	Lupin kernel[b]	Canola	Field pea
Alkaloids (mg/kg DM)	10	200	280	n.d.	n.d.
Glucosinolates (mol/kg DM)	n.d.	n.d.	n.d.	9000	n.d.
Lectins (dilutions)	n.d.	n.d.	n.d.	n.d.	4
Oligosaccharides (g/kg DM)	60	50	66	30	35
Phytate (g/kg DM)	15	5	7	40	5
Protease Inhibitors (g/kg DM)	3.1	0.2	n.d.	n.d.	2.9
Saponins (mg/kg DM)	5000	573	n.d.	n.d.	n.d.
Tannins-total (g/kg DM)	n.d.	n.d.	n.d.	1.8	3.7

n.d. : not determined. [a] *Soybean meal data is that of dehulled and defatted meal.* [b] L. angustifolius *kernel meal.*

fed to animals. Domestication has reduced present levels of alkaloids in lupin varieties, such as *L. angustifolius* to less than 200 mg/kg. Wild-type varieties, still found in their countries of origin (usually the Mediterranean region), may contain up to 40,000 mg/kg of alkaloids. Although there is no specific reported data on the influence of alkaloids on fish, they are generally considered a feeding deterrent because of their bitter taste.

The other potential ANFs in lupins are the oligosaccharides. Oligosaccharides are short-chain sugar groups that can cause a variety of effects on animals including osmotic effects in the intestine and anaerobic fermentation of the sugars resulting in increased gas production. Observations of increased levels of gas production and diarrhoea have been reported with pigs and poultry. Some similar effects have also been reported on fish. These effects include a reduction in the digestion of other nutrients, gas production and diarrhoea.

In general, the levels of most ANF in lupins are considerably less than that of other plant protein resources. Notably, lupins are relatively devoid of protease inhibitors, saponins, lectins, tannins and glucosinolates. Levels of phytate are generally lower than those found in most other plant protein resources. What was once the key issue with lupins, their alkaloid level, is now a negligible one through crop breeding.

Feeding lupin meals to aquatic animals

There are numerous works that have studied the nutritional value of lupins when fed to a wide variety of aquaculture species. For a comprehensive review of this subject download the technical review at http://www.fish.wa.gov.au/res/broc/report/lupin

The depth and quality of the reported work on lupins varies widely. The volume of work is certainly small compared to work published on soybean products. Recently however, there have been some clearer evaluations of lupin meals published with some key implications on how to best utilise these resources in aquaculture diets. Of the three separate species of lupins which have been evaluated, the majority of the international work has been done on *L. albus*. The recent Australian work has focused more on the other two species.

Nutrient and energy digestibility

There are a number of studies on the digestible value of lupins. One of the key studies examined the influence of removing the seed coat (dehulling) on its nutritional value. Both *L. angustifolius* and *L. albus* varieties in their whole-seed and kernel meal forms were studied by feeding the ingredients to silver perch (*Bidyanus bidyanus*), an omnivorous species. Clear nutritional advantages of dehulling lupins were observed from the results of this study. Irrespective of lupin species evaluated improvements were seen in the digestibility of dry matter, nitrogen and energy (Table 3).

More recently the digestible value of the kernel meals of all three species of lupin (*Lupinus albus*, *L. angustifolius* and *L. luteus*) was compared against each other and a reference ingredient of solvent extracted soybean meal and wheat gluten, when fed to rainbow trout (*Oncorhynchus mykiss)* and red seabream (*Pagrus auratus*) (Table 4). The digestibility of protein of all lupin kernel meals is generally better than that of the soybean meal. Minor variability is seen between the lupin kernel meals, but some substantial differences are seen between the lupin kernel meals, soybean meal and wheat gluten. Key among the findings of the lupin digestibility is the excellent overall nutritional attributes of yellow lupin (*L. luteus*) kernel meal. The digestibility of dietary energy from each of the lupin kernel meals is typically less than that obtained from soybean meal. However, the higher gross energy content of most lupin kernel meals means that a similar overall level of digestible dietary energy to soybean meal is obtained.

The level of phosphorus digestibility is better in all lupin kernel meals than that from the soybean meal. Notably in many cases the phosphorus digestibility is 100%. This finding may have been dependent on the low dietary levels of phosphorus (<15 g/kg DM). The low level of phosphorus in the lupins and its high availability to fish may have important implications for the development of phosphorus limiting diets, which are sometimes required in farming systems where algal blooms need to be controlled.

The digestibility of organic matter in most lupin kernel meals is poorer than that of soybean meal. This observation constitutes the primary identified weakness of the lupin kernel meals. Efforts to improve their value by addressing this limitation are being undertaken.

The variability in the protein level of lupin (*L. angustifolius*) kernel meals when fed to rainbow trout has been examined. Digestibility of protein and energy in five kernel meals with protein content ranging from 35% to 48% was studied. The results of this study (Figure 1) found that there is a strong correlation between protein content of a lupin kernel meal and the nutritional value of that protein. Notably, the kernel meal protein content had more influence on its energy digestibility than that of the nitrogen digestibility.

Figure 1. Protein and energy digestibility as a function of crude protein content of lupin (L. angustifolius) kernel meal, when fed to rainbow trout.

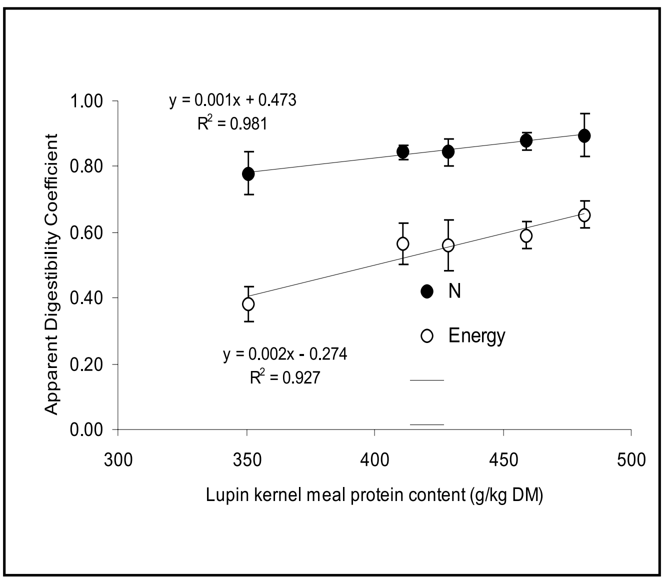

Table 3 Digestibility (%) of L. angustifolius *and* L. albus *whole and kernel meals in the silver perch* (Bidyanus bidyanus).

Nutrient	*L. angustifolius*		*L. albus*	
	Whole-seed	Kernel	Whole-seed	Kernel
Dry matter	50.3	67.6	64.7	77.8
Nitrogen	96.6	100.3	96.1	101.4
Energy	59.4	74.0	72.7	85.2
Phosphorus	71.8	80.1	77.5	73.8

Including lupin meals in fish diets

Studies on inclusion of lupin meals (whole and kernel) have been reported since the late 1980's. Some of the better studies have been those on rainbow trout. Indeed studies examining the incremental inclusion of white, sweet and yellow lupin varieties have been undertaken with this fish species and serve as a good comparison of the nutritional merits of each lupin variety.

The inclusion of a white lupin kernel meal at 300 g/kg, 500 g/kg and 700 g/kg in diets that were designed to be isonitrogenous and isoenergetic, showed that white lupin kernel meal could be included in the diet of rainbow trout up to a level of 500 g/kg with no loss in growth rate and with significantly superior phosphorus retention. The inclusion of white lupin kernel meal at 700 g/kg however, resulted in poorer growth, feed efficiency and nitrogen and energy retention. Interestingly phosphorus retention improved with the higher inclusion level. The loss in growth performance of fish fed the diets containing 700 g/kg white lupin kernel meal was attributed to low feed intakes of this diet. It was suggested that high levels of white lupin kernel meal inclusion lowered palatability of the diet.

A study examining the isonitrogenous and isoenergetic inclusion of sweet lupin kernel meal at 100 g/kg, 200 g/kg, 300 g/kg, 400 g/kg and 500 g/kg of the diet was undertaken. This study showed that sweet lupin kernel meal could be effectively included in diets for trout at up to 400 g/kg, but that at 500 g/kg there was a significant reduction in growth and deterioration in feed efficiency. Further examination of the immunological status of the fish showed no aberrations associated even with the highest inclusion levels.

A study examining the isonitrogenous and isoenergetic inclusion of yellow lupin kernel meal at 125 g/kg, 250 g/kg, 375 g/kg and 500 g/kg of the diet found that the meal could be effectively included in diets for trout at up to 375 g/kg. At 500 g/kg there was a significant reduction in growth, but no loss in feed intake. Similar to the findings with sweet lupin kernel meal, regression analysis suggested that there was a minor reduction in performance at all inclusion levels. This observation supports that there was either or both, deterioration in availability of nutrients or some ANF causing problems. Notably the level of oligosaccharides in yellow lupin kernel meals are twice that in other lupins and it is believed that this may be the cause of the problem.

The inclusion of lupin kernel meals in extruded aquaculture diets confers some interesting physical properties on the pellets. Key observations include an increase in oil absorption capacity of the pellet up to 20% inclusion of *L. angustifolius* kernel meal. The durability (Holman test) of the pellet also increases.

Substantial variability is being found in the functional properties of the lupin kernel meals among the species and also among lupin cultivars. Experimental scale extrusion and rapid viscosity analysis (RVA™) showed that the viscosity of the different lupin meals vary considerably (Figure 2).

New developments in lupin research

Clearly lupin kernel meals possess many of the nutritional advantages of soybean meals, but notably lack many of the anti-nutritional problems. However, there is considerable potential to improve their value by increasing their protein content, primarily through processing.

The development of lupin protein concentrates (LPC) and lupin protein isolates (LPI) is proceeding and early indications are very promising. A major project in Australia is examining technologies similar to those used on soybean products. The prototype protein concentrates show great promise. Besides exhibiting high nutrient digestibility, the concentrates show no negative effect on palatability, feed intake and growth up to 40% inclusion levels in salmonid diets.

Three species of lupins: (Bottom Right) yellow lupin, L. luteus; (Left) narrow-leaf lupin, L. angustifolius; and (Top) European white lupins, L. albus.

Table 4 Digestible nutrient contents (g/kg DM) of key lupin species kernel meals, solvent-extracted soybean meal and wheat gluten when fed to either rainbow trout or red seabream.

Nutrient	White lupin	Sweet lupin	Yellow lupin	Soybean	Wheat gluten
Rainbow trout					
Organic matter	571	561	533	597	877
Energy (MJ/kg DM)	14.8	12.9	13.6	14.4	20.5
Phosphorus	5.0	4.0	5.0	3.2	0.6
Protein	402	383	473	437	846
Red seabream					
Organic matter	509	481	584	679	928
Energy (MJ/kg DM)	14.1	12.9	14.6	15.6	21.7
Phosphorus	5.0	4.0	4.5	5.7	0.7
Nitrogen	455	407	485	484	868

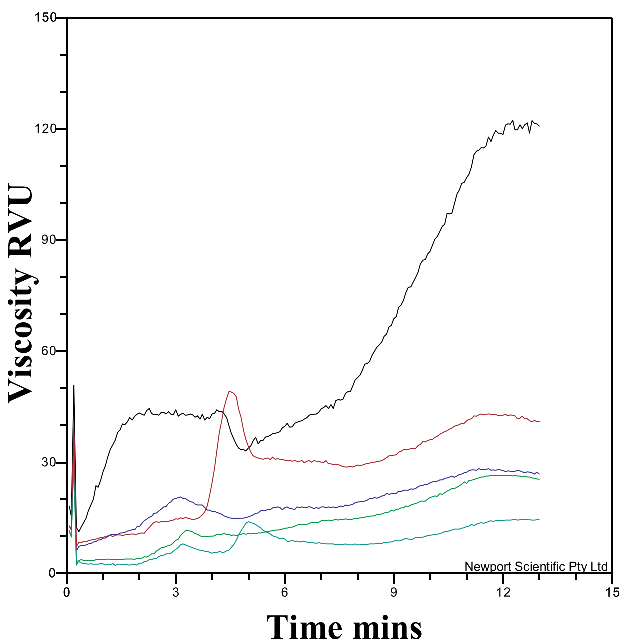

Figure 2 Rapid viscosity analysis (RVA™) assessments of L. atlanticus kernel meal (1), *L. albus* kernel meal (2), *L. angustifolius* cv. Gungarru (3) kernel meal, *L. angustifolius* cv. Myallie (4) kernel meal and *L. luteus* kernel meal (5).

Brett Glencross is currently the Senior Research Scientist for Aquaculture Nutrition and Environmental Management with the Department of Fisheries of the Government of Western Australia. He has a diverse background with research experience in enzyme kinetics, protein purification, endocrine mechanisms of reproductive and nutrient control in pigs and a PhD in aquaculture nutrition, focussing on the essential fatty acid requirements of prawns. Since gaining his PhD he has been involved in research focussing on feed development, product quality assessment and environmental research for southern bluefin tuna, rock lobster, red seabream, barramundi and rainbow trout. Since 1999 research activities have focused on ingredient evaluation and product development for aquaculture diets, with additional projects examining the environmental impact assessment and management of aquaculture in Australia's tropical north.