

Lima Bean International Network: From the origin to the plant breeding

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Abstract

Lima bean (*Phaseolus lunatus* L.) is the second most important domesticated species of *Phaseolus* in the world and could represent a precious alternative for food security and quality, as well as play a major role for sustainability in the face of climate change in Latin America and worldwide. Currently, many experts on conservation, domestication, genetic improvement, and plant-rhizosphere relationship of Lima bean have been working alone or in small groups. This situation has limited obtaining a greater benefit from their research and strongly prompts the study of the Lima bean worldwide. To increase the collaboration between experts in the study of the Lima bean, we present the Lima Bean International Network (LBIN). The main objectives of LBIN are to deepen the knowledge on this species and to promote its use worldwide. The success of LBIN will depend on the collaboration of the international scientific community interested in the study of Lima bean. Hence, we invite people from different sectors of society (researchers, producers, companies, NGOs, governments) to participate in this initiative. To get more information, you can visit <https://www.cicy.mx/sitios/red-internacional-frijol-lima>

Introduction

Beans (*Phaseolus* sp., Fabaceae) are an important source of proteins that contribute to food security, health, and poverty alleviation, particularly in Latin America and Africa (Bitocchi et al. 2017). Lima bean (*P. lunatus* L.) (Fig. 1) is the second most important species within the genus *Phaseolus*; and it is an important source of protein for human populations in Mexico, South America, and Africa (Araujo et al. 2015). Despite of its importance, Lima bean has been poorly studied. In past decades, most research efforts have focused on understanding the origin and domestication of the species, plant breeding, genetic resources conservation and plant-microbe interaction. While this research is important to alleviate the increased food uncertainty imposed by future climate change, stronger collaborations between Lima bean researchers will allow to design better strategies that will increase the resilience of Lima beans in changing environments.

To strengthen the interactions between research groups, in 2014, Brazilian and Mexican researchers started a scientific collaboration to study Lima bean genotypes found in Brazil and Mexico; in this collaboration, they analyzed the genetic resources, domestication, and nitrogen fixation in the roots. This effort contributed to create the Germplasm Bank of Lima bean of the Federal University of Piauí (UFPI). One of the main outcomes of this work was the celebration of the I International Symposium on Lima bean, held in October 2016 in Teresina, Brazil; this workshop lasted two days and had two objectives: bring together researchers from cutting-edge institutions working with Lima bean in Brazil, Mexico, and Colombia, and increasing the research efforts to improve the knowledge of this species. This event was instrumental for developing the first *P. lunatus* breeding program in Latin America coordinated by UFPI.

As a continuation of this initial effort, in 2022, the II International Symposium on Lima bean was held in Quito, Ecuador. This event was attended by numerous researchers from different institutions in Ecuador, Brazil, Mexico, Colombia, Peru, The United States, and Italy (Table 1). This symposium lasted two days and was focused on the conservation of genetic resources, domestication, plant breeding, and rhizosphere-microbiome of the Lima bean (a special issue can be found in <https://revistadigital.uce.edu.ec/index.php/SIEMBRA/issue/view/329>). During this symposium the need of creating the Lima Bean International Network (LBIN) was discussed. LBIN's main goals will be: 1) to integrate the information generated about the origin and evolution, conservation, plant breeding and plant-rhizosphere relationship of Lima bean, 2) to support, generate and coordinate research initiatives, 3) to support the training of high-level human resources, and 4) to promote the production, use and consumption of Lima bean as an alternative to food security and quality in the participating countries and worldwide.

Table 1
Founding members of the Lima Bean International Network

Name	Expertise	Institution	Country
María I. Chacón	Evolution	National university of Colombia	Colombia
Leydi T. García	Evolution	National university of Colombia	Colombia
Luz M. Espinoza	Plant breeding	San Luis Gonzaga National University	Peru
Regina L. F. Gomes	Plant breeding	Federal University of Piaui	Brazil
Ademir S. F. Araujo	Interaction plant-soil microorganisms	Federal University of Piaui	Brazil
Angela C. de Almeida	Plant breeding	Federal University of Piaui	Brazil
Daniel. G. Debouck	Conservation and evolution	The Alliance Bioversity International and the International Center for Tropical Agriculture (CIAT)	Colombia
Luis G. Santos	Conservation	The Alliance Bioversity International and the International Center for Tropical Agriculture (CIAT)	Colombia
Angel Murillo	Conservation	National Institute of Agricultural Research	Ecuador
Elena Bitocchi	Evolution	Marche Polytechnic University	Italy
Jorge Duitama	Evolution	University of Andes	Colombia
Nora Castañeda	Conservation	Crop Trust	Alemania
Rubén H. Andueza	Conservation and evolution	CONACYT-Technological Institute of Conkal	Mexico
Horacio S. Ballina	Plant breeding	Technological Institute of Conkal	Mexico
Jonás A. Aguirre	Conservation and evolution	Autonomous University of Yucatan	Mexico
Eudaldo Jadán	Plant breeding	Technical University of Machala	Ecuador
Eduardo Peralta	Conservation	Independent researcher	Ecuador
Ernesto Ormeño	Plant breeding	Universidad Nacional Agraria La Molina	Peru
Carlos Nieto	Conservation	Central University of Ecuador	Ecuador
Kimberly Gibson	Plant breeding	University of California	United States of America
Andrea León	Interaction plant-soil microorganisms	Central University of Ecuador	Ecuador
Jaime Martínez	Conservation and evolution	The Yucatan Scientific Research Center	Mexico

To show the relevance and importance of the LBIN, in this brief communication, we will first present a summary of the state of the art of Lima bean and the knowledge generated by the different members of the network. We will also present a list of perspectives that, as a group, we intend to carry out in the near future to strength the knowledge of Lima bean and thereby help this species to become an important crop for food security, especially in developing countries where it is grown. Finally, we invite other researchers that could be interested in participating in the LBIN to contact us through our website: <https://www.cicy.mx/sitios/red-internacional-frijol-lima>

1. Origin And Evolution

Lima bean is one of the five species of the genus *Phaseolus* that was domesticated in the Americas. The species is composed of wild (*P. lunatus* var. *silvester*) and domesticated populations (*P. lunatus* var. *lunatus*) (Baudet 1977). Although most of the *Phaseolus* species originated in Mesoamerica (see Bitocchi et al. 2017 for a review), DNA molecular markers indicate that wild Lima bean originated in the northern Andes (Serrano-Serrano et al. 2010). Phylogeographic studies also suggest that wild Lima bean experienced a process of range fragmentation, that lead to the migration of the species into Mesoamerica and the eastern slope of the central-southern Andes to reach its current widespread distribution from northern Mexico to northern Argentina (Serrano-Serrano et al. 2010). Given their geographic and environmental widespread distribution, wild Lima beans display a large range of ecological adaptations that go from semiarid to humid areas and from hot regions at low elevation in Central America to cooler regions at high elevation in the Andes (Freytag and Debouck 2002). The populations of domesticated Lima beans also show a wide range of ecological adaptations and therefore are an important genetic resource that will enable adaptation to current and future challenges associated to climate change.

To better understand the importance of Lima bean genetic resources, García et al. (2021) assembled the first genome of Lima bean that was collected from a landrace in Colombia. Additionally, they performed a comprehensive analysis based on a large set of SNP markers derived from GBS (Genotyping-by-Sequencing) data, for almost 500 wild and domesticated accessions. These and previous analyses have shown that wild Lima bean is structured into four non-overlapping major gene pools: i) the Mesoamerican MI pool at the northern end of the distribution range mainly in northern and central-western Mexico, ii) the Mesoamerican MII pool distributed from southern Mexico to northern Argentina, iii) the Andean AI pool restricted to the western slope of the Andes of Ecuador-northern Peru, and iv) the Andean AII pool found in central Colombia.

Understanding the phylogeography of wild Lima bean has also improved understanding of its domestication process. Molecular markers confirm that Lima bean underwent two independent domestication events (Motta-Aldana et al. 2010; Serrano-Serrano et al. 2012; Andueza-Noh et al. 2013, 2015; Chacón-Sánchez and Martínez-Castillo 2017). One domestication occurred from the AI gene pool and gave rise to the large-seeded Andean landraces known as "Big Lima". Another domestication occurred in central-western Mexico from the MI gene pool and gave rise to the small-seeded Mesoamerican landraces known as "Sieva" and "Potato". Demographic inferences based on GBS data indicated that the genetic bottleneck due to domestication was stronger during the Mesoamerican than in the Andean domestication (García et al. 2021). Although Lima bean was domesticated twice, the Mesoamerican and Andean landraces show phenotypic convergence in traits related to the domestication syndrome such as loss of pod dehiscence (the natural seed dispersal mechanism), pod and seed gigantism, loss of seed dormancy, increased yield, changes in growth habit, and phenology, among others.

2. Conservation

Lima bean is widely distributed in the Americas and has been widespread in the Tropics since it was first introduced to the Old World in 1493 after the voyage of Columbus. However, this crop has low commercial value (except for as a specialty export) in many of the countries where it is cultivated, which has represented a great challenge for the conservation of Lima bean genetic resources.

Ex situ conservation. The Alliance of Bioversity International and CIAT in Colombia is the most important genebank in the world that conserves Lima bean accessions. This genebank conserves 3,301 accessions that were sampled from 63 countries, most of them from America, Africa and Asia. This collection is made up of 3,028 cultivated accessions (82% are landraces), 259 wild forms, 53 weedy and one escaped genotype. Notwithstanding some gaps in coverage, the collection contains accessions adapted to a broad range of temperature, altitude and moisture conditions. As for the *P. vulgaris* collection maintained in genebanks, the Lima bean collection is an asset for breeders, given the wide variety of accessions adapted to conditions that could be important in relation to global warming. This collection will be moved to a new facility at Future Seeds genebank (<https://alliancebioversityciat.org/future-seeds>), a platform that innovates in genomics and big data to improve the use of germplasm collections for adaption of crops to climate change and increase the nutritional value of plants. Another collection that stands out in America is the Regional Plant Introduction Station of the University of Washington with more than 1,100 accessions. In Latin American countries, other genebanks focus on the conservation of their native germplasm (Table 2). Outside the Americas, the Bogor-Indonesia collection at the RDCB (Research and Development Center for Biology) is a large gene bank containing more than 3,800 accessions, mostly of Asian origin.

Table 2
Genebanks that conserves Lima bean native accessions in Latin America

Institution	Location	Domesticated accessions	Wild/escaped accessions	Contact
Brazilian Agricultural Research Company	Brasilia, Brazil	416	0	https://av.cenargen.embrapa.br/avconsulta/Passaporte/bancoAcesso.do?idb=356
Federal University of Piauí	Teresina, Brazil	408	0	acalopes@ufpi.edu.br
National Institute of Agricultural Research	Quito, Ecuador	148	0	https://www.iniap.gob.ec
National Institute of Agrarian Innovation	Lima, Peru	50	0	https://www.inia.gob.pe informes@inia.gob.pe
National Center of Genetic Resources	Tepetitlan, Mexico	-	-	pichardo.juan@inifap.gob.mx

In situ conservation. There are very few studies focused on the characterization of genetic diversity and *in-situ* conservation of Lima bean. For the wild gene pool, studies have shown that: a) in the Central Valley of Costa Rica, strong agricultural intensification has resulted in low population densities and low genetic diversity (Baudoin et al. 1998); b) in the Yucatan Peninsula, medium levels of agricultural disturbance have resulted in high population densities with high genetic diversity (Martínez-Castillo et al. 2004, 2006); and c) high population densities and high genetic diversity were reported across Mexico (Martínez-Castillo et al. 2014). For the domesticated gene pool, studies carried out in the Maya Lowlands have shown that: a) landraces are more diverse in traditional agricultural areas where there is less agricultural intensification (Martínez-Castillo et al. 2004); b) the three landraces that are cultivated most frequently have lower genetic diversity than the common and rare landraces, yet the rare landraces are at higher risk of genetic erosion due to local extinction (Martínez-Castillo et al. 2008); and c) the landraces collected in 1979 had a higher genetic diversity than the ones collected in 2007, indicating that allelic displacement in that period could be due to the introduction of improved varieties or also may be due to changes in the Mayan criteria for selection of germplasm (Martínez-Castillo et al. 2012).

3. Plant Breeding

Although Lima bean is cultivated in many countries of America, just a few research groups have developed breeding programs (i.e., members of LBIN).

In Brazil, the Agricultural Science Center research group of the Federal University of Piauí (UFPI) has conducted a pioneering plant breeding program to generate improved cultivars, that have a determinate growth habit, upright posture, uniform maturation, short cycle, resistance to anthracnose and a commercial grain pattern for agribusiness. They are also developing cultivars with indeterminate growth habit for smallholders, as an option to be used under intercropping with maize. This research started in 2007, when smallholders selected the most cultivated landrace in Piauí state (Boca-de-moça). From 2008 to 2013, studies were developed using artificial hybridization. In 2014, the protocols to carry out artificial crosses were established in UFPI, in Teresina city; in 2015, biparental crosses between germplasm from Brazil, the United States, Mexico, and Argentina were performed at the University of California, Davis, in the United States. Advanced breeding materials were evaluated in UFPI, developing populations with determinate and indeterminate growth habits. In 2019, the program was extended to include aspects related to growth habit, as well as reaction to anthracnose and seed patterns with populations advanced by the modified bulk method. The resulting lines will be evaluated soon.

In the United States of America, the Dry Bean Breeding Program (DBBP) at the University of California, Davis is developing Lima bean varieties for growers in California. In recent years, the region has dedicated approximately 8,100 hectares to the cultivation of Lima bean, harvested each year, with a nearly even split between white, large-seeded varieties and white small-seeded varieties of both determinate and indeterminate growth habit (USDA 2018). To serve this industry, the DBBP is screening new varieties for seed color, seed size, growth habit, pest resistance, and other adaptation traits necessary for high yields in the Central Valley of California. In conjunction with this work, the Gepts Lab at UC Davis has undertaken a series of scientific investigations to improve our understanding of Lima bean genetics and the

inheritance of agronomic traits. This lab group created a population of recombinant inbred lines which were used for linkage mapping during the development of the *P. lunatus* reference genome and has conducted several quantitative trait locus and genome wide association mapping studies of seed dimensions, cyanogenesis, and tolerance to the insect pest *Lygus hesperus* (Dohle 2017; Zullo 2021; Garcia et al. 2021). Additionally, the Gepts lab group has carried out studies of high throughput phenotyping for insect tolerance with novel autonomous insect sensors (Rydmer et al. 2022).

In Peru, the breeding of Lima bean is carried out at the Cotton and Bean Breeding Department of the Ica Farmers Association, which is responsible for obtaining improved cultivars with early-cycle determinate and indeterminate growth patterns as well as semi-late or intermediate cycle. The National Institute of Agrarian Research (INIA) also played an important role in the development of improved cultivars, until it was dismantled more than 20 years ago. Breeding began on one landrace named "Pallar de Ica", characterized by white seeds belonging to the Lima bean cultigroup, which already has its denomination of origin. More than 70% of the Lima bean consumed in Peru comes from the Ica region and from this variety. Since 2013, the legume team of the Faculty of Agronomy of the National University "San Luis Gonzaga" has evaluated and morphologically characterized genotypes that could potentially be more productive than the Pallar de Ica. With the support of the Universidad Nacional Agraria La Molina, they have also carried out i) the molecular characterization of a wide number of genotypes, including those with colored seeds, ii) the analysis of the nutritional and hydrocyanic acid content of colored-seeds genotypes and iii) the evaluation of the correlation between the hydrocyanic acid content and their phytosanitary response. At present, both research groups are evaluating and selecting genotypes with high nitrogen fixation potential and are searching for the optimization of the legume-rhizobia symbiosis (Mendoza-Suárez et al. 2020).

In Mexico, the Technological Institute of Conkal research group has evaluated landraces of Lima bean from the Yucatan Peninsula and managed to identify 12 important morphological and physiological leaf traits for selecting accessions with high yields to achieve sustainable, environmentally safe crop production (Ruiz-Santiago et al. 2021). In Ecuador, Acosta-Quezada et al. (2022) evaluated one Lima bean landrace under two different conditions of temperature and humidity and recorded data for 32 traits related to plant architecture, flower and seeds characteristics and yield, and 17 events in the phenology of the plants. They found that Lima bean is more tolerant to changes in environmental conditions compared to *P. vulgaris* landraces; they also found that the Lima bean was very productive and it might be considered as a potential species that could be grown in greenhouses, replacing other economically less attractive crops.

4. Interaction Plant-soil Microorganisms

The rhizosphere is the narrow zone surrounding and influenced by plant roots and colonized by numerous microorganisms (Mendes et al. 2013). These microorganisms play essential functions for plants, including: increasing their growth and yield. The functions and importance of plants-microorganism interactions in several plant species, such as soybean, maize, and common bean, are well known (Liu et al. 2019; Perez-Jaramillo et al. 2019; Ruger et al. 2021). However, in other plant species, such as *P. lunatus*, the effects of the interaction with microorganisms in their rhizospheres remains poorly understood. Most research about rhizosphere microorganisms of *P. lunatus* have focused on the nitrogen fixing bacteria known as rhizobia. Studies include prospection, characterization and nitrogen fixing efficiency analyses of strains isolated in Brazil, Peru, and Mexico (Ormeño-Orrillo et al. 2006; López-López et al. 2013; Chibeba et al. 2020). These studies have contributed to establish that *Bradyrhizobium* and *Rhizobium* are the main rhizobial genera nodulating *P. lunatus*, with the former genus characterized as the best performing symbionts. Recently, attention has been given to the microbiome of rhizosphere and nodules in wild and domesticated genotypes of *P. lunatus* to understand how the domestication process shape the microbial communities and to establish the potential of different microbial groups on the performance of *P. lunatus*. A recent study observed that domestication modifies microbial communities in the rhizosphere, including decreased diversity and reduced complexity of microbial networks (Silva et al. 2022). Diverse microbial groups were found in the communities around root nodules, including Proteobacteria (*Bradyrhizobium*), Firmicutes (*Bacillus*) and Actinobacteria (Rocha et al. 2020). These microbial groups promote important functions for plant growth which indicate that nodules can host a diverse and beneficial microbial community.

Perspectives

The studies highlighted in this manuscript show that important efforts have been developed by many researchers to understand the origin and evolution, conservation, plant breeding and the plant-soil microorganism interactions of *P. lunatus*. However, it is necessary to broaden the topics that will be studied by the LBIN. 1) To better understand the origin and evolution of Lima bean, future studies will need to answer the next questions: a) Do wild and domesticated Lima bean contain adaptive genetic diversity that could be associated with environmental variables that will be important in future climate change? b) Is there genomic evidence that parallel selection on genomic regions (or set of loci) has occurred during the Mesoamerica and Andes domestications? c) How have the Mesoamerican and Andean landraces evolved similar domestication traits? Due to its wide range of ecological adaptations and displayed phenotypic convergence, this species is undoubtedly an excellent model for evolutionary biologists interested in the study of adaptations and the constraints that shape the

phenotypic diversity of crop plants. 2) For the conservation of Lima bean, it will be necessary to collect more seeds in some specific areas of Latin America. It will also be necessary to use demographic and population genetics approaches to understand the relation between landraces from these regions. It will also be important to perform more ethnobiological studies of the domesticated gene pool in the areas of traditional agriculture of the main ethnic groups of Latin America. 3) For the breeding of Lima bean, it will be important to evaluate the negative impact of breeding programs on the genetic diversity characterizing the Lima bean landraces grown by farmers who practice subsistence agriculture; also, breeding programs should be specifically targeted at production problems related to climate change. 4) For the plant-soil microorganisms interactions, the following research gaps remain: a) which rhizobia nodulate the Lima bean in other regions of America and other parts of the world where it is cultivated?; b) how do microbial communities in the rhizosphere respond to wild and domesticated genotypes from the three known plant gene pools?; c) how does *P. lunatus* breeding affect the microbial community in nodules and rhizosphere?, and d) what is the potential of different rhizobial strain to increase the growth and yield of *P. lunatus*? Finally, it is necessary to increase the collaboration between experts in the study of Lima bean to deepen the knowledge of this species and promote its use worldwide; the success of LBIN will depend on the collaboration of the international scientific community interested in this species. If you want to participate in this initiative or get more information can you visit the website <https://www.cicy.mx/sitios/red-internacional-frijol-lima>.

Declarations

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest directly or indirectly and informed consent to publish this study.

Author Contributions

All authors contributed to the conception and design of this manuscript. The first draft of the manuscript was written by Jaime Martínez-Castillo, María I. Chacón-Sánchez, Ademir S. F. Araujo, Luis G. Santos, Kimberly Gibson, Regina L. F. Gomes, Elena Bitochi, Ernesto Ormeño-Orrillo, Luz Espinoza, Jonás A. Aguirre-Liguori, and Daniel G. Debouck. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

1. Andueza-Noh RH, Martínez-Castillo J, Chacón-Sánchez MI (2015) Domestication of small-seeded lima bean (*Phaseolus lunatus* L.) landraces in Mesoamerica: evidence from microsatellite markers. *Genetica* 143(6):557–669. <https://doi.org/10.1007/s10709-015-9863-0>
2. Andueza-Noh RH, Serrano-Serrano ML, Chacón-Sánchez MI et al (2013) Multiple domestications of the Mesoamerican gene pool of lima bean (*Phaseolus lunatus* L.): evidence from chloroplast DNA sequences. *Genet Resour Crop Evol* 60(3):1069–1086. <https://doi.org/10.1007/s10722-012-9904-9>
3. Baudoin JP, Degreef J, Hardy O, Janart F, Zoro Bi I (1998) Development of an in situ conservation strategy for wild lima bean (*Phaseolus lunatus* L.) populations in the central valley of Costa Rica. In: Owens SJ, Rudall PJ (eds) *Reproduction biology*. Royal Botanic Garden Press, Kew, UK, pp 417–426
4. Bitocchi E, Rau D, Bellucci E, Rodriguez M et al (2017) Beans (*Phaseolus* spp.) as a Model for Understanding Crop Evolution. *Front Plant Sci* 8:722. <https://doi.org/10.3389/fpls.2017.00722>
5. Chibeba AM, Pereira CS, Antunes JEL et al (2020) Polyphasic characterization of nitrogen-fixing and co-resident bacteria in nodules of *Phaseolus lunatus* inoculated with soils from Piauí State, Northeast Brazil. *Symbiosis* 80:279–292. <https://doi.org/10.1590/0034-737X202067050010>
6. Dohle S (2017) Development of resources for Lima bean (*Phaseolus lunatus*) breeding and genetics research. Doctoral dissertation, University of California, Davis
7. Freytag G, Debouck DG (2002) Taxonomy, distribution, and ecology of the genus *Phaseolus* (Leguminosae-Papilionoideae). North America, Mexico and Central America. *Sida, botanical miscellany* no. 23. Forth Worth. Botanical Research Institute of Texas (BRIT), TX, USA, p 298
8. García T, Duitama J et al (2021) Comprehensive genomic resources related to domestication and crop improvement traits in Lima bean. *Nat Commun*. <https://doi.org/10.1038/s41467-021-20921-1>
9. Chacón-Sánchez MI, Martínez-Castillo J (2017) Testing Domestication Scenarios of Lima Bean (*Phaseolus lunatus* L.) in Mesoamerica: Insights from Genome-Wide Genetic Markers. *Front Plant Sci* 8:1551–1551. <https://doi.org/10.3389/fpls.2017.01551>

10. Liu F, Hewezi T, Lebeis SL et al (2019) Soil indigenous microbiome and plant genotypes cooperatively modify soybean rhizosphere microbiome assembly. *BMC Microbiol* 19:201. <https://doi.org/10.1186/s12866-019-1572-x>
11. López-López A, Negrete-Yankelevich S, Rogel MA, Ormeño-Orrillo E, Martínez J, Martínez-Romero E (2013) Native bradyrhizobia from Los Tuxtlas in Mexico are symbionts of *Phaseolus lunatus* (Lima bean). *Syst Appl Microbiol* 36(1):33–38. <https://doi.org/10.1016/j.syapm.2012.10.006>
12. Martínez-Castillo J, Zizumbo-Villarreal D, Perales-Rivera H, Colunga-GarcíaMarín P (2004) Intraspecific diversity and morpho-phenological variation in *Phaseolus lunatus* L. from the Yucatan Peninsula. *Mexico Econ Bot* 58(3):354–380. [https://doi.org/10.1663/0013-0001\(2004\)058\[0354:IDAMVI\]2.0.CO;2](https://doi.org/10.1663/0013-0001(2004)058[0354:IDAMVI]2.0.CO;2)
13. Martínez-Castillo J, Zizumbo-Villarreal D, Gepts P, Delgado-Valerio P, Colunga-GarcíaMarín P (2006) Structure and Genetic Diversity of Wild Populations of Lima Bean (*Phaseolus lunatus* L.) from the Yucatan Peninsula, Mexico. *Crop Sci* 46:1071–1080. <https://doi.org/10.2135/cropsci2005.05-0081>
14. Martínez-Castillo J, Colunga-GarcíaMarín P, Zizumbo-Villarreal D (2008) Genetic erosion and in situ conservation of Lima bean (*Phaseolus lunatus* L.) landraces in its Mesoamerican diversity center. *Genet Resour Crop Evol* 55:1065–1077. <https://doi.org/10.1007/s10722-008-9314-1>
15. Martínez-Castillo J, Camacho-Pérez L, Coello-Coello J, Andueza-Noh R (2012) Wholesale replacement of Lima bean (*Phaseolus lunatus* L.) landraces over the last 30 years in northeastern Campeche, Mexico. *Genet Resour Crop Evol* 59:191–204. <https://doi.org/10.1007/s10722-011-9675-8>
16. Martínez-Castillo J, Camacho-Pérez L, Villanueva-Viramontes S, Andueza-Noh RH, Chacón Sánchez MI (2014) Genetic structure within the Mesoamerican gene pool of wild *Phaseolus lunatus* (Fabaceae) from Mexico as revealed by microsatellite markers: Implications for conservation and the domestication of the species. *Am J Bot* 101:851–864. <https://doi.org/10.3732/ajb.1300412>
17. Mendes R, Garbeva P, Raaijmakers JM (2013) The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. *FEMS Microbiol Rev* 37:634–663. <https://doi.org/10.1111/1574-6976.12028>
18. Motta-Aldana JR, Serrano-Serrano ML, Hernández-Torres J, Castillo-Villamizar G, Debouck DG (2010) Multiple origins of lima bean landraces in the Americas: evidence from chloroplast and nuclear DNA polymorphisms. *Crop Sci* 50:1773–1787. <https://doi.org/10.2135/cropsci2009.12.0706>
19. Ormeño-Orrillo E, Vinuesa P, Zúñiga-Dávila D, Martínez-Romero E (2006) Molecular diversity of native bradyrhizobia isolated from Lima bean (*Phaseolus lunatus* L.) in Peru. *Syst Appl Microbiol* 29(3):253–262. <https://doi.org/10.1016/j.syapm.2005.09.002>
20. Pérez-Jaramillo JE, de Hollander M, Ramírez CA et al (2019) Deciphering rhizosphere microbiome assembly of wild and modern common bean (*Phaseolus vulgaris*) in native and agricultural soils from Colombia. *Microbiome* 7:114. <https://doi.org/10.1186/s40168-019-0727-1>
21. Rocha SMB, Mendes LW, Oliveira LMS et al (2020) Nodule microbiome from cowpea and lima bean grown in composted tannery sludge-treated soil. *Appl Soil Ecol* 151:103542. <https://doi.org/10.1016/j.apsoil.2020.103542>
22. Rüger L, Feng K, Dumack K et al (2021) Assembly patterns of the rhizosphere microbiome along the longitudinal root axis of maize (*Zea mays* L.). *Front Microbiol* 12:614501. <https://doi.org/10.3389/fmicb.2021.614501>
23. Ruiz-Santiago RR, Ballina-Gómez HS, Ruiz-Sánchez E, Martínez-Castillo J, Garruña-Hernández R, Andueza-Noh RH (2021) Determining relevant traits for selecting landrace accessions of *Phaseolus lunatus* L. for insect resistance. <https://doi.org/10.7717/peerj.12088>. PeerJ
24. Rydhmer K, Bick E, Still L et al (2022) Automating insect monitoring using unsupervised near-infrared sensors. *Sci Rep* 12(1):1–11. <https://doi.org/10.1038/s41598-022-06439-6>
25. Serrano-Serrano ML, Hernández-Torres J, Castillo-Villamizar G, Debouck DG, Chacón Sánchez MI (2010) Gene pools in wild Lima bean (*Phaseolus lunatus* L.) from the Americas: Evidences for an Andean origin and past migrations. *Mol Phylogenet Evol* 54:76–87. <https://doi.org/10.1016/j.ympev.2009.08.028>
26. Serrano-Serrano ML, Andueza-Noh RH, Martínez-Castillo J, Debouck DG, Chacón-Sánchez MI (2012) Evolution and domestication of lima bean in Mexico: Evidence from ribosomal DNA. *Crop Sci* 52:1698–1712. <https://doi.org/10.2135/cropsci2011.12.0642>
27. Silva JL, Mendes LW, Rocha SMB et al (2022) Domestication of Lima Bean (*Phaseolus lunatus*) Changes the Microbial Communities in the Rhizosphere. *Microb Ecol*. <https://doi.org/10.1007/s00248-022-02028-2>
28. United States Department of Agriculture (USDA) (2018) Quick Stats 2.0. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington DC. Accessed June 22, 2022. <https://quickstats.nass.usda.gov/>
29. Zullo SS(2021) Developing a molecular linkage map for and understanding the biochemical mechanisms and underlying genetic architecture of biotic stress resistance in lima bean (*Phaseolus lunatus* L.). Doctoral dissertation, University of California, Davis

Figures



Figure 1

Seeds of Big Lima cultigroup (*Phaseolus lunatus* L.). Photo taken by E. Peralta.