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Advances in the selection program of sugarcane (*Saccharum* spp.) varieties in the Colegio de Postgraduados

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ABSTRACT

Objective: To evaluate the progress in each of the stages of the selection program of sugarcane varieties that has been carried out at the Colegio de Postgraduados Campus Córdoba (Mexico) since 2009.

Design/methodology/approach: The breeding program employed the methodology developed by the Institute for the Improvement of Sugar Production (Instituto para el Mejoramiento de la Producción de Azúcar, IMPA). For the varietal description, we employed the protocol of the International Union for the Protection of New Varieties of Plants (UPOV).

Results: In 2009, the Colegio de Postgraduados Campus Córdoba started the varietal selection program with more than six thousand hybrids from 40 crosses, from which 4422 materials were selected after they showed resistance to the sugarcane mosaic virus. From the 4422 materials in the Seedling phase, 352 clones were selected and evaluated in the Furrow phase, selecting 57 varieties for the Plot phase. From those 57 varieties, 35 were selected in the Adaptability testing phase and 27 in the following Agroindustrial evaluation phase. Some of these 27 varieties show yields higher than 100 t ha^{-1}, more than 18 °Brix in juices, and good adaptability to different environments.

Study limitations/implications: The current challenges of the breeding program are environmental due to climate change, economical due to the global recession that affects our country with budget cuts, and sociopolitical as a result of the organizational structure of national the sugarcane sector.

Findings/conclusions: This variety breeding and selection program started with 6000 individuals from 40 crosses, of which to date there are 27 in advanced stages of selection, with the possibility of adaptation and good yields for the area of influence of the Campus Córdoba.

Keywords: Poaceae, *Saccharum* spp., plant breeding, COLPOSCTMex, °Brix.

INTRODUCTION

Sugarcane is a crop highly efficient in the use of solar energy, water, and fertilizers. When evaluating its biomass production capacity per unit area, sugarcane is among the most profitable conventional crops in the world (Moore *et al*., 2014).

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In Mexico, The 2019-2020 harvest in 50 sugarcane mills in an area close to 810,803 ha, reached 50.8 million tons of sugarcane milling and a production of 5.2 million tons of sugar (CONADESUCA; 2020; USDA, 2020), with a value close to 40 billion pesos, with the contribution of 8% of the Agricultural Gross Domestic Product (CEDRSSA, 2020; CONADESUCA, 2020).

In this value chain, there are crucial problems related to lags in the production processes, which require the implementation of different innovation schemes (Gómez-Merino *et al*., 2014a). In terms of genetic resources, in Mexico, the generation of varieties has shown a drop in the last 30 years, and the current production of sugarcane is sustained by only three varieties, which are cultivated in about 70% of the cultivated area of this crop, which endangers the system because with the increase in genotype uniformity, the susceptibility to biotic and abiotic stress factors also increases (Sentíes-Herrera *et al*., 2016; Sentíes-Herrera *et al*., 2017a; Sentíes-Herrera *et al*., 2019). Therefore, since 2009, the Colegio de Postgraduados Campus Córdoba undertook an ambitious variety selection and exchange program. The initial phases have been described by Gómez-Merino *et al*. (2014b).

The variety selection program consists of different logical sequential phases, in which the characteristics to be evaluated increase as the experiment advances. Hybridization is the main part of sugarcane breeding and is the basis for obtaining commercial varieties. This phase is carried out in the Centro de Investigación y Desarrollo de la Caña de Azúcar (CIDCA), in Tuxtla Chico, nearby Tapachula, Chiapas. The experiments should be located in representative sugarcane areas, preferably flat and homogeneous terrains according to the planting season, with sufficient residual humidity or near a water source. Sugarcane breeding aims to develop more productive varieties with greater tolerance to water stress, greater resistance to pests and diseases, and better adaptation to mechanical harvesting. This study recapitulates the breeding and selection program of sugarcane varieties that started in 2009 in the Colegio de Postgraduados Campus Córdoba. We report the most outstanding findings of the 27 most advanced varieties that derived from this program and that are in the Agroindustrial evaluation phase, before the Semicommercial testing phase, based on the methodology described by the IMPA (1983) and by Sentíes-Herrera *et al*. (2017b).

MATERIALS AND METHODS

The selection process began with the progeny from 40 crossings performed in 2009, of which 38 were biparental and two were polycross.

1. Establishment of the Seedling phase

At the initial phase, Fuzz (hybrid seed) was germinated to obtain a population of more than six thousand hybrids, which were mechanically inoculated with the sugarcane mosaic virus. The plants that showed symptoms of this disease were eliminated, which resulted in a total population of 4422 for the establishment of the Seedling phase.

The hybrid material was arranged progressively based on the number of crossing. The transplant was performed following a wide zig-zag pattern from right to left; the planting record and sketch map were performed at the time of planting. Protection furrows and headings were established with the early, medium, and late maturity control varieties. Hybrids were transplanted with 1 m of distance between them and 1.4 m between furrows, with intercalated controls, one at the beginning and another one at the end of each crossing with a 2 m space between them. The agricultural practices were the same as those used in the region, based on those described by Herrera-Solano (2001).

Materials in seedling cycle were evaluated through quarterly phytosanitary inspections (Mosaic, Smuts, and Rusts are discriminatory diseases) and agroindustrial qualifications (°Brix, pith, hollowness, diameter, height, and population 12 months after planting). The hybrid scores were performed following the ranges established in each control maturity type (early, CP 72-2086; medium, Mex 79-431; and late, Mex 69-290).

2. Establishment of the Furrow phase

In 2011, the Furrow phase was established using the 352 sugarcane clones selected in the Seedlings phase. These clones were identified with the following nomenclature: research center in which they were selected, year of crossing, and hybrid number. For example: COLPOSCCMEX 09-1, that is, Colegio de Postgraduados Campus Córdoba, Mexico, generation 2009, and hybrid number one.

Planting was carried out during November. The clones were arranged progressively based on the number of crossing. The transplant was performed following a wide zig-zag pattern; the planting record and sketch map were performed at the time of planting. Protection furrows and headings were established with the control varieties (early, medium, and late maturity). Clones were transplanted into plots with three 3-m-long furrows spaced 1.4 m apart. Clones were spaced 2 m apart, intercalating controls, one at the beginning and another at the end (every 25 clones). The agricultural practices were the same as those used in the region. Clones in plant cane and first ratoon cycles were evaluated. The scores were the same as those in the Seedling phase.

3. Establishment of the Plot phase

In 2013, the Plot phase was established using the 57 sugarcane varieties selected in the Furrow phase. Planting was carried out during November. The clones were arranged progressively based on the variety number. The transplant was performed following a wide zig-zag pattern; the planting record and sketch map were performed at the time of planting. Protection furrows and headings were established with the control varieties (early, medium, and late maturity). Clones were transplanted into plots with three 5-m-long furrows spaced 1.4 m apart. Clones were spaced 2 m apart, intercalating controls every ten clones. According to Herrera-Solano (2001), agricultural practices were the same as those used in the region. Clones in plant cane and first ratoon cycles were evaluated through quarterly phytosanitary inspections and agricultural inspections at 12 months of age. In the seedling cycle, a 20% maximum selection pressure was established based on the considerations indicated in the Seedling phase for the inspection determinations and the stipulated selection criterion. The selection also considers the incorporation of the agricultural characteristics that correspond to uniformity, toughness, juiciness, flowering, and modification of the qualification to smut and rust diseases.

4. Establishment of the Adaptability testing phase

In 2016, the Adaptability testing phase was established using the 36 sugarcane varieties selected in the Plot phase. Planting was carried out at the end of December. The hybrid material was arranged progressively based on the number of crossing. The transplant was performed following a wide zig-zag pattern; the planting record and sketch map were performed at the time of planting. Protection furrows and headings were established with the control varieties (early, medium, and late maturity). Clones were transplanted into plots with four 10-m-long furrows spaced 1.4 m apart. Clones were spaced 2 m apart, intercalating controls. According to Herrera-Solano (2001), agricultural practices were the same as those used in the region. Clones in plant cane and first ratoon cycles were evaluated through quarterly phytosanitary inspections and selection at 12 to 14 months of age. In this phase, the selection criteria are based on the agricultural characteristics, maturity type, and adaptation range of the varieties. The considered characteristics were: stem diameter, bud type, number of small prickles, population of sucker tillers and main stalks, growth habit, stalk height, development uniformity, clearance, toughness, resistance to lodging, flowering, pith, hollowness, internal and external health, maturity, juiciness and sucrose content, purity, and fiber. The adaptability to conditions such as altitude, rainfall regime, soils, drainage, drought, winds, and ground frost was also considered.

5. Establishment of the Agroindustrial evaluation phase

In 2018, the Agroindustrial evaluation phase was established using the 27 sugarcane varieties selected in the Adaptability testing phase. Planting was carried out during December. The material was analyzed following a randomized block design with three repetitions. The planting record and sketch map were performed at the time of planting. A total of 27 promising varieties and three control varieties were transplanted into plots with four 8-m-long furrows spaced 1.4 m apart. Clones were spaced 2 m apart. According to Herrera-Solano (2001), agricultural practices were the same as those used in the region. Clones in plant cane and first ratoon cycles were evaluated; the evaluation of the second ratoon is in progress. In each cycle, the corresponding information was recorded in the different phenological stages of the crop. In this phase, the statistical interpretation of the data related to field and factory yields, along with the information corresponding to the sanitary and agricultural characteristics, are the determinants for the selection of varieties. The characteristics considered in the evaluation of varieties are: germination, tillering, field closure, population of sucker tillers and main stalks, stalk diameter, bud type, number of small prickles, growth habit, stalk height, development uniformity, clearance, resistance to lodging, flowering, pith, hollowness, internal and external health, deterioration (sprouting of buds, emission of adventitious roots, and presence of non-canceled cracks), reaction to herbicides, field yield, qualities related to the mechanical harvest, sucrose percentage, purity and fiber, sugar theoretical yield, juiciness, and rind hardness. The adaptability to conditions such as altitude, precipitation, soils and drainage, winds, drought, and ground frost was also considered. These characteristics were recorded in the two central furrows corresponding to the useful plot and in all repetitions.

Statistical analysis

An analysis of variance was performed for the estimated yield variables and degrees Brix, and the means of each variety were compared with the Tukey test ($P \leq 0.05$) using the statistical software SAS, version 9.4.

RESULTS AND DISCUSSION

Sugarcane breeding can take from 12 to 16 years, which implies that from a germplasm bank it is only possible to select between one and four new varieties (Sentíes-Herrera *et al.*, 2016; Sentíes-Herrera *et al.*, 2017a). In Mexico, where sugar production depends on three varieties that produce 70% of the sugar in the country, it is urgent to generate new materials that broaden the restricted genetic base (Sentíes-Herrera *et al.*, 2017b; 2019).

The variety selection program of Campus Córdoba has established 4422 hybrids in the Seedling phase; these hybrids were selected based on validated scales for the traits considered in said phase and compared to the local controls used. Subsequently, the Furrow phase was established with 352 clones and selected 57 varieties, evaluated in the Plot phase. Of the 57 varieties evaluated in the Plot phase, 36 were selected for the Adaptability testing phase. From those 36 varieties, 27 varieties were selected in the third year of the Agroindustrial evaluation phase. Table 1 describes the details of the progenitors and shows the nomenclature of the 27 varieties selected in the Agroindustrial evaluation phase. Table 2 includes some of the most prominent characteristics of these advanced varieties.

In Table 2 and Figure 1, 11 of the 27 selected varieties in this phase show estimated yields similar or higher than the local commercial controls (between 100 and 120 t ha^{-1}), with juices of good agroindustrial quality (18 to 20 °Brix in the refractometer). The varietal characterization started in this phase based on the protocols described by the UPOV (2004) and Gómez-Merino and Sentíes-Herrera (2015).

Table 1. List of the 27 varieties selected in the Agroindustrial evaluation phase in the Colegio de Postgraduados Campus Córdoba, located in Amatlán de los Reyes, Veracruz, Mexico (18° 86′ N, 96° 85′ W, 650 masl). 2018-2019 period.

Number	Crossing	Progenitors			Variety (COLPOS nomenclature)
		Female		Male	
01	222	LCP 81-10	X	Gloria 57	COLPOSCCMEX 09-29
02	255	CP 52-68	X	CP 70-1527	COLPOSCCMEX 09-50
03	256	CP 92-1401	X	CP 80-1743	COLPOSCCMEX 09-58
04	257	CP 92-1401	X	CP 81-1384	COLPOSCCMEX 09-62
05	257	CP 92-1401	X	CP 81-1384	COLPOSCCMEX 09-66
06	257	CP 92-1401	X	CP 81-1384	COLPOSCCMEX 09-75
07	257	CP 92-1401	X	CP 81-1384	COLPOSCCMEX 09-79
08	258	CP 81-10	X	CP 70-133	COLPOSCCMEX 09-93
09	258	CP 81-10	X	CP 70-133	COLPOSCCMEX 09-95
10	264	Tue 72-9	X	CP 80-1827	COLPOSCCMEX 09-97
11	264	Tue 72-9	X	CP 80-1827	COLPOSCCMEX 09-99
12	264	Tue 72-9	X	CP 80-1827	COLPOSCCMEX 09-125
13	294	CC 93-3826	X	CP 62-378	COLPOSCCMEX 09-132
14	294	CC 93-3826	X	CP 62-378	COLPOSCCMEX 09-136
15	CMI V	LTMex 92-52	X	Multiparental	COLPOSCCMEX 09-208
16	CMI V	LTMex 92-52	X	Multiparental	COLPOSCCMEX 09-212
17	CMI V	LTMex 92-52	X	Multiparental	COLPOSCCMEX 09-217
18	CMI V	LTMex 92-52	X	Multiparental	COLPOSCCMEX 09-220
19	CMI V	LTMex 92-52	X	Multiparental	COLPOSCCMEX 09-222
20	774	PR 62-632	X	CP 80-1743	COLPOSCCMEX 09-273
21	707	Mex 79-431	X	CP 89-2377	COLPOSCCMEX 09-289
22	707	Mex 79-431	X	CP 89-2377	COLPOSCCMEX 09-290
23	529	ITV 92-1424	X	B 45-181	COLPOSCCMEX 09-312
24	529	ITV 92-1424	X	B 45-181	COLPOSCCMEX 09-321
24	527	ITV 92-1424	X	CP 81-1384	COLPOSCCMEX 09-333
26	523	CP 87-1490	X	Mex 79-341	COLPOSCCMEX 09-341
27	523	CP 87-1490	X	Mex 79-341	COLPOSCCMEX 09-348

Cruza multiparental con progenitor masculino no identificado.

Table 2. Prominent traits of the 27 varieties selected in the Agroindustrial evaluation phase in the Colegio de Postgraduados Campus Córdoba, located in Amatlán de los Reyes, Veracruz, Mexico (18° 86′ N, 96° 85′ W, 650 masl). 2018-2019 period.

Variety number	Variety (COLPOS nomenclature)	Flowering	Lodging	Leaf shedding	Estimated yield (t ha^{-1})
1	COLPOSCCMEX 09-29	Present	Present	Excellent	120.80
2	COLPOSCCMEX 09-50	Present	Absent	Excellent	105.80
3	COLPOSCCMEX 09-58	Absent	Absent	Excellent	67.51
4	COLPOSCCMEX 09-62	Absent	Present	Excellent	74.15
5	COLPOSCCMEX 09-66	Present	Present	Excellent	74.03
6	COLPOSCCMEX 09-75	Absent	Absent	Excellent	71.08
7	COLPOSCCMEX 09-79	Absent	Present	Regular	75.64
8	COLPOSCCMEX 09-93	Present	Absent	Regular	76.44
9	COLPOSCCMEX 09-95	Present	Present	Excellent	76.44
10	COLPOSCCMEX 09-97	Present	Absent	Hard	107.91
11	COLPOSCCMEX 09-99	Absent	Absent	Excellent	138.08
12	COLPOSCCMEX 09-125	Present	Absent	Excellent	90.24
13	COLPOSCCMEX 09-132	Absent	Absent	Excellent	90.79
14	COLPOSCCMEX 09-136	Present	Present	Excellent	114.77
15	COLPOSCCMEX 09-208	Absent	Absent	Excellent	70.74
16	COLPOSCCMEX 09-212	Absent	Present	Excellent	70.90
17	COLPOSCCMEX 09-217	Absent	Absent	Excellent	121.18
18	COLPOSCCMEX 09-220	Present	Present	Excellent	100.18
19	COLPOSCCMEX 09-222	Present	Absent	Excellent	93.51
20	COLPOSCCMEX 09-273	Present	Absent	Hard	156.15
21	COLPOSCCMEX 09-289	Absent	Present	Hard	133.39
22	COLPOSCCMEX 09-290	Absent	Present	Excellent	165.56
23	COLPOSCCMEX 09-312	Absent	Present	Excellent	127.48
24	COLPOSCCMEX 09-321	Absent	Absent	Regular	103.48
25	COLPOSCCMEX 09-333	Absent	Absent	Excellent	174.95
26	COLPOSCCMEX 09-341	Present	Absent	Excellent	134.60
27	COLPOSCCMEX 09-348	Absent	Absent	Regular	119.17

According to the mathematical models based on experimental data, sugarcane has been estimated to reach yields close to 400 t ha^{-1} or up to 500 t ha^{-1} in fresh main stalks and between 100 and 200 ha^{-1} of dry matter (Moore, 2009; Waclawovsky *et al.*, 2010; Dal-Bianco *et al.*, 2012; Hoang *et al.*, 2015), which suggests that in Mexico it is possible to expect an increase in yields. Additionally, sugarcane is projected as an essential crop for the establishment of new biofactories for the production of novel compounds such as bioplastics, pharmacological proteins, and alternative sugars (Gómez-Merino *et al.*, 2014c; Gómez-Merino *et al.*, 2017), which encourage efforts to continue breeding programs aimed to increase field and factory yields. Therefore, the Colegio de Postgraduados has implemented strategies like the one described in this report, and in subsequent phases, there will be molecular tools to analyze phylogenetic relationships and genetic variability and identify productive traits associated with the genome. An important advance of these studies has been reported by González-Jiménez *et al.* (2011). They observed two different groups of *Saccharum* spp. and a variety that differed from both. Group I consisted of the varieties C 87-51, ATM 96-40, B 4362, Mex 69-290, Mex 57-1285, and Mex 91-130, which formed a conglomerate and presented a similarity of 0.77%. Grouped II comprised the varieties RD 75-11, Mex 79-431, SP 70-1284, Mex 59-32, and CP 72-2086, which formed a different conglomerate with 0.70%. The Mex 68-P-23 variety differed from the other varieties. In the breeding program in Campus Córdoba, some

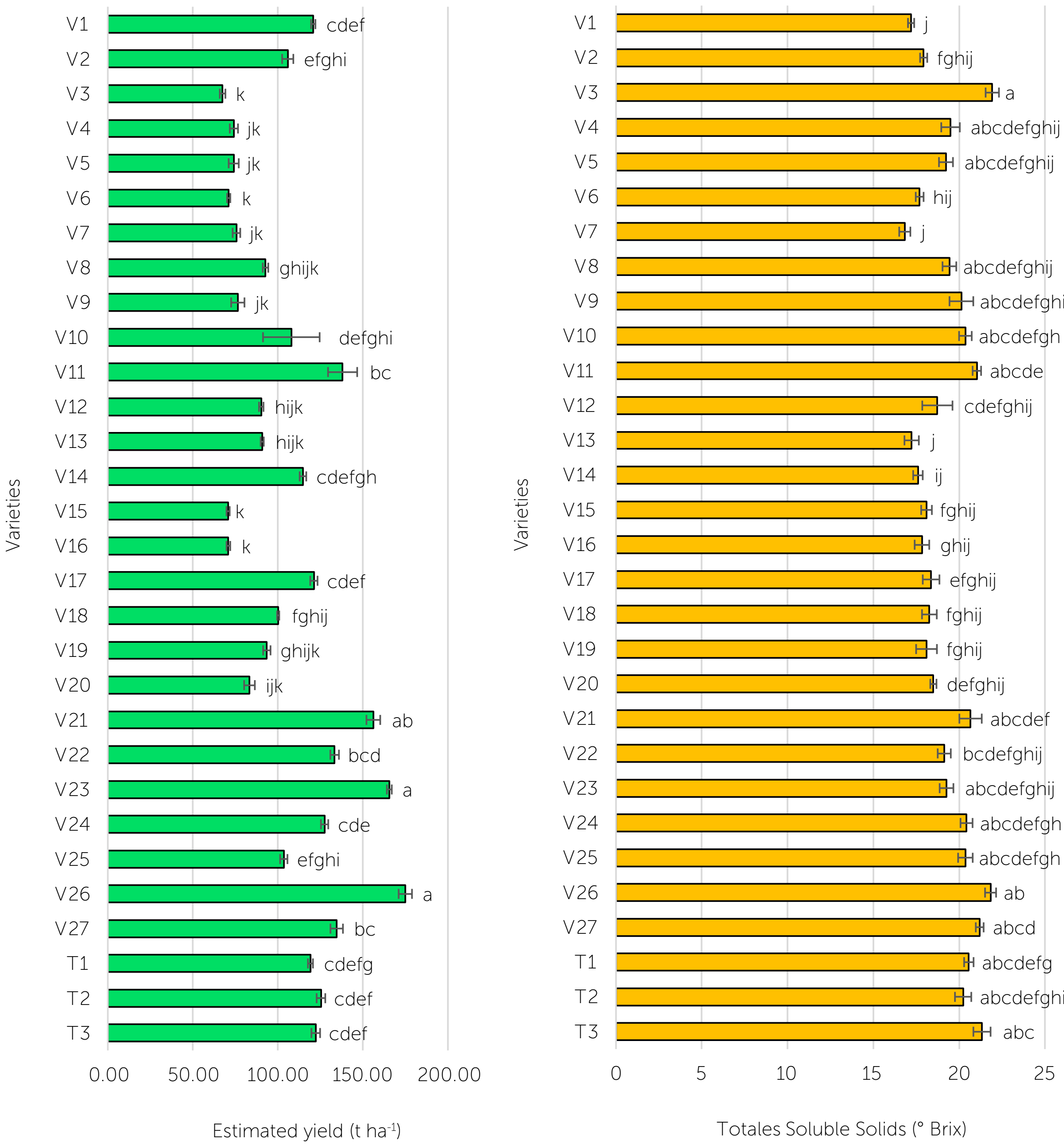

Figure 1. Estimated yields (left) and total soluble solids as °Brix (right) for the 27 sugarcane varieties in the Agroindustrial evaluation phase and three local controls in the Colegio de Postgraduados Campus Córdoba, located in Amatlán de los Reyes, Veracruz, Mexico (18° 86′ N, 96° 85′ W, 650 masl). The nomenclatures assigned to the varieties correspond to numbers 1 to 27 of Tables 1 and 2. The controls are: C1, CP 72-2086; C2, Mex 79-431; and C3, Mex 69-290. 2018 -2019 period. Different letters in the columns of each variety for each variable measured indicate statistical differences between the materials (Tukey, P≤0.05).

progenitors come from this previously analyzed collection, which will facilitate subsequent studies and function as a useful tool for identifying the best crossings (Sentíes-Herrera and Gómez-Merino, 2014).

Additionally, the breeding and variety selection program is carried out along a fertilization and biostimulation program, with promising results in the use of beneficial elements such as iodine, silicon, and vanadium (Sentíes-Herrera *et al.*, 2018).

CONCLUSIONS

In conclusion, the variety selection program started with more than six thousand materials, and to date, there are 27 varieties in the Agroindustrial Evaluation Phase. Of the 27 varieties, 11 show a prominent yield and juice quality. These varieties will have to be evaluated in local and domestic sugarcane mills to continue with the phases in the program.

It is important to mention that of the 40 crossings, only 22 resulted in outstanding individuals under the local conditions of Córdoba. Among these individuals, the most outstanding progenitors are: CP 92-140, Tue 72-9, LTMex 92-52, as PR 61-632, as females; CP 81-1384, CP 80-1827, and CP 80-1743 as males. These progenitors represent important references for future crossings and the continuation of local selection studies for sugarcane varieties.

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