Essay

Genetic improvement in wheat carried out by INIFAP from 1985 to 2020

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Abstract

In Mexico, Genetic improvement made in wheat began in 1944, at the now-called Experimental Field Valle de México, under the command of Dr. Norman E. Borlaug. His research originated the first varieties in 1948, which in the 1950s showed resistance to stem rust and in 1960s reduced plant size and generated varieties that, when sown in Africa, India and Pakistan, launched the 'Green Revolution', impacts that awarded Dr. Borlaug with the Nobel Peace Prize. In 1974 three cross breeding and selection programs were differentiated: Northwest, Bajío and the rainfed, the International Maize and Wheat Improvement Center has greater action in the Northwest but supports Bajío and the rainfed. With the creation of the National Institute of Forestry, Agricultural and Livestock Research, they continued their mission to release varieties. Work with andro-sterility began in 1993 and in 2000 a dominant andro-sterile mutant (Oly) was obtained, which has allowed population improvement. Until 2020, 76 years have passed, and 154 generations of recombination have been obtained, ranking the national program among the most dynamic in the world, with the contribution of more than 250 varieties: 140 released by INIFAP, which have been the basis of domestic production, with Cirno C2008 standing out, sown in more than 1.5 million hectares, which generates additional revenue of $6 700 million. The short-term challenges are to increase the production of grain under irrigation conditions and strengthen research for disease control, greater efficiency in water use, drought and heat tolerance and a better quality in grain; in the medium term, control of rusts and increase planting under reduced irrigation; in the long term, increase the rainfed-sown area, reduce losses due to foliar diseases, droughts and heat and release varieties with better nutritional quality.

Keywords: *Triticum aestivum* L., achievements in genetic improvement, future requirements.

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Globally, wheat (*Triticum* spp.) is the most important cereal after maize, its production is mainly for human consumption (FAO, 2020). In Mexico, during 2018 it stood out as the third most important cereal in terms of sown area (541 789 ha) (SIAP, 2019). By 2050, demand for wheat is expected to increase by 70% due to population growth and changes in eating habits.

In 1943 the Office of Special Studies (OEE) was established in Mexico and American scientists came to collaborate at the Experimental Field El Horno, now Experimental Field Valle de México (CEVAMEX). In 1944 the first crosses were made, and the continuous improvement of wheat began, which to date are carried out by INIFAP and CIMMYT, performed two agricultural cycles per year and in 2020 turns 76 years (154 recombination and selection cycles), ranking among the most dynamic in the world. Contributions up to 1985 are listed below. The selection in winter and summer (Borlaug, 1969), allowed to fix the genes *Ppd1* and *Ppd2* insensitive to photoperiod (Rajaram, 1995).

Stem rust caused by *Puccinia graminis* f. sp. *tritici* was genetically controlled in 1955, with the *Sr2* complex (Borlaug, 1969). The genes *Rht1* and *Rht2* were incorporated for lower plant height (Rajaram, 1995) and in the 1960s, 15 dwarf and semi-dwarf varieties were released, which yielded up to 8 t ha^{-1} (Borlaug, 1969) some of these, when planted in Africa, India and Pakistan, launched the 'Green Revolution', impacts that awarded Dr. Borlaug with the Nobel Peace Prize and in 2014, Dr. Sanjava Rajaram Devi with the World Food Prize. In 1960 the laboratory of industrial wheat quality was installed in CAEVAMEX and an own classification was generated for flour varieties: soft gluten (S), medium (M), strong (F) and tenacious (T) (Villaseñor *et al*., 2009). In the early 1970s improvement was made in: 1) INIA-CIANO and CIMMYT, in irrigation varieties for the northwest, north and northeast; 2) INIA-CIAB, in irrigation varieties for El Bajío; and 3) INIA-CIAMEC, in rainfed varieties (Villaseñor *et al.*, 2009).

In the 1970s and 1980s recombination with winter wheats and species compatible with *Triticum* was performed, which incorporated the translocation *1BL/1RS*, which brought genes such as *Lr26*, *Sr31*, *Yr9* and *Pm8* (Villareal, 1995), other important genes were also incorporated, as the *Lr13* complex (Rajaram *et al*., 1988), *Lr34* and *Lr46* (Huerta and Singh, 2000), all of these have allowed Mexican varieties to be highly productive (Paquini-Rodríguez *et al*., 2016) of wide adaptability, resistant to diseases (Huerta-Espino *et al*., 2020) and of good industrial quality.

Creation of INIFAP and 35 years of research

In 1985 the National Institute of Agricultural Research (INIA) was restructured, and it gave rise to INIFAP and 28 researchers collaborated in the genetic improvement of wheat. To date, the three programs have been maintained, in the Experimental Fields Valle del Yaqui (CEVY now CENEB), Bajío (CEBAJ) and Valle de México (CEVAMEX), each one with the missions indicated in the 1970s and with close collaboration with CIMMYT. The strength achieved in genetic improvement in wheat is due to two reasons: 1) the principles of strategies implemented between the 1960's and 1980's have been maintained, about how to do it, such as rotating segregants in contrasting environments, meeting two selection cycles a year, recombining elite germplasm, continuously incorporating variability, using more practical selection methodologies, among others; and 2) give greater importance to the evaluation of experimental lines in various years and environments.

The generation of lines has been carried out by CIMMYT, INIFAP-CEVAMEX and INIFAP-CEBAJ, and their evaluation by INIFAP; through the formation of national and regional trials evaluated annually in up to 35 different environments. It has also been important since the 1990s, the support obtained through the national projects financed by INIFAP, CIMMYT, CONACYT, COFUPRO, SAGARPA-CONACYT, BIMBO, Mondelez and MASAGRO, which have allowed the continuity of improvement to release new varieties (Villaseñor, 2015). In 35 years of plant breeding, conventional methodologies have been maintained, from 1993 work was initiated to use male sterility to facilitate recurrent selection (MSFRS) (Villaseñor *et al*., 2002; Villaseñor *et al*., 2015) and in recent years molecular tools have been used for pre-improvement or for the generation of uniform lines (Juliana *et al*., 2020).

The lines of research to feed back genetic improvement are: 1) losses caused by rusts; 2) identification and distribution of the main physiological breeds of fungi that cause rusts; 3) rusts resistance analysis; 4) gene application and genetic resistance studies; (5) recombination of resistance genes (*Lr67*) and of dwarfing (*Rht*-D1); 6) introgression of the genes *Yr5a* and *Yr15*; 7) analysis of genotype-environment interaction; 8) study of industrial quality; 9) obtaining a dominant andro-sterile mutant and incorporating the character into elite genotypes; 10) genetic advancement achieved by MSFRS; 11) loss assessment and identification of resistance to *Zymoseptoria*; 12) identification of foliar diseases; 13) identification of the agent causing Fusariosis; 14) evaluation of genetic progress; and 15) yield comparison of flour wheats *vs* durum wheats.

In 2020, 17 male and female researchers collaborate in INIFAP’s wheat program, 11 less than in 1985, but the strength of a well-coordinated work has made it possible to make 142 varieties available to farmers in 35 years, most of them important in domestic production; such as CIRNO C2008, which in the last decade was sown in more than 1.5 million ha, its higher yield, resistance to lodging and resistance to rusts has generated additional income for farmers of $6 700 million.

On the other hand, during this time countless undergraduate, master’s and doctoral students have carried out their internship and research stays, coupled with obtaining undergraduate theses, many of whom are currently professors, researchers of INIFAP or other research centers. In addition, of varieties and human resources formation, all members of the wheat program have made contributions to science with technical and scientific publications through books, book chapters, articles, scientific summaries, leaflets and fold-out sheets.

Challenges in the short, medium and long term

The challenges of the genetic improvement program are synthesized in keeping its continuity for line generation organized and coordinated, which, when evaluated in national trials in contrasting environments and years, allow the release of new and better varieties. To achieve this, it is important to strengthen it with young researchers and under the following challenges. In the short term, increase irrigation production through higher productivity and expansion of the sown area and strengthen research on genetic control of diseases, reduced irrigation efficiency in water use (EWU), drought and heat tolerance and nutritional quality.

In the medium term, achieve genetic control of rusts, reduce losses caused by foliar diseases and increase irrigation production by expanding the area under reduced irrigation. In the long term, expand the rainfed areas (drought environments) and those under reduced irrigation under the conservation farming system, genetically control diseases and sow varieties tolerant of heat stress and of better nutritional quality, with the vision of producing about seven million tons.

Conclusions

The future of wheat production under irrigated and rainfed conditions in Mexico depends on the success of programs in the development of varieties with greater yield potential, long-lasting resistance to diseases, efficient use of water, drought and heat tolerance, better nutrient absorption and good industrial quality. These varieties, planted with adequate agronomic management and optimal technological packages, will allow the farmer to produce profitable wheat in a profitable manner, the industrialist to stock up on good quality grain at competitive price and the consumer to meet their needs with products at a good price and of better quality.

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