Essay

Genetic improvement of oats in Mexico

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Abstract

With the creation of the National Institute of Agricultural Research (INIA), genetic improvement of oats begins in Mexico in the now Experimental Field Valle de México (CEVAMEX). It began with the introduction of germplasm from the USA and Canada, in 1962 the first crosses were made and in 1967 varieties (Chihuahua and Cuauhtémoc) were released. In the 60s to 80s, segregation rotation in various environments was implemented, obtaining two selection cycles per year, the gravimetric mass selection method and the establishment of performance trials in contrasting environments. Currently the National Institute of Forestry, Agricultural and Livestock Research (INIFAP-CEVAMEX) turns 61 and has released 33 varieties (18 as INIFAP). From 1985 to 2019 the sown area of oats has increased from approximately 400 000 to 900 000 ha, due to the productivity of the current varieties, recently 'Turquesa' stands out, which has exceeded 8 t ha^{-1} of grain under rainfed conditions, and that in the last 12 years has been sown in 540 000 ha, which produced a profit of $1 350 million. The challenges in the short, medium and long-term are to increase production in rainfed environment, strengthen research in genetic control of stem rust, drought tolerance and nutritional quality of grain, and sow varieties with high nutritional value for human consumption.

Keywords: *Avena sativa* L., plant breeding, varieties.

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Genetic improvement of oats (*Avena sativa* L.) in Mexico started in 1960 with the creation of the National Institute of Agricultural Research (INIA), and from 1985 known as the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) and where the Experimental Agricultural Field Valle de México (CAEVAMEX) is established.

The improvement program begins, under the command of Engineer Rodolfo Moreno Gálvez, in order to obtain varieties resistant to stem rust (*Puccinia graminis* f sp. *avena* Erikss & Henning) and to lodging and increase unit yield. At the beginning of the 60's the area sown with oats was 80 000 ha and the average grain yield was 800 kg ha^{-1} (Jiménez, 1978).

The beginning of the improvement was with the introduction of germplasm from the USA and Canada, which was evaluated in various rainfed environments, allowing the selection of genotypes tolerant to stem rust, with good performance under drought and with higher yield, these selections were used as progenitors in 1962 and that is how the first plan of crosses was carried out in Mexico, activity that has been important and to date is the strength of CEVAMEX, in INIFAP.

Among the crosses that were made, AB-177 x Putnam was recombined, its segregating generations F_1 to F_6 were evaluated in spring-summer (S-S) (Chapingo, Méx.) and in autumn-winter (A-W) (Roque, Guanajuato) and in 1967 it gave rise to the varieties Chihuahua and Cuauhtémoc, which in rainfed plantings excelled for their yield, tolerance of lodging and resistance to stem rust, advantages that allowed to boost the national production (Jiménez, 1992).

Historically oats plantings have been affected by stem rust, an aggressive and devastating disease and with wide variety of physiological breeds (Villaseñor *et al*., 2009), which when affecting susceptible varieties causes losses in grain yield up to 75% (Leyva *et al*., 2004). During the 1970s eight varieties, that surpassed those already sown, were released, where Diamante R-31 (immune to stem rust), Páramo (very precocious and tolerant of draught) and Dorada (first variety with bare and precocious grain) stand out, varieties that allowed the program to receive international recognition, for the merit of recombining non-adapted germplasm and using genes of additive effects to fix desirable characteristics, such as low size, resistance to stem rust and bare grain, and for the mass or massive selection scheme implemented in segregating generations alternating A-W cycles under regular or limited irrigation, with S-S cycles under contrasting rainfed environments (Villaseñor *et al*., 2009).

Improvement strategies in 35 years of research at INIFAP

At the end of 1980s, CEVAMEX consolidated various techniques of improvement such as: 1) introduction and recombination, where it uses lines generated by the program as progenitors and recombines them with introduced germplasm; 2) hybridization to obtain single and triple crosses, and in specific cases backcrosses; 3) the rotation of segregants in A-W and S-S in contrasting environments; 4) mass selection by gravimetric method, through seed floating; 5)evaluate the segregant in locations suitable for the severe incidence of stem rust, in S-S; and 6) evaluation of performance trials in years and locations under rainfed conditions.

In the mid-90's there were increases in the oats area nationally, in 1996, 460 000 ha were sown and 85% were destined for fodder, so that at the end of the same decade work was done on the increase in forage and grain production (Espitia *et al*., 2002). In 2002, the uniform trials of oats (EUAVENA) were resumed, evaluated in up to 30 rainfed environments from Oaxaca to Chihuahua. In 2003 and 2005 Obsidiana and Turquesa were released, characterized by their high grain yield, producing up to 8 t ha^{-1} and with ratio of straw:grain of 58:42.

Stem rust has been the main phytopathological problem in the improvement of oats, as the fungus shows pathogenic diversity in Mexico, for example, Mariscal *et al*. (2009) reports that, in samples collected in commercial oats plantings in Mexico, 24 physiological breeds were identified. Thanks to genetic improvement, advanced lines with resistance to various breeds are currently available, due to gene accumulation. On the other hand, molecular marker-assisted selection (MAS), which is the identification of markers linked to the genes resistant to stem rust (Torres-Pacheco *et al*., 2007) is being carried out.

In 2021 the genetic improvement program of oats turns 61, with 122 generations of recombination and selection and the release of 33 varieties, 18 of them as INIFAP. From 1985 to 2019, the time that INIFAP has taken since its creation, the area sown with oats has increased by approximately 400 000 to 900 000 ha, thanks to the productivity of the varieties, among which Turquesa stands out, which in the last 12 years has been sown in 540 000 ha and has produced a profit of $1 350 million. In summary, practically 100% of oats production in Mexico, over the past five decades, has been achieved with contributions of INIFAP's genetic improvement program, which can be ranked among the most successful of the Institute. Table 1 lists the oats varieties and the year of release by INIFAP.

Table 1. Oats varieties (*Avena sativa*) released by INIFAP from 1967 to date.

Variety	Year of release	Resistance to stem rust	Uses
Cuauhtémoc	1967	S	Grain-forage
Chihuahua	1967	S	Grain-forage
Guelatao	1972	S	Grain-forage
Páramo	1974	S	Grain-forage
Diamante R-31	1974	MR	Grain-forage
Huamantla	1974	S	Grain-forage
Tarahumara	1974	S	Grain-forage
Gema	1978	S	Grain-forage
Tulancingo	1979	S	Grain-forage
Juchitepec	1987	MS-R	Grain-forage
Dorada	1987	MS-R	Grain-forage
Pampas	1989	MS-R	Grain-forage
Papigochi	1989	MS-R	Grain-forage
Babícora	1989	MS-R	Grain-forage
Cusihuiriachi	1989	MS-R	Grain-forage

Variety	Year of release	Resistance to stem rust	Uses
Rarámuri	1989	S	Grain-forage
Karma	1998	MS-R	Grain-forage
Avemex	1998	S	Grain-forage
Obsidiana	2002	MS	Grain-forage
Menonita	2002	MS	Grain-forage
Bachiniva	2002	MS	Grain-forage
Teporaca	2002	MS-R	Grain-forage
Turquesa	2006	MS	Grain-forage
Arareco	2007	MS	Grain-forage
Ágata	2019	MR-R	Grain-forage
Jade	2020	MR-R	Grain-forage

R= resistant; MR= moderate resistance; MS= moderate susceptibility; S= susceptible to short, medium and long-term challenges.

Oats in Mexico in the last two decades are produced under rainfed conditions, in land with low productive potential, it is considered as an emerging crop when other crops are damaged or the time to sow them is passed, and as a strategic forage in the productive reconversion of land from agricultural vocation to livestock exploitation.

Among its qualities are: i) it is an excellent forage used from early stages of growth (staking) until maturity and that is highly demanded for livestock feeding; ii) it requires less time and fewer inputs than other crops to be produce; iii) it is a rustic plant that expresses good behavior from low-precipitation erratic rainfed environments (El Llano, Aguascaliente) to high and rainy parts (Río Frío, State of México); and iv) it is tolerant of drought environments.

The success of oats production in Mexico will depend on the varieties generated by INIFAP, since by means of these, it will be possible to genetically control the stem rust, increase the quality and quantity of the forage and achieve a stable and sustainable production. The improvement program should continue working in an organized and coordinated manner to achieve its continuity in line generation and evaluation of national trials.

Conclusions

It will be important to incorporate young researchers and contemplate the following challenges: a) in the short term, increase production in rainy environments and strengthen research in genetic control of stem rust, tolerance of drought and nutritional quality of the grain; b) in the medium term, control of stem rust and increase the area in medium rainy environments; and c) in the long term, increase the area in drought and irrigation environments in the northwest and sow varieties that produce grain with high nutritional value for human consumption.

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