

The Andean Lupine-‘El Chocho’ or ‘Tarwi’ (*Lupinus mutabilis* Sweet)

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General Observations on the Culture of Lupine (*Lupinus mutabilis* Sweet)

The Andean lupine, locally known as ‘tarwi’ or ‘chocho’ (*Lupinus mutabilis* Sweet) has been cultivated, processed and consumed for at least 1500 years, whose genetic variability has adapted to many microclimates [1]. Even before the Spanish conquest did this crop play an important role in high Andean production systems and in feeding the indigenous population [2]. Among legumes, the lupine is characterised by its high-quality protein content, suitability for environmentally robust production, and potential health benefits [3]. In the countries of the Andean region, the annual per capita consumption varies, e.g., in Ecuador, it is 4 to 8kg person⁻¹, much higher than in Bolivia (0.2kg person⁻¹) and Peru (0.5kg person⁻¹). However, for the year 2017, production did not meet domestic demand in Ecuador, reporting a deficit of approx. 6,000 tons [4]. The gastronomic versatility and nutritional qualities of this legume crop, combined with the work carried out for more than 20 years by both public and private entities in technological innovations, post-harvest, added value, quality seed, improved varieties, among other aspects, have renewed interest in this cultivation [5-7].

Introduction (Description, Domestication/Cultivation History, Including Current Cultivation, Geographical Distribution, Uses)

Introduction

The history of this species as an Andean subsistence crop demonstrates its potential as a crop for low-input agriculture in temperate climates [8]. The selection activities of Andean farmers have represented the only means of domestication of the lupine, giving rise to semi-domesticated forms characterized by indehiscent legumes/pods, large seeds, multicolored flowers, highly branched architecture and a more or less annual life cycle [9]. It is a robust crop that can be grown in poor soils and dry climates [1], which stands out for its great potential in soil recovery due to its ability to fix nitrogen [10]. Furthermore, in addition to its high alkaloid content (4.5g 100g⁻¹ dw) [11], the crop has a high resistance to microbial infections and insect attacks [12]. The presence of these alkaloids in the seeds and the low yields (800⁻¹,300kg ha⁻¹) have strongly limited the expansion of this crop [13,14]. Efforts have been made to reestablish lupine as a crop in South America and to adapt it to conditions in Europe [15].

The Andean lupine is characterized by the highest grain quality of all cultivated lupines, presenting an oil content similar to that of soybeans (*Glycine max* (L.) Merr.) [16]. Numerous studies investigating the nutritional profile and potential applications of this pulse have found a wide range of possible products ranging from proteins, oils and food additives to cosmetics, medicines and biopesticides. Also, the nutritional advantages make it an ideal product for the transition from meat-intensive diets to diets based on vegetable proteins [16].

Origin, diversification and domestication

The oldest evidence of cultivated Andean lupine is related to the seeds found in tombs of the Nazca culture and representations in Tiahuanaco ceramics in Peru [17,18]. The oldest archaeological evidence of domesticated *L. mutabilis* seeds has been found in the Mantaro Valley in central Peru and dates back to approx. 1800BP. The use of RADseq in the analysis of this archaeological material confirms that *L. mutabilis* was first domesticated in the Cajamarca region (northern Peru), from the wild progenitor *L. piurensis* C.P.Sm. Demographic analysis suggests that *L. mutabilis* separated from its parent around 2600BC and suffered a bottleneck in domestication, with subsequent rapid population expansion as it was cultivated in the Andes [19]. *Lupinus mutabilis* is reported in Eastern South America, from Colombia to northern Argentina, and with a wide altitudinal range from 1500 to 3800m a.s.l. [20].

In the Andean region 83 species have been identified; the wild relatives that show diversity and variability found in the Andean lupine are the following species: *Lupinus aneanus* Ulbr., *L. aridulus*

C.P.Sm., *L. ballianus* C.P.Sm., *L. chlorolepis* C.P.Sm., *L. condensiflorus* C.P.Sm., *L. cuzcensis* C.P.Sm., *L. dorae* C.P.Sm., *L. eriocladius* Ulbr., *L. gibertianus* C.P.Sm., *L. macbrideianus* C.P.Sm., *L. microphyllus* Desr., *L. paniculatus* Desr., *L. sufferuginous* Rusby, *L. tarapacensis* C.P.Sm. and *L. tomentosus* DC. [21].

Germplasm collections

The germplasm collections were started in 1974 by Dr Oscar Blanco at the University of Cusco (Peru) and soon spread to Bolivia and Ecuador; Currently, South American institutions have more than 3,000 Andean lupine genotypes. The largest and most relevant germplasm collections of *L. mutabilis* are found in the gene banks of Peru, Ecuador and Bolivia. However, there are also smaller collections in Chile, Argentina, Colombia, Australia, Russia, Poland, Germany, Spain, Hungary, the United Kingdom and Portugal [20]. Regarding the Ecuadorian collection of *Lupinus*, the National Institute for Agricultural Research (INIAP) has a collection of approx. 530 accessions of which about 70% belong to *L. mutabilis* Sweet (Table 1).

Table 1: Number of accessions of *L. mutabilis* conserved in the INIAP germplasm bank.

Province	No. of Accessions in the Gene Bank*	Percentage	No. of Collected Accessions**	Percentage	Altitudinal Range (m a.s.l.)
Carchi	10	6.41	14	15.73	2597-3172
Imbabura	14	8.97	5	5.62	2204-3057
Pichincha	14	8.97	4	4.49	2690-3500
Cotopaxi	12	7.69	20	22.47	2538-3507
Tungurahua	7	4.49	11	12.36	2600-3390
Chimborazo	76	48.71	30	33.71	2380-3600
Bolívar	2	1.28	-	-	2460-2837
Azuay	10	6.41	2	2.25	2450-2918
Loja	11	7.05	3	3.37	1900-2900
Total	156	100	89	100	

Note: Germplasm collected: *period 1975-1999; ** period 2014-2015.

Botanical description

Three geographically separated morpho-types of the Andean lupine have been suggested based on the considerable genetic and morphological variability and wide ecological adaptation in the Andean zone: a) *Lupinus mutabilis*, lupine (northern Peru and Ecuador), of more prolific branching, very late, greater hairiness of leaves and stems, some ecotypes behave as a biennial, tolerant to anthracnose; b) *Lupinus mutabilis, tarwi* (central and southern Peru), scarcely branched, moderately late, somewhat tolerant to anthracnose; and c) *Lupinus mutabilis, tauri* (highlands of Peru and Bolivia), smaller (1-1.40m) with a developed main stem, very early, susceptible to anthracnose [13,22,23]. High diversity seed characteristics include shape (lenticulate to spherical), primary and secondary seed colour, as well as distribution patterns; colour can range from pearly white to solid black and includes beige/yellow, brown, dark brown, and colors in between such as brownish green and greyish green. Most of the seeds have a secondary colour distribution in darker shades of the primary colour; the secondary

colour distribution also varies among a wide range of patterns, such as brow-shaped, crescent, mottled or spotted, which can be expressed either solitary or in combination [13,24].

The presence of considerable variation in germplasm is shown by different phenotypic traits, such as a wide range of growth periods, branching patterns, colour and shape of grains and flowers, as well as flowering times. Both the Inter-Simple Sequence Repeat (ISSR) and Single- Sequenced Repeat (SSR) markers have revealed a broad genetic diversity among *L. mutabilis* lines [25,26], which could be related to the mixed pollination system that the species has, and which could explain the presence of the test colour [25].

Environments where lupine is grown

The requirement for lupine is variable, depending on the soil, temperature and wind. It grows well in temperatures from 20 to 25 °C; grain development is optimal below 9.5 °C (night temperature), a condition that occurs in the high Andean region [23]; the early ecotypes of Puno-Peru, needs 450mm of precipitation per crop cycle, while the late ecotypes require between 600 and 700mm [13]. The lupine prefers sandy loam soils, with a thick, deep texture,

with a balance of nutrients, good drainage with a pH of 5 to 7 [21,27,28]. In the seedling stage it is susceptible to frost (-4 °C), the higher the temperature, the greater the growth and development, on the contrary, at less than zero degrees Celsius, development and evapotranspiration are inhibited [18].

Uses

Chocho can be consumed directly as a snack [29] and as an ingredient in different products such as fresh salads, soups, cakes, cookies, bread, hamburgers, baby food [29-32]. The new uses of lupine are related to the extraction of oil and production of vegetable milk, yoghurt, obtaining flours and by-products for animal feed [33,34]. Alkaloids such as lupine and sparteine present in the leaves, stem and seed of lupine plants were traditionally used, in combination with paico (*Dysphania ambrosioides* (L.)) Mosyakin & Clemants, *syn. Chenopodium ambrosioides* L., a wild relative of quinoa) to repel pests on potato crops such as the Andes weevil (*Premnotrypes spp.*) and kona kona (*Eurysacca quinoae* P.) the primary pest of quinoa. In livestock, it is used to control internal and external parasites, practices that are disappearing due to the promotion of industrial agrochemicals [35]. Lupine seeds are used for consumption after debittering [30,36] reducing the alkaloid content to 0.02% for people and from 0.4 to 0.6% for pigs, ruminants and poultry [18,37]. To eliminate antinutritive substances (alkaloids), a hydro-thermal process is carried out, which consists of hydrating the dry grain and soaking it for 12 to 14 hours, then it is cooked for 30 to 40 minutes. The seed is left in a stream of continuous drinking water for three or four days, or in circulating water from the river or streams between seven and ten days [38].

Assets/Benefits (Nutrition, Growing Practices, e.g., Crop Rotation, etc.)

Current situation of lupine in Ecuador

The Andean lupine is currently of agricultural importance only in Ecuador, Peru and Bolivia [39]. The area sown according to the III National Agricultural Census was 5974ha, with an average yield of 400kg ha⁻¹, however, with the introduction of improved varieties, the yield oscillates between 1500kg ha⁻¹ [4,40]. Data from [41] report a sown area of 3,642ha, with a production of 1,339 tons and a yield of 3,678kg ha⁻¹. The lupine is produced in the altitudinal strip that goes from 2500m a.s.l., parallel to the cereal area, up to 3400 or 3600m a.s.l. with risks of frost and hailstorms [37]; the provinces where production is centred are Cotopaxi, Chimborazo and Pichincha [40]. Ecuador has two improved varieties of Andean lupine: INIAP 450 'Andino' and INIAP 541 'Guaranguito' from Peruvian lines that have a short crop cycle (6 months) and a high alkaloid content [42].

Crop husbandry

In the highlands of Colombia, Ecuador, Peru, Bolivia and Chile, the Andean lupine and its wild relatives (kela or kera) constitute one of the components of agroecosystems and ecosystems. The consumption of Andean lupine decreased notably since colonial times because it was replaced by the introduced broad bean (*Vicia*

fabu L.) in the crop rotation system [35]. Studies have demonstrated that the Andean lupine can incorporate between 200 and 500kg nitrogen ha⁻¹ into the soil; i.e., an amount equivalent to 350-750kg of urea ha⁻¹ [43]. This is due to the photosynthetic efficiency in converting atmospheric carbon into structural carbon (similar to C4 crops), with its ability to fix atmospheric nitrogen in symbiosis with different species of bacteria and with its ability to solubilise phosphorus from the soil [35,44].

Harvest residues are used as green manure, and the dried stems as fuel due to their large amount of cellulose that provides an excellent calorific value [45]. Something particular that happens in Andean ecosystems is that after earthworks, the first thing that emerges and covers the soil in the plots at rest is a diversity of wild relatives of the Andean lupine, which contributes to the recovery of soil fertility [35].

Nutritional aspects

The Andean lupine, compared to other legumes such as soybeans and beans (*Phaseolus vulgaris* L.), has enormous nutritional and nutraceutical potential. The protein content ranges between 40 and 51%, with a high globulin and albumin content, but it is low in tryptophan; it has calcium, iron, zinc, and a high oil content (18 to 22%), in which fatty acids such as linolenic and linoleic predominate (Table 2) [34].

Table 2: Average of the nutritional and functional components of lupine.

Component	Unit	Amount
Protein (%)	%	51.20
Amino Acids		
Valine	(g/100g*)	1.49
Methionine	(g/100g*)	0.16
Isoleucine	(g/100g*)	1.82
Leucine	(g/100g*)	2.75
Lysine	(g/100g*)	1.79
Lipids	%	21.9
Fatty Acids		
Linoleic acid	%	28.5
Linolenic acid	%	2.5
Fibre	%	13.5
Calcium	%	0.37
Phosphorous	%	0.43
Magnesium	%	0.05
Iron	µ/g	61.00
Zinc	µ/g	92.00

Note: *Content per 100g fresh sample.

Source: [34].

Linoleic acid has properties, which in human metabolism are unique and irreplaceable during specific stages such as pregnancy and the first months of postpartum life. Also, it increases defences and lowers blood pressure, while oleic acid reduces the risk of

cardiovascular disease and is antitumor [46]. It prevents chronic diseases such as diabetes, gout, kidney problems, diuretic and emollient [47], it also has antioxidant properties due to the presence of isoflavones [25].

Limitations: Reproduction Needs

From an agronomic point of view

- i. One limitation is the lack of early maturing and high-yielding genotypes, the lack of locally adapted genotypes [15], and the lack of good quality seed production [39].
- ii. Limited research in plant breeding: recent domestication and history of reproduction fragmented in time and space have also contributed to the lack of genetic improvement and lower yields; lack of participatory approaches with farmers for the selection of local ecotypes. Besides, the lack of advanced biotechnological methods in genetics, molecular cytogenetics or tissue culture, has limited the possibility of exploiting natural variability and performing distant crosses and haploidisation of material from reproduction [16].
- iii. Presence of phytophagous insects: in Ecuador, the increase in demand intensified the ancestral production system of Andean lupine, with the use of improved varieties and broader cultivated areas, which caused the presence of these insects and the indiscriminate use of insecticides [48].

From a nutritional point of view

- i. The Andean lupine has a bitter taste as a result of the high content of alkaloids, which limits direct consumption for both human and animal consumption [49]. Hence, it is necessary to improve the debittering processes [39,50].
- ii. Lack of use since the colonial and the republican times: these crops were devalued, minimizing their consumption and even disappearing because they were considered "Indian food" or "poor man's food" [5]. The challenge is to recognise that Andean grain and pulse crops contribute to food sovereignty [39].
- iii. Generate specific data about the consumption of the Andean lupine or tarwi, which will be very useful for making decisions and actions that allow the promotion of greater consumption [39].

Future Potential

- i. Future work should aim at the development of bitter/sweet lines, with a sufficient level of alkaloids in vegetative tissues to decrease the presence of pathogens [51]. Also, integrated pest and disease management programs are required to improve farmers' production systems [49].
- ii. The combined use of germplasm and modern approaches to broaden the genetic base could help introgression of desirable adaptive traits for environments adapted to certain latitudes [16].

- iii. Converting production into a dual-purpose alternative (protein and oil) similar to soybean could be an economical alternative for the productive and competitive development of the Andean region [3].
- iv. Andean lupine alkaloids could be of commercial importance due to their pharmacological activity [12,52]. Furthermore, specific protein isolates and concentrates could be of commercial importance due to their functional properties for the chemical and food industry [11,53-55]. Furthermore, the presence of ferritin (protein-rich in Fe) in the protein profile [56] increases the nutritional value of this culture by offering a safe way to increase the intake of iron in the diet [57].
- v. In the medical field, quinolizidine alkaloids (Qas) also have an essential role due to multiple properties such as antiarrhythmic, anti-inflammatory, diuretic and hypotensive effects among others [58]. Besides, QAs can also find application in agriculture as a bio-stimulant increasing the growth and yield of other crops [59], as antibacterial agents [60] or as biocidal agents that replace synthetic toxins [61].

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