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Lupinus A Multipurpose Crop: Potentialities and Improvements

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Lupinus species are some of the most valuable in the Fabaceae family. Lupin seeds contain significant amounts of polyphenols, carotenoids, phytosterols, tocopherols, alkaloids, and peptides with antioxidant, antimicrobial, anticarcinogenic, and anti-inflammatory properties. In addition, its nutritional and bioactive compounds have potential benefits for human health in preventing and treating some diseases. The objective of the present study was to review the morphology, nutritional constituents and uses of lupin in different fields. Lupinus recognizes nutritional properties, namely a high content of protein, dietary fibre, and low-fat content, making it a suitable alternative not only for animal protein but also as a substitute for more processed and less balanced flours from a nutritional point of view, used in the preparation of bread, cakes, and cookies, among others.

Keywords: Lupin; morphology; nutritional properties; legume; antinutritional proteins.

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1. INTRODUCTION

Lupinus is a genus of plants in the Fabaceae family that is distinguished by a shrub growth pattern and the presence of inflorescences of various colours above the height of the leaves. The ability of legumes to cohabit with Rhizobium, a type of nitrogen-fixing diazotrophic bacterium, is one of their distinguishing characteristics. It is important to identify agents that increase the effectiveness of this symbiosis in order to raise the protein content in plants, which depends on the system created by the plant and rhizobia (Carvajal-Larenas et al., 2015). Australia and Europe are the two largest producers, contributing 1,006,842 metric tonnes in 2019. Approximately 1,610,969 metric tonnes and 930,717 hectares of cultivated land were used to produce lupin in 2017 (Food and Agriculture Organization, 2022). Lupin is a valuable plant in both agriculture and commerce because of their nutritional value and resistance to harsh climates and soil conditions. In a few countries, its seeds are used as a protein source for animals and humans. People are presently consuming a lot of lupins (KohaJdoVá, et al., 2011). *L. albus* L., the white lupin; *L. angustifolius* L., the blue or narrow-leaved lupin; and *L. luteus* L., the yellow lupin, are the only four species of the genus *Lupinus* that are of importance to agriculturalists (Bebeli et al., 2020).

Accounting for 80–85% of global output and 90–95% of exports, Australia is the world's top producer and exporter of lupin seeds, including to Europe. One of the oldest types of grain legumes, lupine seeds have been grown in Egypt since ancient times. Due to the high seed protein content (35–45%) and oil content (10–15%), lupine seeds have significant nutritional potential. In Egypt, its seeds have really been used as a snack and as a medicinal herb (ARC, 1994). *Lupinus* seeds are a source of dietary fibre, fats, and proteins for both humans and animals, and they can grow in marginal soils and climates. Legumes have been employed as an effective and less expensive alternative to animal protein in many parts of the world where they are the only dietary protein source. There is a wide variety of species, although very few are grown under cultivation. *Lupinus luteus*, *Lupinus angustifolius*, and *Lupinus albus* new, supposedly "sweet" lupin varieties evolved at the turn of the 20th century that were high in proteins and low in bitter alkaloids. That led to a surge in interest in its application, and lupin soon became a source of protein for both humans and animals to eat (Juzoń et al., 2017). Thus, lupin entered modern agriculture and food systems in the 20th century (Sedláková, et al., 2016).

2. MORPHOLOGICAL DESCRIPTION, PHENOLOGY AND CULTIVATION

The source or location can have an impact on the morphological and botanical description of Lupinus. It is easily identified as a bushy shrub that can reach a height of 1.8 m (six feet), with flowers that are vivid blue and purple with white accents (Fig. 1 A, B and C). A fragrant aroma emanates from the blossom. The legume, lupin is a native of Europe and is grown more often there. Their high protein content, good quality, potential health advantages for people, and consumer appeal are only a few of their nutritional qualities (Lucas et al., 2015). A sustainable alternative supply of protein for animal feeding could also come from lupin species (Abraham et al., 2019).

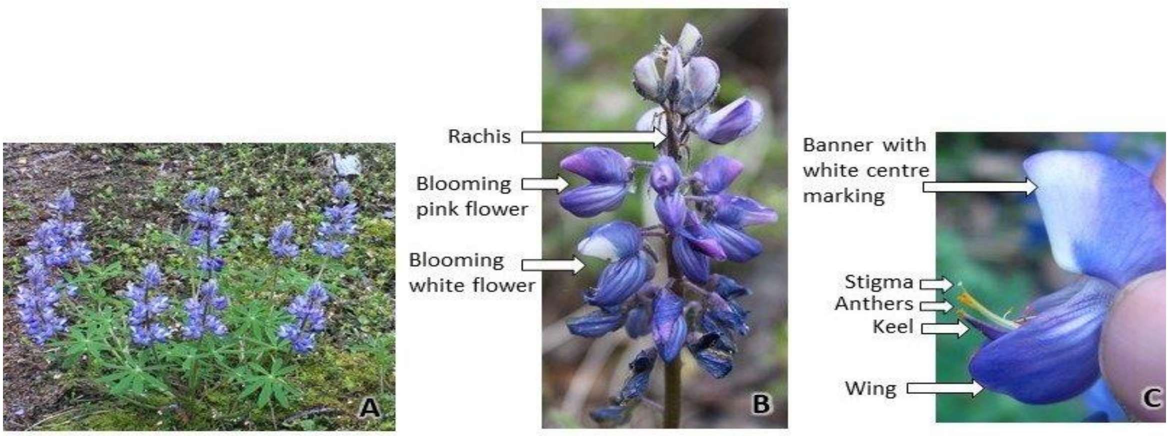

Fig. 1. General morphology and different parts of Lupin

Table 1. Taxonomical classification

Kingdom	Plantae
Division	Magnoloiphyth
Class	Magnoloipsida
Order	Rosales
Family	Fabaceae
Genus	*Lupinus*

The word "Lupus" (which means "wolf" in Latin) is where the name of the genus first came from. The opposite is true since lupins are legumes, contrary to the Romans' belief that they deplete the soil of nutrients in a manner similar to how wolves would steal farm animals (Nigussie, 2012). *Lupin* cultivation has a protracted past that dates back to antiquity (Wiśecicki et al., 2015). Before 2000 BC, *L. albus* was grown in ancient Rome, Egypt, Greece, and other Mediterranean nations for use as green manure, food for humans and animals, as well as for cosmetic and medicinal purposes. Around 700–600 BC, the Andean states domesticated *L. mutabilis*; by contrast, the Baltic countries domesticated *L. luteus* and *L. angustifolius* in the 1860s (Clements et al., 2005). The concern associated with the international trade of soybeans and the reliance of the European Union on imported soybeans could be reduced through the cultivation of lupins as a source of plant proteins for human consumption and livestock production (Abraham et al., 2019). In regions with high rainfall, elevation, and cool-temperate conditions, they could be cultivated for direct grazing or as a winter feed crop for silage, intercropped with maize (Lema & Lindner, 2010). Additionally, growing lupins can disrupt disease cycles in crop rotations and improve soil fertility in regions of the Mediterranean with heavy rainfall (Lema & Soengas, 2022).

In areas with a mild climate, blue lupine is sown in February or March. The early half of April is the best time to sow yellow and white lupine. Similar to soybeans, it is preferable to wait until May in cooler climates during colder years. As soon as the primary crop has been harvested, stubble lupine crops should be sown. The seeds size and the soil type also affect how deeply to sow lupines. Blue lupine should be planted at the shallowest depth, yellow lupine at the middle depth, and white lupine at the deepest level. In comparison to lighter soil, heavier dirt should be sown at a shallower depth. The quantity of seeds needed to sow lupine varies from 70 to 250 kg per hectare due to the varying thickness of the seeds and the characteristics of the soil. Utilising information on seed weight, germination, and purity, the quantity of seeds needed for sowing is determined. With certified seed of sweet types, it's important to follow the breeder's and seed seller's advice, set up the sowing machine appropriately, and check the coverage when sowing (Panasiewicz, 2022).

3. NUTRITIONAL CONSTITUENTS AND ASSOCIATED FUNCTIONALITY

Lupin can be grown on practically all continents; however, the nutritional and chemical composition of the seeds depends on how the plant reacts to its environment. The quantity of other constituents in seeds varies greatly depending on the region of cultivation, while only the protein content is significantly affected.

3.1 Significant Nutrient and Dietetic Components

Lupin seeds are frequently utilized due to their beneficial attributes, such as their high protein content, advantageous relative protein profile, high dietary fibre content, and favourable fat content. Lupin can be grown on practically all continents; however, the chemical makeup of the seeds and their nutritional value depend on how the plant reacts to its environment. White lupin's ability to fix N_2 with the use of atmospheric nitrogen for the formation of protein and other nitrogenous components in seeds, which contain virtually any starch at the same time, is due to its symbiotic relationship with rhizobia (Kurlovich et al., 2002). In the seeds of *L. albus*, the average protein content ranges from 32.9%-38.0% (Straková et al. 2006; Sujak et al., 2006). 15% albumin and 85% globulin constitute the lupin's storage proteins. The three primary proteins, a-, ß-, and a-conglutin, found in the globulin fraction have different amino acid compositions. A sulphur-containing amino acid called conglutin makes up around 4% of the protein's structure and is more abundant in methionine, cysteine, and valine (Carvajal-Larenas, 2019).

Table 2. Essential amino acid profile for major lupin (g a.a. /16g N in seed)

		L. angustifolius	***L. luteus***	***L. albus***	***L. angustifolium***
Non-polar side chain	Tryptophan	0.31	-	0.97	1.00
	Methionine	0.20	0.70	0.66	0.72
	Isoleucine	1.22	2.70	3.80	3.91
	Leucine	2.12	7.89	6.90	6.61
	Phenylalanine	1.18	4.04	3.85	3.65
Polar and uncharged side chain	Cysteine	0.42	2.28	1.34	1.36
	Threonine	1.09	3.51	3.29	3.54
	Tyrosine	1.13	3.1	4.26	3.66
Polar and charged side chain	Histidine	0.79	3.3	1.86	3.66
	Arginine	3.59	11.3	12.2	11.62
	Lysine	1.46	5.35	4.75	4.66

Adapted from Ohadoma, (2018)

Table 3. A preliminary distribution of the seeds from various wild lupin species (g /100 g DM)

Lupinus species	**Carbohydrates**	**Crude fibre**	**Crude protein (n=6.25)**	**Lipids**	**Ash**
L. elegans	3.17	12.9	43.6-45.4	5.8-7.3	4.2
L. hintonni	24.4	-	32.5	7	6.3
L. montanus	28.3	26.5	42.4-45.9	7.1-10	3.6-4.3
L. campestris	39.3	-	40.5	7.5	4.4
L. simulans	35	14.4	40.7	6.3	3.6
L. splendens	36.8	12.7-16.4	34.1-37.2	6.3	3.6
L. reflexus	32.2-34.5	15.1-16.5	37.5-38.5	6.5-7.7	3.5-7.3
L. madrensis	32.8	15.4	41.4	6.8	3.5
L. rotundiflorus	32.5	151	41.9-42.8	5.4-6.3	3.2-4
L. exaltatus	22.8-32.7	14.5-27	32-42	5.7-8.5	3.3-5.3
L. Mexicans	34.3	16.8	34.5-36.5	6-8	3.5-4.2

(Source: Pablo-Pérez et al., *2015; Porras* et al., *2013; Juárez-Fuentes* et al., *2018)*

There are numerous species, forms, and variants of lupine that acquire additional beneficial components in both their qualitative and quantitative structures as well as in their quantitative contents. *L. albus* is one of the species; it is known as "white lupine" and is reported to contain methionine in amounts ranging from 177 to 320 mg per 100 g, or 0.4-0.7% of protein. "Narrow-leave Lupine" is *L. angustifolius*, a plant with narrow leaves. "Andean pearl lupine" is another name for *L. mutabilis*. This species' low-alkaloid variants (sweet), which can be obtained by removing the alkaloids through soaking and cooking, are also known as *L. mutabilis* sweet. Another species of Lupinus, *L. luteus*, is referred to as "yellow lupine," and *L. polyphyllus* is called "multifoliate or Washington lupine." The "blue bush lupine," or *L. chamissonis,* is distinguished from the "yellow bush lupine" by having silver, densely hairy leaves that seem grey-blue and light violet to blue blooms.

3.2 Fatty Acids Content in Lupine Seeds

Lupine seeds have the qualities of a valuable supply of essential fatty acids due to their high level of polyunsaturated fatty acids, particularly linoleic and linolenic acids, as well as oleic acid, as shown by the fatty acid profile of lupine seeds. According to Rybiński et al., (2018), the number of fatty acids in a given species, cultivar, or habitat fluctuates. While the oil content of white lupin was lower (9.76–12.1%), it was nevertheless noticeable in the andean lupin seeds, which ranged from 16 to 20% (Wi et al., 2015). According to Rybiński et al., (2018), narrow-leafed and yellow lupin had oil concentrations that were less typical, at 6.5 and 5.1%, respectively (Bartkiene et al., 2016).

Regarding dietary applications and uses for both humans and animals, the quality of the oil present in lupin seeds is considerably more important than the amount. The ratios between the different acids in a seed oil's fatty acid composition are frequently used to determine its overall quality. According to earlier studies, lupin seed oil has an intriguing phytosterol, triterpene alcohol, and phospholipid composition as well as a well-balanced fatty acid composition with an average 90 % total unsaturated fatty acid (KohaJdoVá et al., 2011). It must be made apparent that the cultivar or variety type, climatic condition, ripening stage, cultural practises, and extraction technology used can all have a considerable impact on the quantitative and qualitative composition of the oil. Numerous studies have been conducted in the last ten years to ascertain the impact of genotype and environment on the quality of lupin seed oil (Sujak et al., 2006, Bhardwaj et al., 2013, Sbihi et al., 2014, Rybiński et al., 2018; Czubinski et al., 2021); nevertheless, there is currently no research published on the effects of the extraction technology on the oil yield.

3.3 Proteins

Lupin seed is enriched with various types of proteins such as albumins, globulins, prolamins, and glutelins. The globulin-to-albumin ratio in lupin seeds is 9:1, and albumins and prolamins comprise the smallest and largest amounts of the proteins, respectively. Prolamins and glutelins make up the remaining proteins. Seed storage proteins of lupins are classified as albumins (2S), 7S, and 11S (conglutins) based on the sedimentation coefficient. Conglutin proteins belong to four different families and conglutins. 11S is a "legumin-like" globulin protein member of the conglutins family and is made up of hexamers with a high molecular weight N-terminal acidic subunit and a low molecular weight C-terminal basic subunit. N-terminal end are glycosylated (Duranti et al., 2008), and these are connected by disulphide bonds (Magni et al., 2007). Β-conglutins, also known as 7S or "vicilin-like" protein, are trimeric proteins with monomers ranging in size from 16 to 70 kDa that are highly glycosylated and devoid of any disulfide bonds. Conglutins are created by the proteolytic cleavage of precursor molecules, both α and β conglutins. Because these proteins are not broken during seed germination, δ conglutins, which make up around 5% of the total protein composition, are not going to fall into the category of traditional seed storage (Lammi et al, 2016).

Lupin conglutin, a basic homo-tetrameric glycoprotein of 47 kDa, is a type of 7S protein. Each monomeric unit is made up of two heterogeneous subunits of 17 and 29 kDa connected by disulfide bonds. Subsequently, the amino acid sequence of γ-conglutinis does not correspond to other legume protein canonical sequences; γ-conglutin exhibits peculiar features. For instance, it bears a single N-linked oligosaccharide chain and binds with divalent metal ions, mainly Zn^{2+} and Ni^{2+} (Duranti et al., 2001). The least amount of research has been done on the last category of lupin seed conglutins, or -conglutins. 2S, a sulphur-rich tiny albumin protein, possesses two heterogeneous chains of 4 and 9 KDa connected by disulfide connections (Lammi et al*,* 2016).

4. LUPIN ALSO CONTAIN ANTINUTRITIONAL PROTEINS

Nutritional value and antinutritional components, species, genotypes, and geography all play a significant role in determining the nutritional value of lupin grain. The impact of environmental factors, including temperature and soil characteristics, has been studied in reports. Quinolizidine alkaloids are mainly responsible for the better taste of lupin seeds. The alkaloid profile is species-specific, and grains often contain more alkaloids than vegetative plant components do. The alkaloid content of contemporary cultivars, however, is extremely low and has little impact on feed consumption. On the other side, lupin grain contains extremely little anti-nutritional material, such as saponins and trypsin inhibitors (Prusinski, 2017). Lupin grains' unique carbohydrate profile, characterised by low quantities of starch, high levels of non-starch polysaccharides (NSP), and high levels of raffinose oligosaccharides, is the primary anti-nutritional component. These characteristics, which are most prevalent in monogastrics, have an impact on how energy is utilised as well as on digestibility. Along with breeding efforts, some additional efforts are used for lupin grain processing, either mechanically or biologically, using techniques like grinding, soaking, heating, etc. to remove anti-nutritional elements (Ruiz-López et al., 2019).

5. BIOACTIVE COMPOUNDS

Moreover, this plant also possesses various bioactive substances like alkaloids, phenols, and oligosaccharides, some of which provide protection against chronic illnesses like cancer, diabetes, and cardiovascular and neurological diseases. The health benefits of this plant are influenced by their chemical make-up, concentrations, exposure durations, interactions with other substances, and, most importantly, their bioavailability. These substances are regarded as either pro- or anti-nutrients, with either detrimental or beneficial impacts on health (Spina et al., 2022).

Table 4. The content of total phenolic compounds (gallic acid equivalent) and flavonoids (catechin equivalent) from seeds of lupine varieties

Varieties	Total Flavonoids (µg Catechin/g DM)	Total Phenolic Compounds (mg GAE/100 g DM
Lupinus angustifolius	269-258	133-362
Lupinus luteus	249-317	-
Lupinus albus	212-271	1100

(source: Bordoloi et al., 2016)

Table 5. Mineral composition of lupin seed flours (mg/100 g of dry matter)

Lupines species	Mg	Ca	P	Cu	Fe	Zn	Mn
L. angustifolius	219.1	143.0	613.4	0.95	4.26	3.79	8.4
L. luteus	294.0	134.8	715.5	1.10	5.84	5.90	5.6
L. albus	145.0	139.0	332.1	0.72	3.80	4.30	90.1

Source: (Porres et al., 2007)

Wild lupins contain essential flavonoids. These flavonoids include the flavones (acacetin, apigenin, chrysoeriol, luteolin), flavonols (isorhamnetin, kaempferol, quercetin), and flavanols (quercetin, kaempferol) as they have been shown to reduce coronary heart disease and cancer and trap reactive oxygen and nitrogen species, which is why they are effective antioxidants (Szczepański et al., 2022). Information is lacking regarding the potential for bioactive phenolic compounds with antioxidant characteristics, among others, because no analysis of the number of phenolic acids or anthocyanins in these species has been carried out.

6. USES OF LUPIN

Proteins from lupin seeds have been isolated using a variety of methods, and research has been done on their bioavailability and physico-chemical properties (Lo et al., 2021). In contrast to other common crops, lupins contain more fibre. Sugar analysis revealed that a pectin with rhamnogalacturonan-I and homogalacturonan domains is the predominant polysaccharide in the enzymatically isolated fibre fraction. In accordance with the current concept of lupin fibre structure, rhamnogalacturonan-I, which has branches of galactan and arabinan, is present; nevertheless, the existence of a linear, unbranched (homogalacturonan) area is novel (Arzami et al., 2022).

6.1 Nutraceutical Potential for Human Health

Lupine and meals supplemented with it have been shown to have positive effects on health and the prevention of several diseases over time. According to Sedláková et al. (2016), white lupine has demonstrated great promise in a number of areas, including improving defaecation, causing a sense of repletion (appetite suppression), disturbing the energy balance, favourably affecting glycaemia, enhancing blood lipid levels, and having a positive impact on hypertension.

6.2 Effect on Energy Intake and Satiety (Appetite Suppression)

According to clinical research, foods containing lupine or chemicals produced from lupine may lower hunger afterward, which may result in a reduction in food intake and subsequently affect the maintenance of a healthy body weight. For instance, it was discovered that breakfast bread produced with 40% lupine flour and the same number of calories as wheat bread resulted in more fullness and reduced energy consumption at lunch as compared to wheat-made bread. This was conducted on 88 healthy adult participants (Hodgson & Lee, 2008). Although the effect of satiety is evident and there is indication that a high-protein diet is more filling than a sugar-rich diet or that a fibre-rich diet is more effective at reducing food intake than a low-fat diet. Till now, no clinical tasting studies have been done on the satiety effect of lupine foods and their effect on actual weight loss. The best way to employ lupine for this effect must thus be understood and explored, as well as what mechanism or substance causes it (Taylor & Millet, 2017; Johnson et al., 2017; Sedláková et al., 2016).

6.3 Role as Cardiovascular Disease Prevention

Currently, in most developed nations, cardiovascular disease (CVD) is the leading cause of death. The major concerns for the development of CVD are the effects of lifestyle and genetic predisposition. These illnesses constitute a significant financial burden on the healthcare system. As a result, taking preventative steps like eating a nutritious diet is essential (Cabello-Hurtado et al., 2016). Though various studies suggest a function in lowering the frequency of cholesterol and atherosclerotic levels, the impact of the lipid profile of lupine is still not entirely clear. White lupin proteins were supplied to mice with atherosclerosis in a research study using mice as animal models, and they were compared to the control group fed casein to see if they affected the development of atherosclerotic lesions (Weisse et al., 2010). Additionally, a randomised trial found that lupine fibre, which ranges from 17 to 30 g per day, can lower total and LDL cholesterol by roughly 5% (Severino et al., 2011; Sirtori et al., 2004).

6.4 Role in Arterial Hypertension

Studies have found a correlation between nutrients such as protein and fibres and blood pressure readings with arterial hypertension being a known risk factor for cardiovascular illnesses (Severino et al., 2011). If plant-based proteins consumed more from sources like lupine and fibre, may lower blood pressure. According to a study from 2001, consuming 66 g of protein and 15 g of fibre per day significantly reduced blood pressure (by about 10 mmHg) (Burke et al., 2001). In 2009, Lee et al., carried out research on overweight men and women to compare the effects of bread made with lupine on blood pressure to bread made with wheat flour. When the data was analysed, it was discovered that the blood pressure of individuals who consumed bread prepared with lupine flour dropped by about 3.5 mmHg compared to those who did not (van de Noort, 2016; Lee et al., 2009; Sirtori et al., 2004). Lupine's positive effects can be partially attributed to the proteins that make it up improving vascular function. Since arginine, the physiological substrate of endothelial nitric oxide synthase, is present in high concentrations in these substances, it enhances the endothelium's ability to dilate blood vessels (Severino et al., 2011; Sirtori et al., 2004; Pilvi et al., 2006).

6.5 Impact on the Metabolism of Insulin and Glucose

Diabetes is one of the world's most prevalent diseases, along with cardiovascular conditions. Over 2030, 400–450 million new cases of diabetes are expected to have been discovered, through 90% of those cases being type 2 diabetes (Guariguata, 2012). Due to their high levels of bioactive compounds that can impact glucose metabolism and their high levels of dietary fibre and vegetable protein, pulses are particularly significant in the treatment of this condition (Cabello-Hurtado et al., 2016). As usual, food is a crucial factor in this illness. Conglutin, a component of lupine seeds, is referred to as a glucose modulator.

Numerous studies have linked the insulin-mimetic abilities of gamma-conglutin with its hypoglycemic characteristics. Gamma-conglutin has been demonstrated to influence the transcription of genes specific to insulin-like muscle in vitro, as well as to accelerate the translocation of GLUT-4 receptors to the cell membrane, activate intracellular kinases and adaptor proteins involved in insulin signalling, and activate GLUT-4 receptors in vivo.

6.6 Effect on Bowel Function

According to Van de Noort, (2016), oligosaccharides, specifically α-galactosides, make up roughly 40% of lupine kernel fibre. These might raise the amount of Bifidobacterium in the colon, which would support a healthy gut. Through the formation of acid, which lowers faecal pH, bifidobacteria limit the proliferation of pathogenic microorganisms and the excessive growth of harmful microflora (Gulewicz et al., 2008). In a 4-month study including 18 healthy

Table 6. Some food and non-food application of lupin

Sr. No.	Application uses	Plant part use	References
1.	Insulin production	Leaves	López et al., 2004
2.	Pesticides	Seeds	Garcinuno et al., 2003
3.	Flour	Seeds	Demmel et al., 2008
4.	Dietary fibre	Whole seed	Keller et al., 2022
5.	milk and yoghurt substitutes	Seeds	Carvajal-Larenas, 2019
6.	Bioactive compounds	leaves	Ruiz-López et al., 2019
7.	bakery or bread products	Seeds	Carvajal-Larenas, 2019
8.	Spaghetti and pasta	Seeds	Carvajal-Larenas, 2019

males, it was found that those who consumed lupine kernel fibre had higher levels of Bifidobacterium spp. and lesser levels of the bacteria from the Clostridia collection in their faeces. Using the same deduction, a study involving 38 healthy men improved bowel function, resulting in a shorter path time, a more advantageously compact stool pH, and higher levels of butyrate (a substrate for healthy colonic cell development), all without changing the participants' self-reported perceptions of their gut health. Smith et al., (2006); Johnson et al., (2017); Taylor & Millet, (2017).

7. RESEARCH ADVANCES AND CROP IMPROVEMENT

Legumes are also subject to the substantial production losses brought on by biotic and abiotic stressors. Although viruses, bacteria, insects, nematodes and parasitic weeds can also infect legumes and lower their production, fungi are the primary biotic stressors that affect legumes (Rubiales & Mikic, 2015). The production of lupin cultivars that are resistant to disease will increase the stability of lupin seed output. Although there are not many diseases that affect lupin, a few of them can result in significant production losses. Fusarium wilt and anthracnose, both brought on by *Colletotrichum lupinei,* are the main fungi diseases.

Lupin growth and output were severely constrained by anthracnose, which even resulted in losses of up to 100% (Riegel et al., 2010). Opportunely, lupins are substantially more tolerant to diverse abiotic stressors than other legumes and have shown potential for resilience on poor or polluted soil. Finding genotypes tolerant to a variety of abiotic stressors associated with climatic fluctuations could eventually make it possible to cultivate lupin under a wider range of agro-climatic settings. Finding genomic material that can be exploited in refinement programmes has been the main focus of research. Under favourable and severe drought stress circumstances, Italy evaluated 21 landraces, one commercial variety, and two breeding lines using a phenotyping platform, and the results showed a significant variation in the genetic diversity of white lupin (Annicchiarico et al., 2018). The effects of changing polyamine production by utilising inhibitors of the development on lupin drought tolerance have been studied in two yellow lupin (*L. luteus*) cultivars, albeit the results are inconclusive (Juzoń et al., 2017). Recent research on the Andean lupin (L. mutabilis)' ability to withstand drought has produced some intriguing findings (Lizarazo, 2010).

Few studies have observed salt tolerance in lupin species. A study was conducted to find out how different NaCl concentrations affected the growth and nitrogen fixation activity in a salt-tolerant variety of white lupin (*L. albus*). It was hypothesised that a shift from osmotic reactions to glycoprotein synthesis is associated with salt tolerance in nodules. Another investigation was made to see if it could be possible to irrigate horticultural crops with non-potable water.

Table 7. Crop potential exploration and improvement made in last decade for lupinus

Category	Main objective	Technique/ instrument/design	References
Genome Sequence	BACs will serve as a reliable framework, to build long-range scaffolds of genomic sequences	Bacterial Artificial Chromosome (BAC) library	Gao et al., 2011 Hong et al., 2003
Effective cross-pollination	Breeders produce cultivars with increased heterozygosity due to suitable functional floral features.	Insect-aided technology crop design system (CDS) approach	Harder et al., 2001 Palmer et al., 2009 Suso et al., 2016
Salt stress	Impact of sodicity on lupinus growth, yield, and cation composition. Effect of seed priming on physiological and morphological characteristics in salt-stressed seedlings.	Germination characteristics and Yield attributes K, Ca, Mg, Na estimation Physiological and morphological parameters	Niu et al., 2008

Category	Main objective	Technique/ instrument/design	References
	The resilience of lupine plants to salt stress was increased by the exogenous application of yeast.	yeast extract is beneficial as a bio-fertilizer	Tapadia et al., 2021
Drought tolerance	The impact of soil drought stress on the yellow lupin yield components. Applied drought stress to the lupin plant's early growth stage to see how it would impact the yield of the cultivars that were being tested.	Chl fluorescence SPAD values Yield component analyses high-performance liquid chromatography (HPLC)	Juzoń et al., 2019 Juzoń et al., 2017
Symbiotic association	The symbiosis between lupinus and *Bradyrhizobium* is comparatively resilient to abiotic stressors.	Strategic review	
Nutraceutical	NLL 5 and NLL 7 have been identified as recently found anti-inflammatory proteins that may be important functional food components for anti-inflammatory nutraceutical compounds that are used to treat and prevent disease.	Polymerase Chain Reaction (PCR), ELISA Assays, β-Conglutin Proteins Structural Modelling.	Lima-Cabello et al., 2023
Agronomic management	It is generally accepted that having the ability to symbiotically fix N2 improves soil. Chemical Composition as Affected by Variety and Tillage System Lupine can be successfully intercropped between two rows of tef by farmers in the northwest Ethiopian highlands two weeks following tef planting. Aimed to use a genome-wide association study (GWAS) to find relationships between 9 agronomical traits and 669 single nucleotide polymorphisms (SNPs) of 223 *L. mutabilis* accessions.	cluster-root formation tillage system relay cropping SNP marker QTL	Pueyo et al., 2021 Panasiewicz, 2022 Hunegnaw et al., 2022 Gulisano et al., 2023

Genetic material might be used in breeding programmes to generate Lupinus species that are fed to animals with salt tolerance.

An important grain legume crop known as *L. angustifolius* L. (NLL) is valued for justifiable farming and is acknowledged as a prospective food for human health. Recently, NLL has drawn attention because of its potential to boost grain output, manage diseases and pests, and increase human health. However, the paucity of comprehensive genomic resources for the species has hampered research. An NLL Bacterial Artificial Chromosome (BAC) library with an average insert size of 99.7 Kbp was developed by Gao et al. using 111,360 Tanjil cv. Tanjil clones. More than 12% of the genome is covered by the library. 13985 BAC end-sequences (BESs), or roughly 1% of the NLL genome, were obtained by sequencing the two ends of 9600 randomly chosen BAC clones. Thanks to the 39% G:C ratio, 16.6% repetitive DNA, and 5.4% potential gene-encoding sections of the BESs, a preliminary assessment of the NLL genome, including elements like organisation and composition, was achievable. From the BESs, 9966 SSR motifs were isolated, and some of these proved to be potential identifiers. They suggested the NLL BAC library as one of the most useful resources for genetic and genomic research on lupin.

8. CONCLUSION

The current study offers data on lupin species that are useful as food, fodder, and medicines. Lupines serve a range of functions because they are a substantial protein source and have a balanced amino acid composition that can be separated and used as constituents in various foods. Additionally, due to the presence of symbiotic bacteria, lupins fix atmospheric nitrogen, enhancing soil fertility. The physiological status of the human body is positively impacted by the high biological value of proteins and significant sources of amino acids, particularly in those with diabetes, hypertension, obesity, and cardiovascular disorders. They are particularly excellent for vegans, ovo-lacto vegetarians, and those with celiac disease who must adhere to a gluten-free diet, as well as diabetics and pre-diabetics who may benefit from them in controlling their blood sugar levels. People's serum cholesterol, including the LDL level, and blood pressure significantly decrease with a diet high in lupin protein. Like all crops, lupin needs ongoing development and adaptation to the increased environmental factors resulting from climate change.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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