Essay

Genetic improvement of barley at INIFAP (1985-2020)

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Abstract

The genetic improvement of barley in Mexico began in 1954 in cooperation with the National Malt Industry, the Ministry of Agriculture and Livestock and the Rockefeller Foundation. In 1959, the first improved variety obtained by INIA's barley program, Toluca I, was increased. Since its inception, INIFAP's barley program has set out the objective of obtaining varieties that, given their quality and yield, satisfy the needs of both the farmer and the malting and brewing industrialists. For this reason, improvement research has focused on increasing yield, precocity and quality, as well as resistance to the most common diseases of the crop. Between 1959 and to date, the National Barley Program has released 22 varieties of barley (17 malting and 5 forage). With the creation of INIFAP in 1985, the program continued with research and the obtaining of genotypes suitable for malting and brewing. In these 35 years, great achievements in the release of varieties have been obtained, being Esperanza and Emerald the most important that, given their resistance to yellow stripe rust, allowed the production of barley for brewing under both irrigated and rainfed conditions; achieving national self-sufficiency in 2000. With these varieties, more than six million hectares were sown in Mexico, more than 300 000 ha per year and more than 50 000 families in the country were benefited.

Keywords: genetic improvement, quality, varieties.

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The development of malting barley in the country began with the establishment of the first malt factory in Mexico City in 1906. Barley is the raw material for brewing. With the establishment of the Office of Special Studies (OEE) in 1943, at the Experimental Field 'El Horno', today the Experimental Field Valley of Mexico', work on barley improvement began during 1946; however, the barley produced did not meet the quality requirements demanded by the brewing consortia.

For this reason, in 1954 the genetic improvement of malt barley began in Mexico in cooperation with the Nacional Malt Industry, the Ministry of Agriculture and Livestock (SAG) and the Rockefeller Foundation. The first research results were obtained in 1959 with the first improved variety obtained by the barley program of the National Institute of Agricultural Research (INIA), called Toluca I (Zamora *et al*., 2012).

Between the 50's and the 70's, the main problems with diseases consisted of leaf rust, stem rust, covered and loose smuts and foliar diseases that affected the malting quality of barley, being essential that the varieties generated had malting quality, good yield and tolerance of these diseases (Riojas, 1973). Since its inception, the barley program of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) has set out the objective of obtaining varieties that, for their quality and yield, meet the needs of both the farmer and malting and brewing industrialists, for both irrigated conditions in El Bajío and for rainfed conditions in the High Valleys of Central Mexico.

To date, the barley program has released 22 varieties of barley (17 malting and 5 forage), in three generating fields: CE Valle de México (CEVAMEX), for rainfed areas, CE Bajío (CEBAJ), for irrigated areas and CE Valle del Yaqui (CEVY, now Experimental Field Norman E. Borlaug CENEB), at the latter, research work for irrigated areas allowed to obtain five varieties, of which Rumorosa and Cucapah 87 stand out, forage varieties for the Northwest of the country in addition to the varieties Centinela and Cerro Prieto that, together with Puebla (obtained at CEBAJ), were of vital importance for irrigated and rainfed production systems in Mexico, as well as for the malt industry, allowing self-sufficiency of barley in the country during the 1980s (Navarro, 1983; Zamora *et al*., 2012). Currently, only at the experimental fields of CEVAMEX and CEBAJ genetic improvement is carried out, with CEVAMEX continuing as the headquarters of the program.

Due to the presence of the disease called yellow stripe rust (YSR) caused by *Puccinia striiformis* f. sp, *hordei* Eriks, research work intensified, since in 1988 this disease caused losses of up to 50% of the yields of all Mexican improved barley varieties, that were sown in the rainy season in the country's Central High Valleys. Smaller losses were determined in the plantings of El Bajío under irrigated conditions.

To control this disease, in 1989 the variety Esperanza for irrigated plantings in El Bajío and in 1992, the Esmeralda variety for rainfed conditions in the Central High Valleys were released (González *et al*., 2006). Currently the varieties released by the barley program are tolerant of the main diseases of both cultivation conditions in Mexico, with excellent yield and with the quality required by the malting-brewing industry.

The research strategies applied by INIA between 1960 and 1980, in coordination with the malting-brewing industry, were decisive in generating varieties with high yield and good malt quality, allowing to increase the area cultivated with barley and diversify agriculture in several regions of the country. Obtaining better harvests made it possible to significantly reduce imports; for this, the participation of Impulsora Agrícola, SA (IASA), was fundamental. IASA was created in 1958 by the brewing industries of the time (Cuauhtémoc, Moctezuma and Modelo) with the task of achieving the self-sufficiency of the country in malting barley production and increasing the standard of living of barley producers. Its activities were of vital importance, as it played an important role in the production chain, promoted the diffusion of the crop, as well as serving as a link between brewing industrialists and INIA, today INIFAP, and at the same time becoming an important means for technological change in barley cultivation (IASA, 1983; Aguilar and Schwentesius, 2004).

INIFAP: 35 years of research in barley cultivation

In August 1985, INIFAP was created with the merger of INIA, INIP and INIF. In this new stage, the barley program continued with its objective of carrying out genetic improvement to develop and generate varieties with yield, quality and tolerance of diseases, that the malting-brewing industry required. Since its formation, INIFAP's National Barley Program has participated in the development of most of the varieties released in Mexico, for both irrigated and rainfed conditions.

Currently, diseases are the main limitation of barley cultivation, causing yield decline up to 100%. Yellow stripe rust, first reported in Mexico in 1987, is considered the most serious problem. During the period from 1960 to 1980, the increase in grain yield was vital in the growth of the country's barley production. However, at the end of the 80s these achievements faded due to the presence of YSR.

To solve this epiphytia, the experience derived from crop management and from the genetic improvement process, coupled with the constant assessment of malting quality and tolerance of diseases, were decisive factors in obtaining varieties tolerant of YSR, in a timely manner. The Esperanza variety released in 1989 was the first malting variety in Mexico of semi-dwarf characteristic, with grain yield potential greater than 8 t ha^{-1} under irrigated conditions in El Bajío. For rainfed conditions in the High Valleys of Mexico the Esmeralda variety was released in 1992, it is the first malting variety with tolerance of YSR (Zamora *et al*., 2015).

With the development of these varieties, it was possible to save the production of malting barley under the two production conditions: irrigated and rainfed, achieving national self-sufficiency in 2000, generating significant benefits for producers and industrialists. With these varieties more than 6 million hectares in Mexico were sown, more than 300 000 ha per year and more than 50 000 families (UPR) benefited in the country. The environmental benefits, although not quantifiable, are enormous, as the good resistance of these varieties to YSR prevented the application of fungicides in both production conditions (González *et al*., 2006).

At the beginning of this century, the research work developed by the National Barley Program allowed the obtaining of the varieties Adabella in 2004, Armida in 2005 and Alina in 2006 (Zamora *et al*., 2015). The first recommended for rainfed conditions, while the other two, recommended for

irrigated conditions in El Bajío. These varieties have better characteristics, good industrial quality and a yield higher than that of their predecessors. In 2016 the Maravilla variaty, barley with forage attributes, was commercially released (Zamora *et al*., 2017).

In Mexico, advances in malting quality have been continuous since the beginning of research on this crop. In six-row materials the extract has been increased annually by 0.07%, while the protein content has been reduced by 0.04% per year. According to Schwarz and Horsley (1995) in the course of 1910 to 1990, malting barley genetic improvement programs in the United States of America increased the extract by 0.06% and reduced protein content by 0.01% annually.

The barley quality laboratory interacts closely with the genetic improvement area of the National Barley Program, evaluating the quality of the segregating lines (F_4-F_7) up to advanced generations (> F_7) obtained during the selection process. In segregating generations, quality aspects related to protein content and grain size are evaluated; while in advanced generations, inherent grain characteristics are analyzed for the malting process and malt quality, based on the parameters set out in the Mexican Standard NMX-FF-043-SCFI-2003 (barley quality) and by the National Malt Industry (malt quality) (Zamora *et al*., 2017).

The strength of the barley genetic improvement program is that the research carried out responds to the demand of the malting-brewing industrialists, who through agreements financed the research that allowed the release of malting varieties. INIFAP-funded projects have contributed to the diversification of this important cereal in other sectors of the country's agri-food chain. In these 35 years of genetic improvement, conventional methodologies (pedigree or genealogical improvement method) have been maintained and other strategies have been incorporated (combinations between improvement methods: Pedigree, massive, individual; additionally, *on-site* and *ex situ* tests for tolerance of diseases, among others) that allow optimizing resources to obtain genotypes with characteristics appropriate to the different systems and sectors of production in the country.

Priority barley research activities are related to yield and quality. To do this, genotype-environment interaction is evaluated, losses caused by rusts and foliar diseases are determined, their identification, distribution and analysis of rust resistance, pest resistance, efficient use of water. Besides, industrial quality analyses are performed, allowing the selection of genotypes with the required quality.

Genetic improvement work, carried out alternately at the experimental fields Valle de México and Bajío, allow to shorten in half the time of selection and obtaining advanced lines, which are evaluated in contrasting environments. The evaluation involves strategic areas of different barley-producing regions under rainfed conditions of the states Hidalgo, Tlaxcala, Puebla, State of Mexico, Guanajuato, Sonora, Durango, Coahuila, Aguascalientes, Tamaulipas, Chihuahua, Jalisco, Zacatecas and Oaxaca, where genotypes with yield potential, tolerant of diseases and stable in most environments are selected (Zamora *et al*., 2015; González *et al*., 2016).

In the national barley program during these two stages (INIA and INIFAP), through the research work carried out by means of the tripartite agreement Breewing Industry-IASA-INIFAP, researchers from at least 16 experimental fields and sites, distributed in six regions across the country, have collaborated, whose participation has been of vital importance in the different projects addressed by the program: genetic improvement, quality laboratory, integrated disease management, agrosystem productivity, integrated weed management, integrated pest management, use and management of water and technology transfer (Zamora *et al*., 2009).

Short-term, medium- and long-term challenges

Since its inception, INIFAP's barley program has generated varieties suitable for the malting-brewing industry. Currently, demand for this sector requires two-row varieties, with yield potential, quality (low protein and β-glucans content and high starch content) and tolerant of diseases, while, in other sectors, such as livestock, research focuses on the generation of six-rowed, awnless genotypes with forage potential (quality and yield, among other variables of interest).

Recent environmental variations make it necessary to obtain new cultivars with malting quality adapted to a wide range of biotic and abiotic stress conditions (Zamora *et al*., 2015). Diseases in barley cultivation are the main limitation and affect the quality and yield of the grain so the resistance of varieties to diseases is indispensable. INIFAP is a pioneer and benchmark in the generation of barley varieties for the brewing industry, the experience gained in this sector facilitates the application of research knowledge in other areas allowing the Institute to continue at the forefront in the generation of barley varieties for the benefit of Mexican producers.

Conclusions

INIFAP's national barley program has released 17 varieties of malting barley and five varieties of forage barley. The most important varieties are Esperanza and Esmeralda that, because of their resistance to yellow stripe rust, allowed the production of barley for brewing under both irrigated and rainfed conditions, achieving national self-sufficiency in 2000. Agronomic research in the main producing areas of this cereal focuses on solving the problem of dates and densities of planting, fertilization, weed and pest control and use and management of water, the results have significantly contributed to increase the yield and industrial quality of the grain.

Cited literature

Aguilar, A. J. y Schwentesius, R. R. 2004. La producción de la cebada maltera en México: ventaja comparativa no capitalizada. Reporte de Investigación 72. Primera (Ed.). Centro de Investigaciones Económicas, Sociales y Tecnológicas de la Agroindustria y la Agricultura Mundial (CIESTAAM). Universidad Autónoma Chapingo. Estado de México. 62 p.

González, E. A.; Zamora, D. M.; Márquez, C. L. A.; Ramírez, P. F.; Ibañez, A. M.; Islas, G. J. y Wood, S. 2006. Impacto económico del mejoramiento genético de la cebada en México: variedad Esmeralda. Serie: estudios de evaluación del impacto económico de productos del INIFAP. Publicación técnica núm. 19. 69 p.

González, G. M.; Zamora, D. M. y Solano, H. S. 2016. Evaluación agronómica y física en líneas avanzadas de cebada maltera. Rev. Mex. Cienc. Agríc. 7(1):159-171.

IASA. 1983. Impulsora Agrícola S. A. El cultivo del a cebada maltera de temporal. Impulsora Agrícola, SA. México, DF. Folleto informativo. 68 p.

Navarro, F. M. 1983. Logros y aportaciones de la investigación agrícola en el cultivo de la cebada. Publicación especial Núm. 107. SARH, INIA. México, DF. 5-16 pp.

Riojas, G. E. 1973. Variedades mexicanas de cebada. INIA, SAG. México. Folleto de divulgación núm. 49. 20 p.

Schwarz, P. B. and Horsley, D. 1995. Malt quality improvement in North American six-rowed barley cultivars since 1910. J. Am. Soc. Brewing Chem. 53(1):14-18.

Zamora, D. M. R.; Pérez, R. J. A.; Huerta, Z. R.; López, C. M. L.; Gómez, M. R. y Rojas, M. I. 2017. Maravilla: variedad de cebada forrajera para Valles Altos de México. Rev. Mex. Cienc. Agríc. 8(6):1449-1454.

Zamora, D. M.; Solano, H. S.; Huerta, Z. R. 2009. L a cebada maltera (*Hordeum vulgare* L.) cereal fundamental en la historia del Campo Experimental Valle de México. *In*: Reseña histórica 66 años de investigación al servicio de México 1943-2009. Publicación especial núm. 1. 45-49 pp.

Zamora, D. M.; Solano, H. S.; Huerta, Z. R.; González, G. M. y López, C. M. L. 2012. Programa Nacional de Cebada del INIFAP: cinco décadas de investigación aplicada. *In*: Día de Campo CEVAMEX 2012. Memoria técnica núm. 13. 137-140 pp.

Zamora, D. M.; Solano, H. S.; Pérez, R. J. A.; López, C. M. L.; Gómez, M. R.; Rojas, M. I. y Huerta, Z. R. 2015. Avances y perspectivas del cultivo de cebada en México. *In*: contribuciones científicas y tecnológicas del Campo Experimental Valle de México a 30 años de la creación del INIFAP y retos ante el cambio climático. Memoria técnica núm. 2. 116-127 pp.