Essay

Grain legumes in Mexico: improved varieties of bean and chickpea developed by INIFAP

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Abstract

Common bean, chickpea, broad bean, lentil and cowpea are among the best known and most consumed grain legumes in the world. In Mexico, bean *(Phaseolus* spp.) is the one with highest production and consumption. Of those five species, the National Institute of Forestry, Agricultural and Livestock Research has had a great participation in both the development of common bean varieties and large-grained white chickpea and small-grained brown chickpea. At the national level, some bean varieties have become a benchmark for their yield and quality of their grain, such as ‘Negro Jamapa’, ‘Mayocoba’, ‘Azufrado Higuera’, ‘Flor de Junio Marcela’ and ‘Pinto Saltillo’. In recent years, varieties of the types with the greatest demand are starting to be used, some developed using molecular markers in the selection process, as in the cases of ‘San Blas’ and ‘Rubí’, resistant to BCMV and BCMNV. In the case of chickpea, for two decades the variety ‘Blanco Sinaloa-92’ has been the dominant in the local and export markets, and new varieties of white grain are available for Sinaloa, Sonora and El Bajío. With the aim of publicizing INIFAP's contribution to the improvement of grain legumes in Mexico, this essay presents the organization of the INIFAP bean and chickpea improvement headquarters and the varieties they have developed and registered in the last 20 years.

Keywords: *Cicer arietinum*, *Phaseolus vulgaris*, genetic improvement, varieties.

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Legumes are leguminous that are cropped to obtain their dry grain. Common bean (*Phaseolus vulgaris* L.), chickpea (*Cicer arietinum* L.), broad bean (*Vicia faba* L.), lentil (*Lens culinaris* Medik.) and cowpea (*Vigna unguiculata* L. Walp.) are among the best known and most consumed legumes in the world (FAO, 2019). Legumes used as vegetables or for oil extraction are not included in this group.

In Mexico, legumes are important from an agricultural, food and nutritional perspective, so it is necessary to promote their production and consumption. Beans, broad beans, chickpeas and lentils are consumed in the country, and bean represents a particular case because different species and types are produced and consumed according to the preferences of each region.

The species of greatest economic and social importance, to which almost all the improvement efforts are directed, is *P. vulgaris* L. (common bean), it is estimated that this legume represents 36% of the daily intake of proteins of the Mexican population, although there are other species such as *P. coccineus* L. (Ayocote or patol bean), *P. lunatus* L. (lima bean), *P. acutifolius* A. Gray. (Tépari bean) and *P. dumosus* (gordo bean) whose consumption is restricted to some localities in Mexico.

According to official information, between 2015-2019, Mexico was self-sufficient in chickpea production, of which about 54% of the national harvest is exported, not so in the rest of the legumes, as in this period an average of 138 646 t of bean, 1 085 t of broad bean and 75 456 t of lentil were imported, and 46 554 t of bean, 26 803 t lentil and 466 t of broad bean were exported (FAOSTAT, 2020). Except for chickpea, legumes are mainly rainfed-produced where yields are limited by environmental stressors.

The main bean producing states are Zacatecas (33%), Sinaloa (12%), Durango (10%) and Chihuahua (8%), while chickpea is mainly produced in Sinaloa (42%), Sonora (23%), Jalisco (13%) and Michoacán (9%), broad bean for grain in Puebla (49%), Veracruz (36%) and Tlaxcala (9%), lentil in Michoacán (90%) Guanajuato (10%), and cowpea, mainly in Yucatan (93%) (SIAP, 2020).

In Mexico, there are currently registered in the National Catalogue of Plant Varieties (CNVV) 100 varieties of bean, 16 of chickpea, six of broad bean, and none of lentil or cowpea; of these, INIFAP has 80 varieties of beans and 14 of chickpea inscribed (SNICS, 2020a). Although INIFAP made efforts to improve lentils, no variety was recorded. The six varieties of broad bean registered with the CNVV were developed by the Institute of Agricultural, Aquaculture and Forestry Research and Training of the State of Mexico (ICAMEX) (SNICS, 2020a). In Mexico genetic improvement of cowpea and lentil is not carried out, planting is mainly done with Creole varieties.

Due to the agricultural, food and nutritional importance of legumes, in this essay is to describe the organization of INIFAP’s bean and chickpea improvement programs, and their contribution to the improvement of grain legumes through the development of bean and chickpea varieties for Mexico over the past 20 years.

Importance of legumes

Together, in the period 2015-2019, the cultivation of legumes in Mexico had a production value of almost 17 000 million pesos and occupied about 1.78 million hectares, the equivalent of just over 12% of the area destined for cyclic crops in the country. The largest area was occupied by cultivation of bean (90.7%), followed by chickpea (6.8%), broad bean (2%), lentil (0.5%) and cowpea (0.02%) (SIAP, 2020). In the same period, an annual average of 1.08 million tons of bean was produce; 250 032 t of chickpea; 34 426 t of broad bean grain; 6 754 t of lentil and 1 029 t of cowpea (SIAP, 2020).

Legumes, in addition to carbohydrates, have a high content in protein (15-30%) and essential amino acids such as lysine and leucine (Wolf-Hall *et al*., 2017), so they are a source of protein in regions where physical or economic access to meat and milk is limited, they are low in fat, rich in soluble fiber and in bioactive compounds.

Their consumption is associated with lower cancer mortality (Papandreou *et al*., 2019), they help reduce the risk of developing obesity and diabetes type 2 (Moreno-Valdespino *et al*., 2020), and provide benefits to cardiovascular health (Blekkenhorst *et al*., 2018). In addition, due to its iron content, bean consumption can help eradicate the anemia prevailing in marginalized areas of the country. For farmers, they are important crops, as they are easy to store after drying and can be sold or consumed at the family level, which contributes to maintaining the food security of their homes and generates economic stability.

Compared to cereals, legumes have lower scores on the nutritional carbon footprint, an indicator that reflects nutritional quality at the product level per unit of environmental impact (Chaudhary *et al*., 2018) and in symbiosis with soil microorganisms, they fix atmospheric nitrogen (N_2) incorporating it into the plant and soil. Their cultivation can help mitigate climate change by reducing dependence on synthetic fertilizers and on greenhouse gases, such as CO_2 produced during their manufacture and N_2O released into agricultural fields for using nitrogen fertilizer. It is estimated that the 241 million hectares (Mha) cultivated with legumes in the world set 28.4 Tg of nitrogen annually.

Background of genetic improvement of legumes in Mexico

Agricultural research in Mexico began in the 1930s with the creation of the Department of Experimental Fields (DCE) dependent on the General Bureau of Agriculture. In 1943, with the support of the Rockefeller Foundation, the Office of Special Studies (OEE) was created as a research unit of the Ministry of Agriculture and in 1947 the Institute of Agricultural Research (IIA) was created, whose purpose was to continue the work initiated by the DCE.

Until 1961, genetic improvement made by the OEE and IIA depended mainly on local varieties. With the demise of the OEE, in 1961 the National Institute of Agricultural Research (INIA) was created, today the National Institute of Forestry, Agricultural and Livestock Research (INIFAP). Since its inception, INIA began the collection and introduction of plant genetic resources intensively and in 1978, when the germplasm banks of different crops were transferred to it, the Genetic Resources Program of INIFAP was initiated, which in 1995 had 12 652 bean accessions (INIFAP, 1995).

Genetic improvement of chickpea began in 1961. Mexican varieties were developed from germplasm coming from the mediterranean and asian region. The Mediterranean white grain came from France, Spain and Italy, while the Asian were small brown bean materials from India and Afghanistan, and in Mexico these are destined for animal consumption. In the Northwest, the improvement focused on developing high yield varieties, large-sized grain suitable for export, and with resistance to root rots, which was obtained by crossing the forage chickpea with varieties of white chickpea. It is estimated that 95% of the national area for chickpea cultivation is sown with varieties generated in the country.

Currently, INIFAP has five regional headquarters where the genetic improvement of bean takes place and two headquarters where that of chickpea is carried out. These improvement locations are in different experimental fields (CE) and they develop varieties according to the problems and types of bean and chickpea produced in the region to which they belong. The genetic improvement of bean is carried out in the Experimental Fields Valle del Guadiana, Bajío, Valle de México, Valle del Fuerte and Cotaxtla, while that of chickpea in the CE Valle del Culiacán and Costa de Hermosillo.

Bean genetic improvement headquarters in INIFAP

Three macroregions, including 22 federal entities, account for 96% of bean production in Mexico: the semi-arid Plateau-Bajío-High Vallyes region and the Gulf and Pacific coastal regions. These share similar environmental parameters and production systems; however, they differ in socioeconomic importance, types of grain grown, volume of production and agronomic problems. For more than a decade, in INIFAP there has been no National Program for genetic bean improvement, this is carried out in five experimental fields according to the demand, problems and needs of each region.

The genetic improvement of bean in the CE Valle del Guadiana (CEVAG), located in Durango, focuses on generating varieties for the semi-arid plateau region, where bean of pinto type and bright black type are produced, and on a smaller scale flor de mayo, flor de junio, bayo and garbancillo; this region includes the states of Zacatecas, Durango, Chihuahua, San Luis Potosí and Northern Guanajuato. The varieties developed by this headquarters in the last 20 years, as well as their main characteristics are shown in Table 1.

Table 1. Bean varieties developed by CE Valle Guadiana between 2000 and 2021.

Variety	Year	Type	Cultivation	Attributes
NOD 1	2018	Opaque black	Irrigation	High yield potential
PID 1	2018	Pinto	Irrigation	High yield potential
Dorado	2012	Pinto	Rainfed	Slow darkening grain
Pinto Bravo	2010	Pinto	Rainfed	Slow darkening grain
Pinto Coloso	2010	Pinto	Rainfed	Slow darkening grain
Pinto Centenario	2010	Pinto	Rainfed	Slow darkening grain

Variety	Year	Type	Cultivation	Attributes
Pinto Libertad	2010	Pinto	Rainfed	Slow darkening grain
Pinto Centauro	2010	Pinto	Rainfed	Slow darkening Grain
Pinto Durango	2012	Pinto	Rainfed	Grain with functional properties
Negro Vizcaya	2004	Bright black	Rainfed	Rust
Flor de Mayo 2000	2001	Flor de Mayo	Rainfed	Drought tolerant

The semi-arid region of the plateau, despite limiting environmental conditions, is mainly a bean producer under rainfed conditions with surplus production that are channeled to other entities in the country. However, due to the negative effects of climate change, as precipitation reduces and temperature increases, lower bean productivity is expected in this region. Among the biotic problems, the diseases that stand out are rust (*Uromyces appendiculatus* var. appendiculatus), and anthracnose (*Colletotrichum lindemuthianum*), as well as root rots (*Fusarium* sp., *Rhizoctonia solani*, *Macrophomina phaseolina*). The most important pests are the bean pod weevil (*Apion godmani* and *A. aurichalceum*), Mexican bean beetle (*Epilachna varivestis*) and warehouse weevils (*Zabrotes subfasciatus* and *Acanthoscelides obtectus*).

The area of influence of the CE Bajío improvement headquarters (CEBAJ), located in Celaya, Gto., includes parts of the central plateau and the trans-Mexican volcanic belt. Adjoining regions characterized by a variety of agricultural niches including El Bajío, sub-humid and semi-arid Plateaus and High Valleys. This region comprises part of the states of Guanajuato, Querétaro, Michoacán and Jalisco, where bean as monoculture can be grown at two times during the year: under irrigation with sowings at the end of winter (January-May) and another of rainfed and half irrigation in the summer cycle (June-October).

The types of bean grown are flor de mayo, flor de junio, and bright black, and at a smaller scale the pinto type, opaque black and rosa de castilla types. In this subregion the main problems are intermittent drought and high temperatures, especially in spring plantings under irrigation. Among the biotic problems, rust, anthracnose, common bacterial blight (*Xanthomonas campestris* pv. *phaseoli*) and halo blight (*Pseudomonas syringae* pv. *phaseoli*), angular bean leaf spot (*Phaeoisariopsis griseola*) and root rots.

The most important pests, particularly in irrigated areas, are leafhoppers (*Empoasca kraemeri*), whitefly (*Trialeurodes vaporariorum*), thrips (*Thrips* sp., *Caliothrips phaseoli*, *Frankliniella occidentalis*) and diabrotica (*D. balteata*), white grubs (*Phyllophaga* spp.), bean pod weevil, Mexican bean beetle and warehouse weevils.

A characteristic of the bean varieties developed by CEBAJ (Table 2), which attracts special attention and has to do with adapting to the erratic conditions of the establishment of the rainy season and with the appropriate planting date, is the reaction of the plant to photoperiod. This reaction is controlled by the gen *Ppd Ppd*, of sensitive or short-day phenotype, while the allele *ppd ppd* gives the neutral reaction.

Table 2. Bean varieties developed by CE Bajío between 2000 and 2021.

Variety[a]	Year	Type	Cultivation[b]	Attributes[c]
San Blas	2018	Opaque black	T, HR, R	BCMV and BCMNV (genes *II* + *bc-3*), neutral
Salinas	2018	Pinto	T	Slow darkening, short-day grain
Granada	2013	Red	R T	BCMV and rust, short-day
Rarámuri	2012	Pinto	R T	Slow darkening, neutral grain
San Rafael	2012	Pinto	R T	Slow darkening, neutral grain
Dalia	2012	Flor de Junio	R T	BCMV and rust, short-day
Junio Leon	2012	Flor de Junio	R T	BCMV, high yield, short-day
FM Dolores	2010	Flor de Mayo	T	BCMV and rust, neutral to photoperiod
FM Eugenia	2010	Flor de Mayo	R and T	BCMV and rust, neutral to photoperiod
Ng Guanajuato	2008	Opaque black	R T	Rust resistant
FM Anita[d]	2003	Flor de Mayo	R and T	BCMV
Coranay[e]	2010	Opaque black	T HR R	For Nayarit coastal area
Costenay[e]	2010	Opaque black	T HR R	For Nayarit coastal area
Frijozac N-101[f]	2006	Opaque black	T	High yield potential

[a]Ng= negro; FM= Flor de mayo; [b]= cultivation conditions; T= rainfed, R; Irrigation; HR= residual moisture. [c]= BCMV= bean common mosaic virus; BCMNV= bean common mosaic necrosis virus; [d]= public domain; [e]= developed in CE Santiago Ixcuintla; [f]= developed in CE Zacatecas.

The CE Valle de México (CEVAMEX) improvement headquarters, located in Texcoco, State of Mexico, is the oldest of the country and its main area of influence includes the high valleys and sub-humid plateau of the states of Puebla, Hidalgo, Tlaxcala and the State of Mexico. Bean is mostly produced under rainfed conditions.

In this region the crop is affected by various diseases such as rust (*Uromyces appendiculatus* var. *phaseoli*), anthracnose, white leaf spot (*Pseudocercosporella albida*), and bacterial blight (López-Friaz, 1991), as well as by pests such as Mexican bean beetle, bean pod weevil and brown bean weevil (*Acanthoscelides obtectus*). Among the abiotic factors, low temperatures and intermittent drought stand out. The varieties developed by this headquarters in the last 20 years, as well as their main characteristics are shown in Table 3.

Table 3. Bean varieties developed by CE Valle de México between 2000 and 2021.

Variety	Year	Type	Cultivation[a]	Attributes
Luciomex	2020	Ejotero	R T	For High Valleys and sub-humid plateau
Xicuco-10	2020		T	For High Valleys and sub-humid plateau
Mayomex	2019	Flor de Mayo	T	For High Valleys and sub-humid plateau
Azufradomex	2019	Yellow (sulfur)	R T	Plant of determinate habit
Huitel-143	2019	Franciscano	Rainfed	For High Valleys and sub-humid plateau

Variety	Year	Type	Cultivation[a]	Attributes
Azufradoro	2014	Yellow (sulfur)	R T	Plant of determinate habit
Altiplanomex	2014	Opaque Black	T	For High Valleys and sub-humid plateau
Primavera 28	2011	Opaque Black	T	For High Valleys and sub-humid plateau
Albicampo	2010	Opaque Black	T	For High Valleys and sub-humid plateau
Bayo Azteca	2010	Bayito	T	Resistant to bean pod weevil
Pinto Saltillo	2004	Pinto	T	Drought-tolerant, slow darkening grain
Negro Otomí	2000	Bright Black	T	Tolerant of diseases

[a]= cultivation conditions; T= rainfed, R= irrigation; HR= residual moisture.

The headquarters of CE Valle del Fuerte (CEVAF), in Los Mochis, Sin., is responsible for the improvement in the Pacific coastal region, comprising the production areas of the west of the country Sinaloa, Sonora and Nayarit, where the types of bean mainly sown are large-sized yellow(sulphur)-peruvian (Sinaloa), pinto moteado (Sonora) and opaque black (in more than 50% of the area cultivated in Nayarit) and on small areas of southern Sinaloa.

In this region viral diseases stand out, mainly the bean golden yellow mosaic, caused by the bean golden yellow mosaic virus (BGYMV), the bean common mosaic caused by the bean common mosaic virus (BCMV) and the bean common mosaic necrosis virus (BCMNV) and black root (BCMNV), foliar diseases such as rust, common bacterial blight, white mold (*Sclerotinia sclerotorium*) and root rots, the insects with the highest incidence are the whitefly (*Bemisia tabaci*), which acts as a disease vector, doradillas (*Diabrotica* spp.) and leafhopper, which cause severe damage in the early stages of plant development. Terminal drought in areas of residual humidity and high temperatures are among the abiotic factors.

Historically, this headquarters has developed varieties of light-colored, pinto and black, two of them, Azufrado Pimono-78 (Mayocoba) and Azufrado Higuera developed in 1978 and 1995, respectively, still have a big impact on the bean surface planted in Mexico, particularly Azufrado Higuera. Azufrado Pimono-78 (Mayocoba) was the first variety of large Peruvian-type grain while Azufrado Higuera became practically a new class of bean with very high acceptance by marketers.

In the last 20 years, in this headquarters were developed the varieties ‘Azufrasin’, ‘Janasa’ and ‘Aluyori’, the first two of yellow (sulphur) type and the last of large kidney type, all of them for irrigation conditions, with resistance to rust and tolerance of BGYMV. In CE Cotaxtla (CECOT), located in Medellin de Bravo, Veracruz, in collaboration with CE Centro Chiapas, black grain varieties of high yield potential, wide adaptation, resistance or tolerance of diseases and periods of terminal drought are developed, its area of influence extends to the southeast of the country, to the states of Chiapas, Quintana Roo, Yucatán, Campeche, Tabasco, Veracruz and the tropical are of San Luis Potosí and southern Tamaulipas (Table 4). It is mainly grown opaque black bean.

Table 4. Bean varieties developed by CE Cotaxtla between 2000 and 2021.

Variety[a]	Year	Type	Cultivation[b]	Attributes[c]
Rubí	2019	Small Opaque black	T, HR, R	BGYMV and BCMV (genes *II* + *bc-3*), precocious
Verdín	2014	Opaque black	T, HR, R	BGYMV, BCMV (genes *II* and *bgm-1*), precocious, terminal drought resistant
Sangre Maya	2013	Red	T, HR, R	BGYMV, BCMV (genes *II* y *bgm-1*),
Frailescano	2013	Semi bright Black	T, HR, R	BGYMV, BCMV (genes *II* y *bgm-1*),
Ng Tacaná	2012	Opaque black	T, R, HR	BGYMV, BCMV (genes *II* y *bgm-1*)
Ng Comapa	2010	Opaque black	T, HR	Angular spot, rust; high yield and wide adaptation
Rojo INIFAP	2008	Red		Rust, BGYMV
Ng. Papaloapan	2006	Small Opaque Black	T, HR, R	Rust, angular spot; tolerance of acid soils
Ng Grijalva	2003	Opaque Black	T, HR, R	BGYMV; precocious, erect plant, tolerance of acid soils
Ng Tropical	2002	Opaque Black	T, HR, R	Rust, BGYMV, BCMV
Ng Medellín	2001	Opaque Black	T, HR, R	Angular spot; wide adaptation

[a]Ng= negro; [b]= cultivation conditions; T= rainfed; R= irrigated; HR= residual moisture; [c]=BCMV= bean common mosaic virus; BCMNV= bean common mosaic necrosis virus; BGYMV= bean golden yellow mosaic virus. There is resistance in the case of BCMV and BCMNV, and tolerance in the case of BGYMV.

Landraces varieties of *P. coccineus* and *P. dumosus* are also sown in the highlands of Chiapas, and *P. acutifolius* in the Soconusco. In this region, diseases such as the bean golden yellow mosaic, the common mosaic, rust, angular spot, anthracnose and root rots (López-Salinas *et al*., 2006), pests such as the whitefly, doradillas and leafhopper, a mollusk known as 'babosa', which causes severe damage in the early stages of development, stand out. Among the abiotic factors, the main problems are terminal drought in the residual moisture plantings (López-Salinas *et al*., 2008) and low fertility acid soils (Zetina-Lezama *et al*., 2002).

Methods of genetic bean improvement

The most used improvement method in the bean improvement program is pedigree, with some modifications. Backcrossing and mass method are sometimes used. Improvement begins with the cross of progenitors with complementary traits of interest. To accelerate the process, progenitors with similar grain characteristics, but complementary in relation to the resistance genes they possess, are used. On the other hand, traditional genetic improvement activities in the field and greenhouse include identification of progenitors, complementary crosses, selection and evaluation under a combined genealogical-mass scheme (Fehr, 1987).

One advantage, in the case of the CEBAJ headquarters, is that two growing cycles per year can be established, allowing a quick progress in the process of selection and development of lines. The initial process of generation advancement and selection takes place in two consecutive plantings within the spring-summer cycle, one under irrigation conditions established in February, and the other under rainfed conditions established in July. Subsequently, preliminary yield tests are carried out in advanced generations and the outstanding lines are incorporated into tests that are established in different locations in the region.

Assisted bean selection by molecular markers

For a decade, CEBAJ has had molecular marker laboratories. In this, the protocols for performing disease-assisted selection, mainly anthracnose, common mosaic and black root (BCMV and BCMNV), selection of the slow darkening phenotype of the testa are set out and molecular tools to detect the main viruses that infect bean in Mexico are developed (Chiquito-Almanza *et al*., 2017).

The molecular marker laboratory provides services to breeding locations that require it. Besides, insulation is routinely performed for the identification of anthracnose breeds and their multiplication to be used in artificial inoculations under controlled conditions. In the case of anthracnose, the resistance gene that has been used the most in the program is $Co4^2$, while for common mosaic and black root are *II* and *bc-3*, and inoculations are performed with the BCMNV NL3 strain under controlled conditions.

The process for selecting Pinto-type materials with slow darkening of the grain testa consists of the use of MM associated with the gen *sd sd* linked to slow grain darkening (Felicetti *et al*., 2012) and exposure of grain to ultraviolet light for 72 h (Junk-Knievel *et al*., 2007). The variety Pinto Saltillo has been the source of slow darkening.

In recent years work has been done to incorporate the gen *sd sd* of pinto materials into the Flor de Mayo and Flor de Junio types, but neither the marker nor the selection process based on exposure to ultraviolet light has worked. Thus, the selection is based on color preservation after nine months of storage under natural conditions. So far, the use of molecular tools has focused on electrophoresis-based selection systems in agarosa gels and molecular markers (MM) type SCAR (sequence characterized amplified region) and CAPS (cleaved amplified polymorphic sequences).

These are used in the final phase of evaluation of outstanding lines, for which the presence of MM in a group of 300 individual plants of each line is confirmed, and the seed of 200 uniform progenies is multiplied according to the presence of MM to obtain the original seed. This has reduced the costs associated with using MM and accurately selecting lines of interest.

Improved bean varieties registered and released by INIFAP

There are currently 100 varieties of bean registered in the CNVV, 80 of which were developed and registered by INIFAP. It is important to highlight that improvement efforts have focused on the development of shrub varieties for monoculture systems.

Because in Mexico producers do not acquire seed on a regular basis, but instead use grain for their plantings, it is difficult to know which varieties are being grown. In this sense, qualified seed production data provide an overview of the main varieties in use. According to SNICS, during the agricultural years 2018 to 2020, bean seed of the yellow (sulfur) types (‘Azufrado Higuera’, ‘Azufrado Regional 87’, ‘Azufrado Noroeste, ‘Janasa’ and ‘Reyna’), pinto (‘Pinto Saltillo’, ‘Pinto Libertad’), opaque black (‘Negro Jamapa’, ‘Negro Comapa’, ‘Verdin’, ‘San Blas’, ‘Negro Chapingo’, ‘Frijozac N-101’), bright black (‘Negro Brillante’, ‘Bruján’), Flor de Junio (‘Flor de Junio Marcela’, ‘Dalia’, ‘Junio León’), white (‘Aluyori’) and peanut (‘Red Scratch’) (SNICS, 2020b). Except for the varieties ‘Reyna’, ‘Negro Chapingo’, ‘Negro Brillante’, ‘Bruján’ and ‘Rayado Rojo’, they were developed by INIFAP. Nationally, the varieties that are being multiplying in higher volumes are ‘Pinto Saltillo’ and ‘Azufrado Higuera’.

Headquarters and methods of genetic improvement of chickpea in INIFAP

There are two chickpea breeding headquarters, one in CE Valle del Culiacán, in Culiacán, Sinaloa, and another in CE Costa de Hermosillo in Hermosillo, Sonora, that work closely with the CE Bajío headquarters. Among the main abiotic factors that affect chickpea are terminal drought when only a pre-plant irrigation is used or established with residual moisture and extreme temperatures, heat stress or frosts that affect November plantings in the autumn-winter cycle and that in extreme case cause the death of the plant.

The most important biotic factors are the high incidence of soil fungi, being the main *Fusarium oxysporum* and at lower frequency *F. solani*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Macrophomina phaseolina* and *Pythium* sp., which reduce the yield by up to 80%, under conditions of high environmental humidity there is incidence of foliar diseases, in the South of Sonora and Sinaloa these are downy mildew (*Peronospora ciceris*), gray mold (*Botrytis cinerea*) (Fierro-Corrales *et al*., 2015), Alternaria blight (*Alternaria alternata*) and occasionally rust (*Uromyces ciceris-arietini*), white mold (*Sclerotinia sclerotiorum*) and blight (Ramírez-Arredondo *et al*., 2017).

Among the most common pests, the armyworm (*Spodoptera exigua*) and fruit worm (*Heliothis* sp.) stand out, whose incidence is favored with high relative humidity and cause reduction in the yield and quality of the grain (Padilla-Valenzuela *et al*., 2008).

In the genetic improvement of chickpea, the genealogical method with alternate mass and individual selection is mainly used, also the use of plots infested with the pathogens that cause root rots. The superior lines are included in preliminary performance trials in the host fields and the top lines form a national trial.

Improved chickpea varieties registered and released by INIFAP

In the last 25 years the institute has registered and made available to producers 14 improved varieties (Table 5), among them ‘Blanco Sinaloa-92’ occupies more than 90% of the area cultivated with chickpea. A few years ago, two cultivars of large white-cream grain were registered, ‘Blanoro’ and ‘Jumbo 2010’ with resistance to root rots (*Fusarium* spp.), which cover the quality requirements of the export market, and two varieties of small colored grain, El Patrón and Penjamo.

Table 5. Improved chickpea varieties developed by INIFAP.

Variety	Year	Grain	Plant	Resistance/characteristic[b]
Blanco Sinaloa-92	1992	Creamy white	Semi-erect	PR, wide adaptation
Costa 2004[a]	2004	Creamy white	Erect	PR, late
Lerma	2001	Light coffee	open	PR
San Antonio 05	2005	Dark coffee	open	PR
Tequi Blanco-98	1999	Creamy white	Semi-erect	PR
Jumbo 2010[a]	2010	Creamy white	Semi-erect	PR, wide adaptation
Blanoro	2011	Creamy white	Semi-erect	PR
El Patrón[a]	2015	Light coffee	Semi-erect	PR, wide adaptation
Pénjamo[a]	2015	Light coffee	Erect	PR
Mazocahui[a]	2017	Creamy white	Semi-erect	PR, wide adaptation
Blancoson	2017	Creamy white	Semi-erect	PR
Nubia	2018	Creamy white	Semi-open	PR
Sinalomex-2018[a]	2018	Creamy white	Semi-erect	PR
Combo-743[a]	2018	Creamy white	Semi-erect	PR, wide adaptation

[a]= apt for direct harvest; [b]= PR= root rots.

Recently, five new varieties of large white grain were registered: Sinalomex, Combo 743, Blancoson, Mazocahui and Nubia, the first two in Sinaloa, the following in Sonora and the last in Guanajuato. According to SNICS during the agricultural years 2018 to 2020, qualified chickpea seed of the varieties 'Blanco Sinaloa-92', 'BlancoSon', 'Jumbo 2010', 'Lerma', 'Mazocahui', 'SG Criollo' and 'SG Porquero' were produced (SNICS, 2020b). Of these, the variety that is multiplying in higher volume is 'Blanco Sinaloa-92', and except for 'SG Criollo' and 'SG Porquero', all varieties were developed by INIFAP.

Conclusions

INIFAP is the institution in Mexico with the greatest impact and contribution to the production of grain legumes through the development of bean and chickpea varieties for the different regions and types of demand in the domestic market; some varieties of beans such as 'Negro Jamapa', 'Mayocoba', 'Azufrado Higuera', 'Flor de Junio Marcela' and 'Pinto Saltillo' and the chickpea variety 'Blanco Sinaloa-92' are a benchmark for the national and international market.

Except for 'Pinto Saltillo', all of these were developed more than 20 years ago. Other recently developed varieties of the most demanded types are starting to be used, as in the case of the bean varieties 'Janasa', 'Pinto Libertad', 'Negro Comapa', 'Verdin', 'San Blas', 'Frijozac N-101', 'Dalia', 'Aluyori', and the chickpea varieties 'BlancoSon', 'Jumbo 2010', 'Lerma' and 'Mazocahui'. The inclusion of molecular markers and other molecular tools in the bean improvement program has helped increase accuracy and reduce time for the development of new varieties.

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