Lupins – Botany and Global Use in Agriculture

Lupin (sometimes lupine) is the common name of a genus (*Lupinus*) of plants in the legume family Fabaceae. The genus includes over 200 species which cluster into 2 groups based on their centre of origin – the Mediterranean and African (Old World) species and the American (New World) species. Most species occur in natural landscapes but some are used in agriculture and others as ornamental flowering plants or for soil remediation. Generally, lupins are plants adapted to open and well-lit habitats, and do not tolerate shading (Gladstones, 1998),

Some sources believe the origin of the name is 14th century, from the Latin lupīnus - "wolfish" (from lupus - "wolf") as it was believed that the plant ravenously exhausted the soil. In fact, in natural and agricultural ecosystems, lupins thrive on infertile soils due to their ability to fix nitrogen from the atmosphere, their efficient phosphorus uptake. As phytoremediation plants they can replenish soil fertility through their root and shoot biomass stabilising the soil. Some lupin species, particularly *Lupinus albus*, form cluster (or 'proteoid') roots, which are clusters of closely spaced short, lateral rootlets that mobilise and take up nutrients in poor soils.

Lupin roots are symbiotically nodulated by the slow-growing Bradyrhizobium soil bacteria. This symbiosis serves the important process where atmospheric nitrogen is reduced by the bacterial nitrogenase enzyme to ammonia, a form that can be readily assimilated by the host plants. Abiotic stresses, including drought, high temperature, soil acidity, salinity, extremes of soil pH and soil nutrient deficiency, are major constraints for biological N2 fixation in legume-rhizobium symbiosis.

Australian Sweet Lupin (*L. angustifolius*) in flower and in pod

Lupins are mainly herbaceous annual or perennial plants, but a few are taller, partly woody shrubs, with one known small tree species. The leaves of most species have a typical palmate form with 5 to 16 leaflets and plants produce dense whorls of colourful pea-like flowers (1-2cm long) on an erect spike. The fruit (a pod), typically contain 4-9 seeds.

The taxonomy of *Lupinus* remains somewhat contested but, two sub groups are widely recognised. They are classified within the following taxonomic hierarchy: order Fabales; family Fabaceae; subfamily Papilionoideae; tribe Genisteae; genus *Lupinus*.

The Old World lupins includes 12 species from the Mediterranean region and Africa (chromosome number 2n = 32, 36, 38, 40, 42, 50, 52) , consisting of Malacospermae (smooth-seeded) and Scabrispermae (rough-seeded) lupin species.

The New World Lupin species from North, Central, and South America (chromosome number 2n = 36, 48 or 96), have as few as 2 ovules in the ovary and generally smaller seeds. Some better-known well-known examples include:

- *L. mutabilis* – Andean lupin, used agriculturally in the Andean highlands
- *L. polyphyllus* (and hybrids with other species) - that are widely cultivated as ornamentals with a wide range of flower colours
- *L. texensis* - the blue bonnet, the official state flower of Texas
- *L. arboreus* – the tree lupin, yellow bush lupin, commonly seen in California
- *L. nootkatensis* – Nootka lupin, west coast of North America and naturalised (invasive) in Iceland
- Russell lupin – thought to be a hybrid between primarily *L. arboreus* and *L. polyphyllus* Early use, to domestication for modern agriculture

Pearl lupin (*L. mutabilus*) in flower

Table 1. Some characteristics of crop lupin species

SPECIES	DISTRIBUTION	CLIMATE & SOIL-TYPE ADAPTATION	SEED PROTEIN %	SEED OIL %
L. albus *2n= 50*	Landraces in Greece, Albania, Yugoslavia; cultivated widely, including in the Mediterranean basin, Europe, Russia, North-Eastern Africa, South America	Cool to moderately warm, some frost tolerance; moderate nutrient requirement, mildly acid to mildly alkaline loamy sands and loams, very intolerant of waterlogging, efficient P uptake, low Cd accumulation, Mn accumulator	36.1	9.1
L. angustifolius *2n=40*	Landraces in Mediterranean basin and France; cultivated in Germany, Poland, Russia, South Africa, Australia, USA, South America	Cool to mild temperatures, moderately frost tolerant; low-moderate nutrient requirement, moderately acid to neutral sands and sandy loams, intolerant of waterlogging, low Cd accumulation	32.5	5.8
L. luteus *2n=52*	Landraces in Western Mediterranean, Israel; cultivated in Germany, Poland, Spain, Portugal, Russia, Chile	Cool to mild temperatures, frost susceptible; low nutrient requirement, strongly to mildly acid sands and sandy loams, some waterlogging tolerance, aluminium tolerant, intolerant of alkaline soils, Cd accumulator, efficient P uptake	38.3	5.6
L. mutabilis *2n=48*	Landraces and semi-domesticated in Peru, Bolivia, Ecuador.	Mild temperatures, narrow temperature range, frost susceptible; low-moderate nutrient requirement, mildly acid to neutral loamy sands and loams, some waterlogging tolerance, low Cd accumulation, low P requirement	41.5	17.5

From (Wolko et al., 2011; Clements et al., 2005; Gladstones, 1970)

The domestication of lupin species for agriculture

Lupinus albus (European White lupin, Albus lupin)

Cultivation of the *L. albus* is believed to date from about 2000 BC in the Mediterranean basin and it is generally accepted that Egypt was the country of origin for the agricultural use (Gladstones, 1974).

The earliest historical data on the cultivation of lupins comes from the Greek and Roman cultures. Roman agriculturalists recognised their ability to improve the fertility of soils and planted it throughout the Roman Empire for green manuring and for seed harvest.

After the fall of Rome, *L. albus* continued to be cultivated as a minor subsistence crop throughout the Mediterranean area around the Black Sea and the Nile Valley extending into Ethiopia. L. albus by this time had been semi-domesticated through selection, having non-shattering pods that aided harvesting, larger seeds that were more attractive to consume and water permeable seeds to aid germination.

However, the seeds were still bitter and were leached for a long time to remove most of the bitter alkaloids and then brined.

Even today the large seeded, bitter L. albus are called lupini in Italy and in Egypt they are known in Arabic as ترمس termes, and is a popular street snack. In Lebanon, Israel, Jordan, Syria, and Palestine the salty and chilled beans are called turmus and are served as part of an apéritif or a snack. In Portugal and Spain they are consumed with beer and wine and referred to as tremoços and altramuces respectively

The development of sweet (low alkaloid) varieties of *L. albus* was first undertaken in Germany in the 1930s and breeding continued in Germany, France and the Ukraine to develop sweet varieties with better adaptation to northern European agriculture accelerated in the 1970s. *L. albus* cultivation remains limited to the warmer climate and more fertile soils of eastern central and Mediterranean Europe.

Lupinus luteus (Yellow Lupin)

The bitter yellow lupin has long been used in Spanish and Portuguese agriculture as a green manuring crop. It is still used as an understory legume in cork oak plantations where its seeds naturally shatter and regenerate annually.

In mid-1800s *L. luteus* was introduced as a crop improving the poor acidic or marshy soils of northern Germany, the Baltic states, Belarus, the Ukraine and Russia. It was primarily used for forage and green manuring and for seed production.

As with *L. albus*, it was the German plant breeder Von Sengbusch who selected the first low alkaloid *L. luteus* in the 1930s. This genetic material formed the basis of ongoing breeding after World War II fully domesticated varieties (non-shattering, permeable seeds, early flowering,

disease resistant) from programs in Germany, Poland, Ukraine and Russia. These varieties are widely grown, harvested for grain and are utilised as a high protein livestock feed.

Lupinus angustifolius (Australian Sweet Lupin, Narrow-leafed lupin)

The bitter narrow-leafed lupin, a native of the Iberian Peninsula, was first utilised agriculturally in the early nineteenth century in southwestern France for cattle fodder, in Germany for green manuring, and then in England for sheep folding and improvement of sandy soils (Oldershaw 1925). Its basic advantage in the climate of northern Europe was frost tolerance. The cultivation of bitter *L. angustifolius* gradually extended eastward into the acidic soils of Poland, Belarus, and Russia, largely mirroring the usage of *L. luteus*.

The first fully domesticated varieties of *L. angustifolius* were not developed until the 1960s by John Gladstones at the University of Western Australia. These low alkaloid varieties were suited to vast tracts of acidic sandplain soils in Western Australia. Farmers rapidly adopted this novel grain legume crop to improve the productivity and sustainability of wheat production. Within 25 years *L. angustifolius* grain production exceeded 1 million tonnes, saturating domestic demand as a livestock feed, and seeing the birth of an export industry of a grain marketed as the 'Australian Sweet Lupin'.

Subsequently, the Australian sweet and non-shattering *L. angustifolius* genetics has been utilised by plant breeders in Germany, Poland, Belarus and Russia to breed sweet grain varieties suitable for northern European conditions. *L. angustifolius* is referred to as the Blue Lupin in Europe. Australia adopted the common name 'Australian sweet lupin' to emphasise that Australian narrow-leafed lupin has alkaloid levels within the Food Standards Australia and New Zealand standard of seed with 0.02% total alkaloids or below.

L. angustifolius has become increasingly grown in Europe due to its greater resistance to anthracnose disease compared to *L. albus* and *L. luteus* and its more reliable time to maturity and ease of harvesting.

Lupinus mutabilis (Andean lupin, tarwi, chocho, pearl lupin)

The Pearl Lupin was a widespread food grown in the Andean highlands of South America (Ecuador, Peru, Bolivia) for more than 3000 years. There is evidence that farmers selected for genetically larger and water permeable seeds. The Inca civilisation gave rise to a cultivation system which introduced lupin as a regular part of the crop rotation system. The bitter seeds, known locally as tarwi or chocho, were soaked for several weeks in mountain streams to remove most of the alkaloids and then cooked or toasted the seeds to make them edible. Spanish domination led to a change in the eating habits of the indigenous peoples, pushing lupin cultivation to more marginal, higher altitude environments.

In the late 20th century interest in using *L. mutabilis* has been renewed and plant breeders, first in Chile, then in Europe and Australia have attempted to develop low alkaloid (sweet) varieties

suitable for mechanised agriculture. An example is the cultivar Inti, bred by Erik von Baer (of Semillas Baer) in Chile.

Current Agricultural Situation

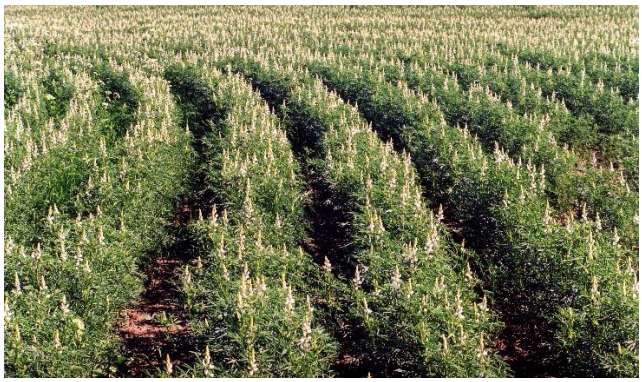
Australia

Australia is the global leader in lupin production since the 1980s but its current output is only 44% of its peak over twenty years ago in 1999. The Australian Sweet Lupin is by far the main species grown, mostly in Western Australia, but also in New South Wales, South Australia and Victoria. A smaller area of sweet albus lupin is grown and some production of yellow lupin and bitter lupini bean takes place.

Currently, the export and domestic trade in Australian Sweet Lupin is primarily for the stockfeed use. It is sought after as a high protein ingredient for rations used in the intensive dairy, beef and pork industries as well as for the sheep industry and has desirable properties as an aquaculture feed. Lupin is increasingly being used for human consumption where ingredient products include lupin kernel flakes, flour and grits. The adoption of plant-based diets is a growing trend and Australia has been active in the development of lupin products for inclusion in foods, via both institutional research and the establishment of a commercial companies focusing on the unique attributes of lupins for these end uses. The high protein, gluten-free, high-fibre status of lupins increases its desirability for use in foods.

Lupins are highly regarded by Australian farmers for their role in crop rotation. Not only are they a cash crop in their own right but they boost the yield of subsequent cereal and canola crops. They do this by fixing nitrogen in the soil; by providing reducing stubble and soil-borne fungal pathogen and nematode populations; and by enabling different weed control strategies. After harvest, the remaining lupin stubbles provide excellent over summer grazing for farmers with sheep.

The Australian Sweet Lupin is particularly well adapted to acidic sandy soils where other legumes and pulses are not suited. They continue to be bred for increased yield, water-use efficiency and disease resistance.



A crop of Australian Sweet Lupin in Western Australia

Europe

Lupin production in Europe steadily declined during the second half of the 20th century due to low and unstable yields driven by seasonal variability, the low price of lupin seed and anthracnose and Fusarium wilt diseases. Additionally, EU policies promoted the importation of readily available soya bean from the USA and South America, particularly Brazil. Gradually, concerns emerged about the sustainability, and dependence of non-European plant protein sources, as well as the realisation of potential environmental advantages of a productive, nitrogen-fixing legume grown locally. These factors led to a renewed interest in lupins and other legume crops, and production has increased since around 2003 (Lucas et al., 2015).

The former USSR had areas of more than half a million ha in the 1950s as forage and green manure of primarily *L. luteus*, but this declined due to the spread of Fusarium wilt. Better resistance has led to a steady increase in regions such as Ukraine and Belarus. *L. angustifolius* cultivation has increased in Europe due to better disease resistance and more reliable maturity at harvest, which occurs near the onset of Autumn rains when production is in central and northern Europe. In the UK, a rapid increase in the use of lupins in lupin/cereal forage mixtures has also occurred. Each of *L. albus*, *L. luteus* and *L. angustifolius* have been grown across Europe, with breeding programs in each located particularly in Poland, Germany and also in Ukraine, Belarus and Russia. Overall, *L. angustifolius* has become dominant due to its less troublesome agronomic performance and disease resistances.

Europe have been leaders in the inclusion of lupin in foods and there has been a gradual increase in the diversity of products produced with lupin flours and flakes as an ingredient as well as development of lupin protein concentrates and isolates, with valuable functional properties for use in foods.

North America

In the USA *L. luteus*, *L. angustifolius* and *L. albus* were grown on over one million hectares of the southern Coastal Plain between 1930 and 1950 primarily as a winter-spring green manure nitrogen source, prior to cotton and other summer crops. Occasional severe 'winter freezes' disrupted *L. albus* and *L. angustifolius* plantings in the 1950s and the arrival of cheap nitrogen fertilisers and government programs favoured other more profitable crops. Furthermore, a seed-borne virus disease (probably Bean Yellow Mosaic Virus) caused major damage to *L. luteus* crops, leading to a decline in interest. There has been experimental *L. albus* cultivation in California, the Pacific north-west, Minnesota and Michigan. Despite competition from other crops, there is still some interest in lupins in southern USA for use as a late winter, high protein livestock feed and as a cover crop for cotton.

Canada has been trialling *L. albus* as a new crop since around 2004 on the Canadian Prairies, with elevated efforts over the past 5 years. The crop can achieve protein levels of up to 40 percent, which is well above any other pulse crop grown on the Prairies. In 2016 and 2017 new varieties of *L. angustifolius* became available from Europe, to include in trials to test whether they

could be adapted to Alberta's growing conditions. Typical agronomic research is ongoing. There is evidence that some lupins varieties are resistant to an important soil pathogen, *Aphanomyces*.

South America

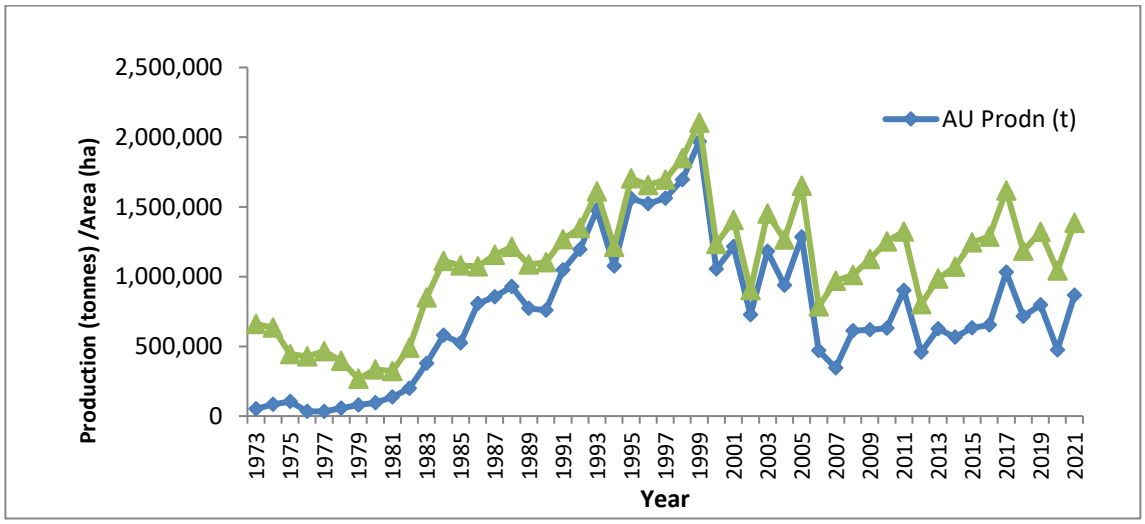
Currently, Chile is the major South American country where lupin production has increased substantially to peak in 2019 at 45600 tonnes, most of which is *L. albus* grown in Araucania. However, there is increasing interest in *L. angustifolius* and *L. luteus* with local breeding activities. A significant proportion of lupin is being utilised by the Chilean salmon aquaculture industry and in animal production. In the Andean highlands a small quantity of bitter *L. mutabilis* is still cultivated using traditional methods and seeds debittered in water by farmers in Peru, Ecuador and Bolivia. FAO production data shows production in Peru is consistently in the order of 15 to 16,000 tonnes annually, which includes both *L. mutabilis* and *L. albus*.

Africa

Lupins, mainly *L. angustifolius* and *L. albus*, have been grown successfully in areas of the Western Cape in South Africa, particularly in deeper sandy soils. Approximately 20,000 ha of lupins were planted in the Western Cape in the late 1990s. The occurrence of various wilt and root diseases such as Fusarium, Pythium and Rhizoctonia limited lupin production potential on heavier soils and has steered production to well-drained lighter textured soil types. Anthracnose became a serious disease in the Western Cape in the 1990s with L. albus being particularly susceptible while *L. angustifolius* was demonstrated to be more resistant and reliable. Local production data for South Africa also indicate that the FAOSTAT data may greatly underestimate production in that country – a 2022 article mentioned that the Western Cape could more than double its lupin usage to over 105,000 tonnes (Briedenhann, 2022).

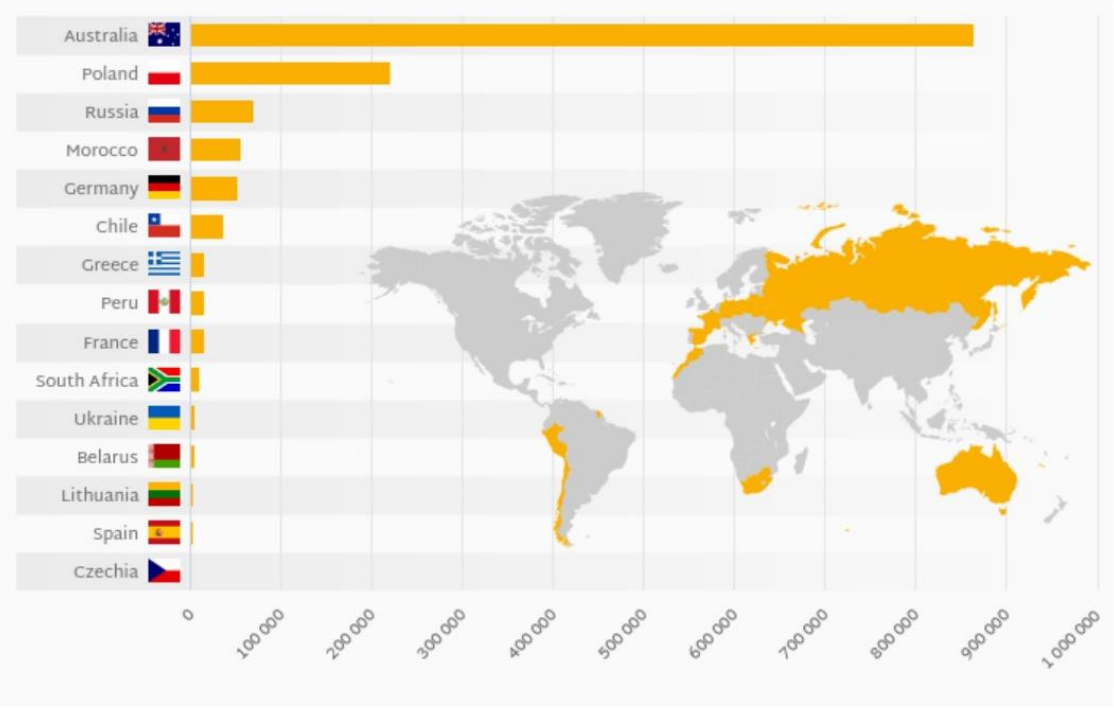
Lupin production has been increasing in Morocco, now at approximately 57,000 tonnes. In Ethiopia and Egypt, production of mostly *L. albus* has been relatively minor. In Ethiopia, most of the small production has been in the Amhara and Benishangul Gumz regions. There is a need for varieties that are better adapted to these specific climates and crop rotations.

World and Australian lupin production



FAOSTAT 2023

Lupin production by country, 2021



Source: www.tridge.com

References

Briedenhann E. (2022). Lupin production shows great potential for western cape. SA Grain 57. https://sagrainmag.co.za/2022/07/04/

Clements J, Buirchell B, Yang H, Smith P, Sweetingham M & Smith C. (2005). Lupin. In Genetic Resources, Chromosome Engineering, and Crop Improvement, Vol. 1 (Eds R Singh and P. Jauhar). CRC Press

FAOSTAT (2023).FAO Statistics Division. ProdSTAT Crops.

Gladstones JS. (1970). Lupins as crop plants. Field Crops Abstracts 23: 123-148.

Gladstones JS. (1994). An historical review of lupins in Australia. In First Australian Lupin Technical Symposium, pp. 1-38 (Eds M. Dracup and J. Palta). Perth, Western Australia: Department of Agriculture, Western Australia.

Gladstones JS. (1998). Distribution, origin, taxonomy, history and importance. In Lupins as crop plants. Biology: production and utilization, 1-39 (Eds J. S. Gladstones, C. Atkins and J. Hamblin). CABI, Oxon.

Lucas, M. M., Stoddard, F., Annicchiarico, P., Frias, J., Martinez-Villaluenga, C., Sussmann, D., Duranti, M., Seger, A., Zander, P. & Pueyo, J. (2015). The future of lupin as a protein crop in Europe. Frontiers in Plant Science 6: https://doi.org/10.3389/fpls.2015.00705.

Wolko, B, Clements J, Naganowska, B, Nelson, M & Yang, H. (2011). Lupinus. In: Wild Crop Relatives: Genomic and Breeding Resources. pp. 153-206. DOI:10.1007/978-3-642-14387-8_9.

Information prepared by: Jon Clements and Mark Sweetingham