Lupin Project for the PRF 2020/2021

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09/02/2021

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LUPINS

1. Introduction

Lupins are legume crops common all over the world with an annual production of 1,2 million tons (FAOSTAT 2019) the 5 largest producers in 2019 are listed in table 1.

Table 1. World Lupin production (tons) by country

Australia	474 629
Russia	166 271
Poland	145 690
Morocco	67 928
Chile	45 650

Source: FAOSTAT 2019

Lupins represent a cool season crop that may grow in regions where soybeans would not prosper. In the early years of Lupin production, Lupin grains were grown in rotation with other crops such as cereals. This benefits the farming system by reducing disease in cereal crops, increasing the supply of organic nitrogen as well as increasing the supply of high-quality sheep feed. (White et al, 2008)

Impediments to increasing lupin availability include lack of local knowledge by crop farmers and those feeding livestock as well as anti-nutritional factors. A sustainable market must be established for producers to devote to lupin production.

Lupins can be fed without processing and although dehulling is preferred it is not essential. The hull fraction represents approximately 25% of sweet lupins, lupin meal (un-dehulled) will therefore contain more fibre and less protein than soybean meal.

Leguminous crops including Lupins are an important source of protein and other nutrients. The coexistence with nodule bacteria Bradyrhizobium sp. (Lupinus) results in the capability of synthesising protein by acquiring molecular nitrogen from the atmosphere. There are a large variety of lupins which differ in their qualitative and quantitative structure (Kurlovich, 1998). The nutrient content of lupins differs considerably between specie, variety, and location (Kurlovich et al, 2006)

Lupins are also promoted as human food with medical studies confirming the benefits in combating high blood sugar, heart disease and obesity.

1.1 White Lupin – *L. albus* has a large variability in protein content depending mainly on seed and the environment where it is produced, from 40 to 55% protein. Methionine contents between 177 to 320 mg 100 g have been observed. The ratio of methionine to protein can be variable. Oil content can vary from 6 to 12% dependant on cultivars and country of production. Unfortunately, there is a strong negative correlation between nutrient content of the lupins and productivity in the form of yield.

1.2 Yellow Lupin – *L. luteus* has a range of protein between 35 and 55% depending on origin. Experience in the Europe, Russia and Ukraine illustrates that in lower rainfall areas (537 mm) that plants accumulate much less protein than in areas with higher rainfalls (800 – 1000 mm).

1.3 Narrow-leafed lupin – *L angustifolius* has a protein content between 18 and 42% with a variation of oil content between 3 and 8%. The degree of accumulation of nutrients depends on plant genotype and the conditions and place of cultivation. Negative correlation between protein and oil accumulation rates has also been found (Kurlovich et al 2006). Lupins are an important source of protein for feed and food and can be used in several species to replace oilseed meals. Australia has made the greatest progress in narrow leafed lupin cultivation (Gladstone 1998). If compared to other species the seed of *L angustifolius* accumulates less protein (*L. albus or L. luteus*)

1.4 Andrean pearl lupin – *L mutabilis* Sweet has a protein content between 42 and 54% and oil between 10 and 16%

1.5 Multifoliate or Washington lupin – *L polyphyllus* protein can vary from 42 to 48%

2. Global production of Lupins

The demand for lupin plants is continuously growing due to the increasing demand of plant-based dietary fibre and proteins in food and beverages. Populations around the world are looking for gluten-free high fibre diets which is why lupin plants have been gaining worldwide popularity. Multiple food manufacturers are looking to substitute soy protein for lupin protein due to their rich protein profile. Lupins are an alternative to imported feed such as soya as they are a cost effective, safe source of high protein feed for livestock. (Research, 2017)

The largest consumers of lupins globally are the United States (Table 2) flowed by Australia.

Table 2 World largest lupin consumers (tons)

United States	1 519 000
Australia	362 020
Spain	205 580
Canada	133 290
Italy	112 530

Source: Tridge, 2021

3. Production in South Africa

Lupins, mainly *L. Angustifolius* and *L. Albus* have been grown successfully in areas of the Western Cape, particularly in deeper sandy soils. Approximately 20 000 ha of lupins were planted in the Western Cape in the late 90’s. The Free State grew 1 000 ha of sweet white lupin (Killian, 1999). The occurrence of various wilt and root diseases such as Fusarium, Phythium and Rhizoctonia historically limited Lupin production potential on heavier soils. Lupins are suited to crop rotation systems with grain crops. It is important to have at least a two-year break before planting Lupin again on the same land. Lupins increase the nitrogen availability for the subsequent cereal crop as well as reducing soil density and stabilise soil aggregates thus increasing wheat yields (White *et al*., 1978). Anthracnose (caused by the fungus Collectotrichum Gloeossporiodes) became a serious disease in the Western Cape with *L. Albus* being particularly susceptible. The “narrow leaf” *L. Angustifolius* was therefore recommended (Hardy, 1998).

The production of *L. Angustifolius* in place of *L. Albus* has a significant impact on the market for Lupins with respect to the animal feed sector, considering that *L. Albus* has a significantly higher nutritional value than *L. Angustifolius* (Hill, 1977).

Just after 1947 sweet lupin cultivars were introduced into the western cape of South Africa. The effective populations of Bradyrhizobium in the Western Cape were established by widespread cultivation of lupin. In the winter rainfall region of the Western Cape field trials were carried out at five sites to determine whether inoculation increased yields of L. angustifolius. In moderately alkaline soils, populations were 380 rhizobia g and >5,000 rhizobia g in moderately acid soils.

Lupin inoculant was introduced in the 1960s and contained a VK7 strain. This strain was then replaced by WU425 which is effective on lupin. The South African Rhizobium collection has a VK10 sub-culture strain. However, thirty percent of farmers in the western cape rely on naturally – occurring soil populations for nodulation. Inoculation can be assumed to be unnecessary if soil populations of rhizobia are large and effective, however it is beneficial if they are small and not effective. (J.Botha, 2002)

4 Anti-nutritional factors

Lupins historically contained high concentrations of alkaloids which are bitter and cause reduced feed consumption as well as reduced nutrient digestibility. Lupins have been selected for low alkaloid content but still contain non-starch polysaccharides (NSP) that can affect nutrient digestibility and feed passage through the gut. NSP in lupins consist mainly of galacturonic and galactomannans as well as cellulose. Feed enzymes that will target the NSP such as Xylanase can have a positive effect on animal performance.

Due to the low levels of sulphur amino acids it is important to ensure the correct supplementation of these. Manganese levels in lupins can also be excessive and should be considered in micro mineral formulations.

4.1 Alkaloids

The range of variability in total alkaloid content in bitter lupins is from 0,1 to 4% while in low alkaloid (sweet) forms levels between 0,025 and 0,009% can be found. It is especially important to have low alkaloid (sweet) forms. Bitter plants sometimes appear in plantings of sweet cultivars.

Comparison with other grain legumes shows that lupins may be recognized as the lowest inhibited crop. The average inhibitors for soybeans is 27 mg/g, string beans 10mg/g and peas 2mg/g.

The average alkaloid content found in L. angustifolius and L. albus is reasonably low at <0.04g/kg. It is important to continuously monitor the alkaloid content of lupins especially regarding new varieties and the environments in which they are grown. Pigs are known to be sensitive to the presence of alkaloids in diets, however it can be concluded that the poor acceptance of L. albus by pigs is not from alkaloids. Poultry are less sensitive to the presence of alkaloids in lupins than pigs. Seeds from different lupin species including L. albus, L, angustifolius and L. luteus were put in diets for pigs and chickens. Pigs were the most sensitive to alkaloids of L. albus as the concentration could be tolerated at below 120mg/kg and chickens had no negative effect between intake of their diets and the alkaloid content.

4.2 Tannins

These are complex compounds that can form cross-linkages between proteins which makes them unavailable for digestion. Piglets are more sensitive to tannins than chickens, however the tannins in L. angustifolius are considerably low enough to not be a problem when feeding pigs. There is very little knowledge on the levels of tannins in L.albus and L.luteus which needs to be looked at further. (Barneveld, 1999)

4.3 Saponins

These are glycosides with a steroid compound as the non-sugar and have a bitter taste which acts as a detergent in animal feed. There are traces of saponins that are found in L. albus and concentrations from 480 to 730 mg/kg that are found in L. angustifolius and 50 mg/kg in L. Luteus. However, there is no evidence that these concentrations have any effect on feed intake or gut absorption. (Peterson, 1997)

4.4 Protease inhibitors

In L. albus, L. angustifolius, L. luteus and L. Cosentinii there is less than 0.3 mg/kg of trypsin inhibitor and less than 0.6 mg/kg of Chymotrypsin inhibitor activity.

4.5 Lectins

In L. albus and L. angustifolius there is no lectin activity found in standard tests and slight activity can be induced if the red cells are specially treated which creates an advantage over soybeans which need heat treatment to inactivate lectins.

4.6 Oligosaccharides

In the lupinus species, oligosaccharides are a galactosyl homologues of sucrose. This cannot be metabolised by monogastric animals whereby carbon dioxide, methane and hydrogen are produced in the colon which causes abdominal cramps, gut distention, and flatulence. Osmotic regulation of poultry and other species may be benefited by oligosaccharides but have no effect in ruminants.

5 Nutritional factors

Lupins have significant potential as a protein and energy source for livestock due to their chemical composition. Lupins in their raw unprocessed form have many favourable characteristics for feeding single-stomached animals and ruminants. The greatest form of lupin utilization in Australia is as a whole-grain supplement to grazing sheep. There have been many positive effects on the growth and reproductive efficiency of ruminants consuming a diet supplemented with lupins.

5.1 Carbohydrate

Lupins differ from most legumes as they contain insignificant levels of starch, but high levels of soluble and insoluble NSP and oligosaccharides. The major polysaccharide in lupins is B-(1-4)-galactan which consists of galacturonic acid, L-rhamnose, L-arabinose and D-galactose. Lupins have a high level of readily fermentable NSP which effects the way in which Livestock obtain the energy. Animals and ruminants that are single stomached utilize the energy obtained from monosaccharides absorbed by the small intestine differently from that of volatile fatty monosaccharides. The high levels of fermentable NSP and insignificant levels of starch in lupins play a part in the high ME value for ruminants. The ME contents for Lupins such as L. angustifolius is 12.2MJ/kg and 12.5MJ/kg for L.albus for sheep. (Barneveld, 1999)

5.2 Proteins and amino acids

Lupins have unique physiochemical properties due to the structure of their proteins. Lupins storage proteins are largely comprised of globulins which are higher than most other legumes, the globulins consist of two major proteins legumin type protein and 7S-like protein. Since lupin storage proteins are predominantly globulins this means that they have poorer emulsion properties and suggests that lupin proteins are less vicious and have a lower buffering capacity in the neutral pH range.

For single stomached animals, lupins are poor sources of methionine and lysine. On the contrary they supply excessive levels of arginine to the diet which thus make lupins ideal complements to cereal for single-stomached animal diets. Therefore, making lupins a valuable resource from a diet formulation perspective.

Lupins contain low levels of sulphur amino acids but can be compensated for by methionine contributions from other diet ingredients or by dietary supplementation such as synthetic methionine when feeding single-stomached animals or ruminants.

Lupins such as L. Luteus have shown to contain lysine, threonine, cystine and methionine concentrations that are dramatically higher than more traditional varieties which shows great potential as livestock feeds. (Barneveld, 1999)

5.3 Lipids

The crude fat content of lupins is typically 86.6-130 for L. albus, 49.4-69.7 for angustifolius, 13.0-46.0 for L. atlanticus, 27.0-41.6 for L. consentinii and 52.0-61.0 for

L. Luteus. Livestock production will be influenced by the lipid content and composition of lupins by affecting DE and ME contributions to the diet.

5.4 Minerals

High manganese of which L. albus is an accumulator of, has been suggested to reduce voluntary feed intake (VFI). However, a study was undertaken whereby barley-based diets containing soybean meal and L. albus seed meal or L. angustifolius seed meal was fed to grower pigs which contained 43, 750 and 72 Mn/kg. The L. angustifolius diet was then supplemented with 210-1260 Mn/kg. VFI and daily gain were reduced and there was no further effect of increasing levels of manganese. Therefore, the reduction of VFI is not caused by excessive levels of manganese in lupins. L. luteus extracts more concentrations of minerals from the soil, however this does not affect their nutritional value.

6. Nutritional table

The nutrient values that can be used for feed formulation are presented in table 1. It can be noted that there is a major difference in nutrient content between different lupin species. There is a large variability in nutrient content of lupins. The amino acid digestibility of amino acids for poutltry is very favourable. The energy content for poultry is low. The high fibre levels and available energy content (Ruminant) are more suitable for ruminants.

6.1 Table of Chemical composition and nutritional value

		L. angustifolius (Narrow-leafed)	L. albus (White)	L. luteus (Yellow)
Main Analysis				
Dry matter	% as fed	90	88.1	88.8
Crude protein	% DM	33.7	37.9	42.2
Crude fibre	% DM	16.1	13.7	16.6
Ether extract	% DM	6	9.6	5.4
Ash	% DM	3.5	4	4.6
Insoluble Ash	% DM	0.2	9.2	0.5
Neutral detergent fibre	%DM	23.9	21.9	24.3
Acid detergent fibre	%DM	19.1	16.4	19.7
Starch	%DM	4.8	8.1	6.1
Amino Acids				
Lysine	g/16g N	5	4.9	4.8
Threonine	g/16g N	3.9	3.7	3.6
Methionine	g/16g N	0.9	0.8	0.7
Cystine	g/16g N	1.8	1.7	1.6
Methionine & Cystine	g/16g N	2.6	2.4	2.3
Tryptophan	g/16g N	0.7	0.7	0.7
Isoleucine	g/16g N	4.7	4.6	4.6
Arginine	g/16g N	10	10.8	11.4
Broiler Digestibility: Lysine 87%, Methionine 89%, TSAA 85%, Threonine 83%, Arginine 91% (INRA, 2010)				
Minerals				
Calcium	g/kg DM	2.8	3	3.4
Phosphorus	g/kg DM	3.8	4.4	5.2
Magnesium	g/kg DM	2.1	1.6	2.6
Potassium	g/kg DM	10.1	11.5	10.7
Sodium	g/kg DM	0.5	0.33	0.6

Sulphur	g/kg DM	2.5	2.8	2.8
Ruminant Nutritive value				
ME Ruminants	MJ/kg DM	14.1	14.8	13.9
Energy digestibility ruminants	%	89	90.6	89
Nitrogen digestibility ruminants	%	80	79.9	80
Nitrogen degradability	%	80	86	86
Pig nutritive values				
DE growing pigs	MJ/kg DM	15.8	17	15.6
MEn growing pigs	MJ/kg DM	14.7	15.8	14.4
NE growing pig	MJ/kg DM	9.3	10.5	9
Poultry nutritive values				
AMEn cockrel	MJ/kg	9.1*	9.1*	9.1*
AMEn broiler	MJ/kg	(7.91-9.27)**	(8.05-9.68)***	

*Recommended for practical use until further information available (Variation 6.5 to 11 MJ/kg)

(Petterson, 2000)

** Kaczmarek et al 2014

*** Nalle et al 2011

7. Application in animal feeds

Protein average for white lupins range between 33 to 37% with an average of 35%, while yellow and blue lupins have an average of 43 and 33 percent, respectively. Protein and amino acid digestibility average approximately 85%. Sulphur amino acid and lysine concentration per gram of protein are similar to soybean meal, protein levels are however lower. Metabolizable energy levels average 2300 kcal/kg for poultry with metabolizable and digestible energy for swine 3300 and 3500 Kcal/kg, respectively.

Inclusion level of lupins should be adjusted for the age of the animal being fed; inclusions should be restricted in piglet diets while in older pig feeds 10% inclusion would be acceptable. Poultry seem less sensitive to antinutritional factors in lupins than pigs. Broiler feeds efficiency appears to be affected at inclusion levels over 20% while in adult birds such as layers higher levels of lupin inclusion is possible (Hess, 2017).

One of the main benefits of lupins as a protein source is that low alkaloid varieties have little anti-nutritional factors and a low level of fibre. No processing or extrusion is required to make the product acceptable for use in monogastric diets. *L. Albus* has a higher protein and oil content with a lower fibre and is therefore of greater nutritional value, for monogastric animals (Hill, 1977). Alkaloids are detrimental to effective use of lupins in pig diets and a rapid test developed by Ruiz (1977) can be used to monitor the alkaloid content of lupins.

With some appropriate precautions, lupins can be used in pig and poultry feeds in times of scarce or expensive soybean meal. If lupins are produced in sufficient quantities to provide dependable supply to feed producers, they present a useful protein diversification.

7.1 Poultry

7.1.1 Broilers

Some research has indicated that lupin protein is utilized to a similar degree as soybeans (Steenfeldt et al., 2003; Mieczkowska et al., 2005) The high alkaloid level in narrow-leafed lupin (Lupinus angustifolius) as well as the non-starch polysaccharide (NSP) content has shown that it negatively affects growth, feed intake and nutrient utilization (Olver and Jonker, 1997; Hughes et al., 2000). Fortunately, recently plant breeders have developed cultivars with very low alkaloid contents (Jezierny et al., 2010; COBORU, 2011) which has improved their nutritional value for monogastric feeds. They do still however contain approximately 35% NSP limiting their use in poultry feeding (Choct and Hughes, 1999).

Published data on nutrient and amino acid utilization and apparent metabolizable energy (AME) of narrow-leafed lupins for broilers is limited and inconsistent. Nalle et al., (2011) illustrated an AME ranging between 6,38 and 7,12 MJ/kg for narrow-leafed lupins. The content of oligosaccharides increases under drought conditions illustrating that drought conditions could affect digestibility. Kaczmarek et al., (2014) illustrated a difference of between 7,91 and 9,27 MJ/kg AMEn for Polish lupins while apparent amino acid digestibility ranged from 71,3 to 91,2% mainly influenced by cultivar. They concluded that narrow-leafed lupins are a good source of protein but a poor source of AMEn for chickens. They also emphasised that current alkaloid levels in Polish L. angustifolius cultivars are low and they have a negligible impact on broiler performance.

Narrow-leafed lupins contain NSP that can lower nutrient digestibility and performance (Jezierny et al., 2010), the cultivar and growing season can influence the quantity of antinutritional factors (Choct and Hughes, 1999). Dehulling lupins can increase the protein of L angustifolius from 25 to 31% and AME from 5,9 to 8,8% and amino acid contents. Addition of enzymes can also contribute to the value of lupins. It was concluded that dehulled lupins with enzymes in broiler diets could obtain similar body weight gains in broilers fed soybean meal, but higher feed intake is required, lupin diets also decreased welfare related variables (Mera-Zuniga et al 2019).

Using white lupin seed free of alkaloids in broiler feed is justified by the high content of protein (40%) and the high fat content (9,7%). It has been suggested that the use of white lupins up to 25% inclusion does not affect the performance of broilers (Nalle et al., 2010; Suchy et al., 2010). White lupin seeds can substitute 50% of soya meal provided synthetic amino acids are supplemented (Suchy et al., 2006). Substituting of soybean meal protein with white lupin beans in broiler feed has no negative effect on broiler performance (Mierlita 2015). Inclusion of L angustifolius or L luteus at 15% was found to be acceptable in broiler diets at an inclusion of 16% provided adequate amino acids and fat is supplemented (Smulikowska et al., 2014). The replacement of soybean meal with lupin meal in experimental diets failed to produce any difference in broiler liveweight at 42 days, it was considered suitable to replace up to one third of protein with lupins higher inclusion may reduce growth intensity, it is however necessary to optimize individual nutrients particularly amino acids when formulating lupin containing diets (Pavel et al., 2010).

7.1.2 Layers

Levels of 5% up to 35% of lupins in layer diets have been found not to have any negative effect on egg production (Sentek *et al*., 1979; Vogt *et al*., 1979; Larbier 1980; Watkins and Mirosh, 1987). Prinsloo (1990) evaluated locally produced *L. Albus* in layer diets at levels between 0% and 30% with no significant difference in egg production and feed conversion (Table X). Higher feed intakes were however experienced with increased levels of lupins.

Table 7.1 The effect of dietary levels of lupin inclusion on egg production

Dietary Lupin Level (%)	0	5	10	15	20	25	30
Egg Production (% h.b.d)	76.8	79.4	75.7	79.4	78.1	75.5	78.2
Feed intake (g/hen/day)	106.6	109.6	107.8	112.9	112.6	110.3	113.8
F.C.R	2.288	2.273	2.387	2.331	2.381	2.404	2.387

Source: Prinsloo (1990)

Levels of up to 40% lupins can be successfully used in broiler diets (Yule and Mcbride, 1976). The level of up to 40% lupin inclusion has been substantiated by Erikson and Elliot (1984), Olver (1987) and Watkins *et al.* (1988). Practical levels used are however much lower than those recommended and a maximum of 20% is more commonly used.

No evidence exists to suggest that alkaloids levels commonly found in *L. Angustifolius* have a negative effect on any reproductive traits in broiler breeders. Levels as used in commercial layer diets should apply to breeding chickens but a more conservative 10 % maximum is recommended.

7.2 Pigs

Western Australia accounts for 72% of global lupin production. Such an abundant protein source available in Western Australia for pig producers is beneficial in reducing the cost of feeding.

Lupins have an excellent potential for use in pig diets due to favourable chemical composition and cost competitiveness. The accurate definition of amino acid availability and digestible energy being hard to define could result in variable pig performance. Certain types of lupins such as L. albus can reduce feed intake in pigs. L. albus is a superior cultivar in terms of crude protein, amino acid, fat and gross energy. In addition, there are lower levels of crude fibre and alkaloids whilst levels of other anti-nutritional factors are similar for L. albus and L. angustifolius. In Australia L. angustifolius is preferred for use in pig diets (Barneveld et al 1995) whilst L albus is not recommended in pig diets due to the depression in growth rates.

Lupin seed has been used in pig diets since the development of low alkaloid varieties by Gladstone (1972), Tavener (1975), Pearson and Carr (1976) and Batterham (1979) have all shown that *L. Angustifolius,* Uniwhite and Unicorp, which contain no anti-nutritional factors, can be used successfully as a protein source for pigs. *L. Albus*, however which contains a higher alkaloid content, has been shown to depress feed intake and growth rate in pigs. Kemm *et al*. (1987) demonstrated that provided lupins are low in alkaloid content they can be used successfully at up to 8% in diets of young growing pigs. Pigs are more sensitive than any other animal to alkaloids and growing pigs can only tolerate 0.02%. At common alkaloid levels of 0.009% extremely high levels of Lupins can be included without concern. Recommended levels of Lupins are 8 % for low alkaloid varieties and 0 % for other varieties. According to XXX research results indicated that dietary inclusion of up to 35% in grower and finisher diets did not depress growth provided that essential amino acid supplementation could support gain and FCR. Increasing lupin concentration up to 35% did not alter carcass composition or meat quality.

7.3 Dairy and Beef cattle

Studies at the University of Minnesota showed that dairy cows supplied with 37.9% of total crude protein from Lupins as compared to 34.2% from soybean meal consumed 2.4 kilograms less dry matter per day and produced 1.5 kilograms less milk. Lower protein content of milk was also found to decrease. Fat percentage and total solids remained constant (Feedstuffs, 1987). It is suspected that lactating cows may be sensitive to micro quantities of alkaloids. High rumen degradability of lupin protein may also be responsible for a less than satisfactory performance in dairy diets.

7.4 Sheep

Lupins fed to sheep specifically in Australia are fed as a whole-grain feed. Lupin dry matter has shown to have roughage quality adequate for sheep to maintain their weight or grow slowly. The supplementation of lupin results in higher intake, liveweight gain and wool growth compared to other cereals. (Valentine, 1989) A barley/lupin mixture was fed to weaners ad lib with a crude protein content of 10%. Supplemented lambs weighed more than unsupplemented animals and differences in body weight were up to 15kg between high and low nutrition and 10kg between supplemented and normal nutrition groups. Lupin seed also has a great impact on wool production and fleece characteristics. (Hill, 1977)

8 Lupin Breeding

In a breeding program split seeds are important, as splits can reduce germination considerably, they should be max 1 to 2% but can be as high as 40%. The time of sowing (early or late depending on rainfall) determines the type of seed that should be planted.

9 Lupin Diseases

9.1 Aphids

Reduce yields by direct feeding damage which causes flower and pod absorption and occasional plant death. Cowpea aphid, blue-green aphid and green peach aphid are the three main species that affect lupins. This disease can be detected through wilted plants with aphid clusters and flower abortion. Pasture and weeds assist aphids to move into lupin crops but there are several ways in which they can be managed, which include spraying insecticide, using resistant varieties and green bridge control.

9.2 Brown Spot

This is a widespread foliar disease of Lupins in Western Australia which infects Lupins at all stages of growth, but seedling infection has the most impact on yield. Spores are splashed by rain from the soil which then lands on new lupin plants and creates infection. This disease can be detected if the leaves of the crop develop dark brown spots and often reduce in size before falling off. Brown marks on the stem may also occur which develop into larger brown-black marks and kill the stem. The management for this disease includes longer rotations, iprodione application which may reduce the infection, early sowing, care in herbicide use and sowing onto advantageous soils.

9.3 Anthracnose

This is a fungal disease whereby all lupin species are affected, but Albus Lupin, Yellow Lupin and WA Blue Lupins are more prone to this disease than narrow-leafed lupins. The highest risk for this disease is in medium to high rainfall areas as it prefers warm and wet conditions. This disease can be detected through the bending and twisting of stems. The stems injury is usually dark brown with a pale orange spore mass. Seeds can be tested for the intensity of the infection and treated thereon. The management for this disease includes thiram-based seed dressing fungicide which may prevent the spread from the infected seed, the separation of blue lupins from susceptible varieties and the application of registered foliar sprays during early podding.

9.4 Phomopsis stem and pod blight

This disease occasionally causes yield loss but has a major impact on mature lupin stems or in the seed as it produces mycotoxin by the fungus. If the crop is infected and stubble is poorly managed the toxins may cause sickness or death in livestock when grazing occurs. Dark brown and purple lesions start to appear on dry lupin stems and the surface of green pods may become slimy due to lesions developing. This disease can be managed through increasing breaks between lupin crops and variety resistance.

9.5 Bean yellow mosaic virus (BYMV)

This disease is transmitted to lupins from infected clover plants through aphids. It affects Lupins that are mostly found in high rainfall areas and builds up in clover pastures. This disease mostly occurs during summer rain which aids the migration of aphids. This disease can be detected through necrotic streaking from the youngest shoot which leads to the growing tip dying and falling off. (Geoff. j Thomas, Brenda Coutts, 2018.)

10 Growing Lupins

Lupin crops require a large amount of nitrogen for normal growth and is obtained through symbiotic nitrogen fixation. Once the crop has been harvested, a large amount of this nitrogen is left behind as stubble, decaying roots and fallen leaves. This nitrogen then becomes available to crops that are grown afterwards.

There are several environmental influences on lupin growth which include sunlight, water use, temperature, and photoperiod, balancing vegetative and reproductive growth and soil. The energy source for all crop growth is solar radiation which is captured by crop leaves and is transformed into chemical energy. The crops ability to capture this radiation may inhibit its growth which is determined by the crops total leaf area and the orientation of the leaves. Lupins are grown in wide rows or narrow rows. Lupins grown in wide rows take longer to grow as they take longer to achieve full canopy cover.

Water is especially important in Lupin growth as it is required for the uptake of mineral nutrients from the soil which maintains the leaves and young stems. Most of the water used by the crop is through photosynthesis, however the plants internal hydration needs to be maintained by absorbing more water through the soil.

Normal plant growth temperatures range from 0 degrees Celsius to about 35 degrees Celsius in which plant growth expedites. Temperatures above the optimum temperature hinder growth and development rates. The optimum temperatures for the growth of Lupins is 20 degrees Celsius. Germination, leaf growth and plant development respond to this temperature in Lupins. When there are warm autumn days lupins germinate and emerge quickly, but when the weather – such as in mid-winter is cooler lupins grow slowly. Temperatures outside of the plants suitable range may also cause the plant to die.

The transition from vegetative to reproductive growth in Lupins depends on environmental conditions, flowering may be followed by pod set and then rapid grain filling or it may be followed by further branch growth. If branches continue to grow rapidly this may lead to a copious amount of vegetative growth and few filled pods which then gives a disappointing yield. This occurred in the 1980’s during cooler conditions and water-limited conditions in the southern parts of the wheatbelt of Australia, however this problem is occurring less frequently in more modern lupin cultivars.

A wide range of soils may be used when growing lupins. They are grown on very acid and calcareous soils and on deep sands in the wild. For example, In Western Australia Yellow Lupins prefer acid soils and coarse sands. Lupins are mostly grown on deep acid to neutral sands. When Lupins are grown on shallow neutral to alkaline soil, they are less adaptive and are sensitive to either too much or too little rain. Lupins can produce very deep roots of up to 2.5 metres within acid sandy soils and therefore are adjusted to those soils.

Lupin species provide an excellent example of how farming in Australia evolved in response to changes in technology and economics. The modern wheat lupin rotation became possible due to the work of the University of Western Australia and department of Agriculture. Lupin is unusual among broadacre crops in that domestication has played a crucial role in its modern development. In Australia once sound management packages were available the lupin industry grew rapidly in the 1980s and 1990s reaching peak production in 1999. The decline in production and the area sown to lupin reflects the decrease in price of lupin grain relative to other commodities, difficulty in controlling weeds that have become resistant to herbicides and the availability to the Western Australian farmers of a greater range of alternative land uses such as canola, new pasture species and field pea.

Lupin is uniquely well suited to the deep, acid sandy soils that occur over large areas of the Western Australian wheat belt. Improvements in the techniques for producing lupin and the development of premium niche markets which can pay higher prices is the only way Australia could ensure that lupin remains a vital component of profitable and sustainable farming system.

(White et al, 2008)

11 Weed Control

When growing lupins, it is important to maintain weed management. This is because it has many benefits which include: Higher yields as more sunlight, water and nutrients are available to the crop, higher prices, and more productive systems. There are several ways in which to control weeds in lupins, these include planning rotations in advance, controlling the weeds before sowing using physical and chemical methods and understanding how to use herbicides to maximise its capabilities with controlling weeds in the crop. (White et al, 2008)

12 Economics of Lupin usage in South Africa

Lupins are highly suitable feed for ruminants if it can be produced at a relatively low cost as is the case in Australia, the relative cost of its high protein and high energy combination with virtually no starch can result in lupins making a valuable contribution to the raw material requirements of the animal feed industry.

The composition of the carbohydrates in lupins make them suitable for the fermentation nature of rumen digestion, while less suited to the acid hydrolysis typical of monogastric animals. The energy recovered in pigs (digestible/metabolizable) is lower than that of ruminants where it can be in some cases as high as cereals. In the digestive system of poultry fermentation does not take place which compromises the energy value that can be extracted in poultry significantly.

L. *Albus* is far more suited for use in poultry feed where its higher nutrient value and availability will unlock value while L. *Angustifolia* are ideal for ruminants. Unfortunately, in Australia the main availability is of Angustifolia and prices obtained are for this variety.

Lupins replace and compete with both protein meals and grains, due to the fact that that they supply both protein and energy, it is therefore difficult to express their value as a ratio to either an oilseed-meal or a grain.

The extent of replacement of regular raw materials in animal feed is largely based on price and feed manufacturers use least cost linear programming to determine "cut off" prices for inclusion of lupins. Values are different between various species so it will be dependent on the type of feeds the potential miller is manufacturing. As a price indication the below relative values could be used as a guideline.

Table 12.1 Prices of Lupins in Australia (angustifolia) 2020/21

March 2019	USD285
December 2019	USD366
January 2021	USD430

Table 12.2 Prices EX Farm Australia, 27 January 2021 (Calculated relative %)

Lupins	USD310	
Canola Seed	USD460	67%
Canola Meal	USD365	85%
Maize	USD250	124%
Wheat	USD204	152%
Barley	USD160	194%

Reference: igrain.com.au, 2021

Table 12.3 Prices W Cape South Africa (Rand/USD 15,2), 27 January 2021

Canola Seed	USD427	67%	USD286	R4347
Canola Meal	USD395	85%	USD336	R5107
Maize	USD254	124%	USD315	R4788
Barley (Feed)	USD178	194%	USD345	R5244
Average			USD320	R4872

12.1 Relative value to Soybean meal

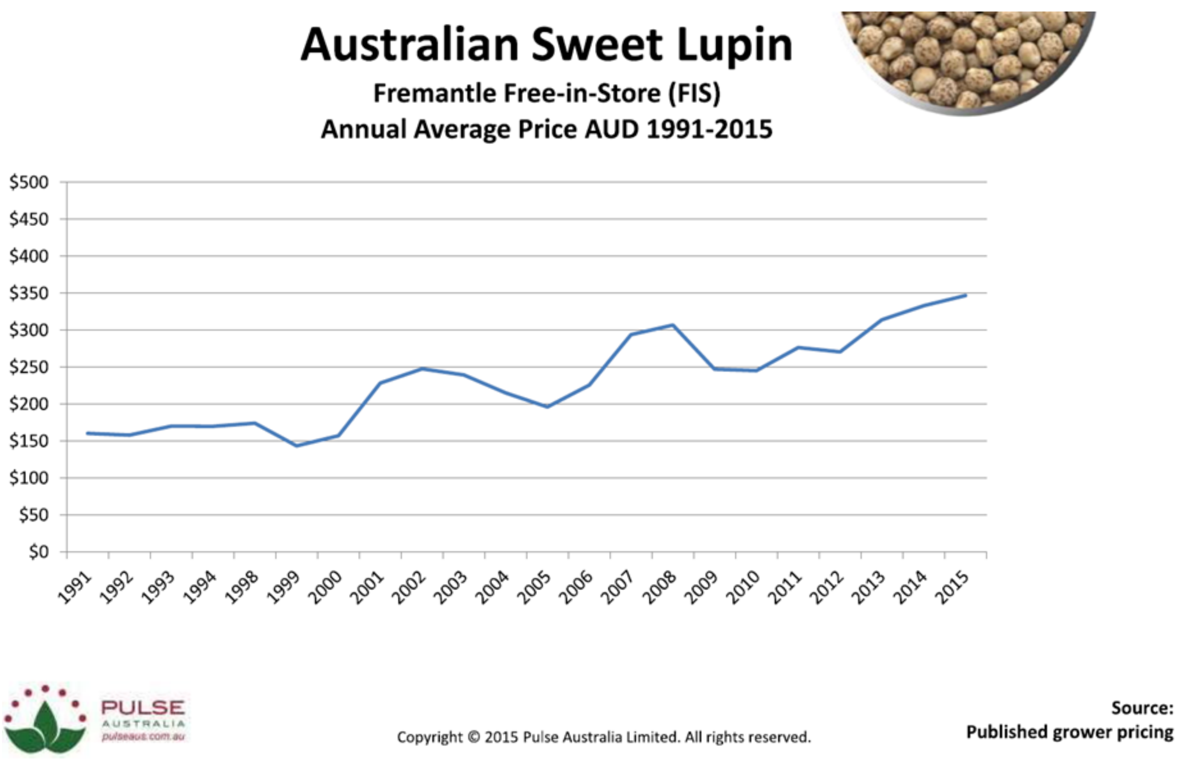
In Western Australia it has been stated (Government of Western Australia, 2021)) that lupins generally compete against soybeans in export markets and are typically. valued at 70-75% of the price of soybean meal.

On the 27 January 2021, the estimated imported Argentine soybean meal in the Western Cape was R9300/ton (including 4,9% import duty), at 70% this would be R6510/ton which appears high when compared to the domestic price of canola meal.

12.2 Long term Lupin prices Australia

The price of lupins in Australia was between AUD150 and AUD200 between 1991 and 2000 but steadily increased to AUD350 in 2015 and is currently +_AUD430 in 2021. Currently 1AUD = 1,3 USD (Forexdirectory 2021).

Figure 12.1 Lupin prices



Australia FIS 1991 to 2015

12. 3 Lupin evaluation in poultry rations (Least cost formulation).

Poultry rations were formulated by a consultant to assist in determining a relative value between L Angustifoloia, L Albus and Yellow Lupins in poultry rations as well as attempting to establish a relative value to maize and soya oilcake.

Broiler diet

At 10% inclusion the highest value is for:

Yellow Lupins 100%,
L Albus 88%
L Angustifolia 76%

Relative value to maize in a broiler ration:

Yellow Lupins	195%
L Angustifolia	148%
L Albus	171%

Relative value to soybean meal in a broiler ration:

Yellow Lupins	77%
L Angustifolia	59%
L Albus	68%

Layer diet

At 10% inclusion the highest value for:

At 10% inclusion the highest value is for:

Yellow Lupins 100%,
L Albus 89%
L Angustifolia 79%

Relative value to maize in a layer ration:

Yellow Lupins	212%
L Angustifolia	168%
L Albus	189%

Relative value to soybean meal in a layer ration:

Yellow Lupins	84%
L Angustifolia	67%
L Albus	75%

(Kleyn, 2021)

12.4 Lupins Feed Usage Volume maximum potential

It is important for the industry that we attempt to establish the potential volume of usage of Lupins in animal feed in South Africa in order to establish maximum usage.

The feed market in the Western Cape will extract the highest market value for lupins which will not require excessive transport to inland markets.

Based on AFMA feed volumes in the Western Cape (this is conservative considering AFMA make up 60% of total feed ins SA skewed to monogastric). The immediate potential should the raw material be readily accepted is estimated at 104 375 tons.

Table 12.4 AFMA Lupin potential usage Western Cape

Animal Feed Sales	Western Cape (TONS)	Inclusion	Lupins
Dairy	383 028	15	57454
Beef & Sheep	131 333	15	19700
Pigs	135 318	0	0
Layers	135 592	20	27118
Broilers	454 061	0	0
Broiler Breeders	70 052	0	0
Horses	2 043	5	102
Dogs	-	0	0
Other Mixtures	891	0	0
Maize-free Mixes	20 325	0	0
Aquaculture	4 042	0	0
Ostriches	13 611	0	0
Game Feed	2 633	0	0
TOTAL 2019/2020	**1 353 397**		**104375**
Source: AFMA STATS			0

The potential usage of lower density protein sources in the inland part of the country is extensive but price pressure on producers will be high. We have sunflower oilcake which is produced in these regions as a major competitor.

The maximum usage of Lupins in the country considering transport was not an impediment and L. *Angustifolia* is the choice (ruminant animals). Maximum potential usage can exceed 1 million tons under the correct circumstance.

Table 12.5 National Lupin potential usage

FEED TYPE	Feed tons/year	Lupin Inclusion	Lupin usage
Dairy	2309659	15	346 449
Beef & Sheep	3117788	15	467 668
Pigs	993 356	0	0
Layers	1244683	20	248 937
Broilers	3292842	0	0
Dogs	345 696	0	0
Horses	123 568	5	6 178
Ostriches	75 727	0	0
Aquaculture	5 202	0	0
Other	62 076	0	0
Total	**11570597**		**1 069 232**

13 Conclusion

Lupins will adapt well to growing conditions in the winter rainfall region of the Western Cape and could result in great advantage if used in a rotational crop system, mainly by the supply of organic nitrogen and reducing diseases found in cereal crops.

There are a large variety of lupins that differ in their qualitative and quantitative structure. Nutritive content of lupins differs considerably between specie, variety, and location. It is extremely important that there is a coordinated effort for the industry to agree on which lupins will be best suited to South Africa from both a production point of view as well as the application in the animal feed market.
Both L. *Angustifolius* and L. *Albus* could be grown successfully in the Western Cape in a crop rotation system. Lupins are more suitable for sandy solid rather than heavy soils in order to limit disease challenges.

L. *Albus* has a significantly higher nutrient content resulting in a larger market range and value for animal feed. L. *Albus* is also more suitable for feeding poultry while *L Angustifolius* is more suitable to feed ruminant animals and pigs (lower alkaloid level). L Angustifolius contain NSP that lowers the digestibility and performance in monogastric animals.

The supplementation of diets with NSP enzymes should be considered to improve performances. Modern varieties with low alkaloid content have made the use of lupins in monogastric diets more accessible. For monogastric animals' lupins are low in energy as well as lysine and methionine which needs to be supplemented. L. *Albus* has considerably higher energy, protein & amino acids than L *Angustifolius.*

It is extremely important that Lupins chosen to be grown in South Africa have a reasonable uniformity and that the end user has a reasonable description of attributes, nutritional value of what they are purchasing.

Lupins replace and compete with both protein meals and grains. The extent of replacing other raw materials is based mainly on linear feed formulation. Based on historical global pricing it is expected that Lupins (Angustifolia) could obtain a price of 67% of Canola seed and 124% of maize.

Currently a price of R4872 could be used in a feasibility to evaluate if production of lupins could be economically viable.

The Western Cape could more than double its lupin usage to over 105 000 tons. The potential usage for the country is beyond any production envisaged should the price be competitive.

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