Article

Yield and quality of seven varieties of sugarcane in El Mante, Tamaulipas

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Abstract

The agro-industrial yield and juice quality of seven varieties (IMMEX 91-589, XMEX 91-917, IMMEX 95-25, MEX 95-59, ATEMEX 96-40, MEX 96-60 and IMMEX 98-13) of sugarcane (*Saccharum officinarum* L.), plus CP 72-2086 as a control, were evaluated at the beginning of maturity. The experiment was conducted in El Mante, Tamaulipas, Mexico, between 2019 and 2020, under a randomized complete block design, with four repetitions and considering the varieties as a treatment. The variables were the yield of processable stalks (PSY) and sugar (SY), degrees Brix (°Bx), sucrose concentration (S), purity (P), reducing sugars (Rs), moisture (M) and fiber (F). It was obtained that all showed significant statistical differences ($p\leq 0.05$) between varieties, except M and F ($p> 0.05$). In PSY, they increased the yield between 2.8 and 20% with respect to the control, except for IMMEX 98-13, which decreased 9.5%, and in SY all were equal to the control, except MEX 95-59 and IMMEX 98-13, which decreased the yield by 25.3 and 18.8%, respectively. As for Brix, S, P and Rs, all varieties obtained values similar to CP 72-2086 and in some cases they differed from each other. The results indicated that the varieties XMEX 91-917 and IMMEX 95-25 surpassed the control variety in PSY, while in SY and juice quality, they matched it, so they can be an option to diversify the varieties in the region of the state.

Keywords: *Saccharum officinarum* L., Brix, processable stalks, sucrose.

Reception date: March 2022
Acceptance date: July 2022

Introduction

Sugarcane (*Saccharum officinarum* L.) is a crop that, in tropical and subtropical regions, is considered of importance in the food agribusiness due to its ability to produce large amounts of biomass (Waclawovsky *et al*., 2010) and store high concentrations of sucrose in stalks, which is used for the production of different types of sugars (SIAP, 2020).

In this sense, Mexico ranks as the sixth producer of sugarcane worldwide, with a production of 64.5 million tons in an area of 856 thousand hectares, which is equivalent to an average production per hectare of 75.4 t (SIAP, 2020). In turn, in 2019, Tamaulipas ranked as the sixth producer of this crop nationwide, with a production of 3.14 million tons (SIAP, 2020) and the main municipalities where sugarcane is grown are El Mante, Xicoténcatl, Ocampo, Antiguo Morelos, Nuevo Morelos and Gómez Farías and of these, El Mante concentrates just over 35% of the state's total production (García-Fernández *et al*., 2014). However, it is highly dependent on the variety CP 72-2086, which represents a risk in the event of the appearance of any emerging pest or disease to which it may be susceptible (Suárez *et al*., 2018).

In addition to the above, the productivity of the state is below the national average, which makes it necessary to incorporate new varieties to increase diversity, and even, if possible, increase the productivity and quality of the cane produced in the region (Gómez-Merino *et al*., 2014). In this sense, the variety to be chosen for planting must show adaptation to different agroecological environments, resistance to pests and diseases of economic importance, as well as high productivity and juice quality (Sentíes-Herrera and Gómez-Merino, 2014).

On the other hand, according to Gravois (2020), sugarcane varieties are the vital element of the sugar industry, their selection is one of its most important decisions since it has long-term consequences, therefore, the objective at the time of selection should be to maximize profitability in each year of a long cultivation cycle. In addition, no variety of sugarcane is perfect, as each has an inherent risk (Gravois, 2020). Therefore, the objective of the present research was to evaluate the agro-industrial yield and juice quality of seven varieties of sugarcane at the beginning of maturity in the region of El Mante, Tamaulipas, under the hypothesis that there are varieties that can equal or surpass the commercial variety CP 72-2086 in yield and quality.

Materials and methods

Location and description of the experimental site

The evaluation was conducted from October 2019 to August 2020, in the sugarcane region of Tamaulipas, specifically in the locality of Quintero, municipality of El Mante (22° 43' 00" north latitude and 98° 59' 34" west longitude, at 84 masl). The soil is classified as vertisol, with a clay texture, pH of 8.2 and high amount of calcium carbonates.

The climate, according to the Köppen classification, is of type Aw_0 (Vargas *et al*., 2007), which corresponds to warm subhumid and is characterized by a rainfall and an average annual atmospheric temperature of 1 053.7 mm and 24.6 ºC, respectively. The environmental conditions that occurred during the evaluation period are shown in Figure 1.

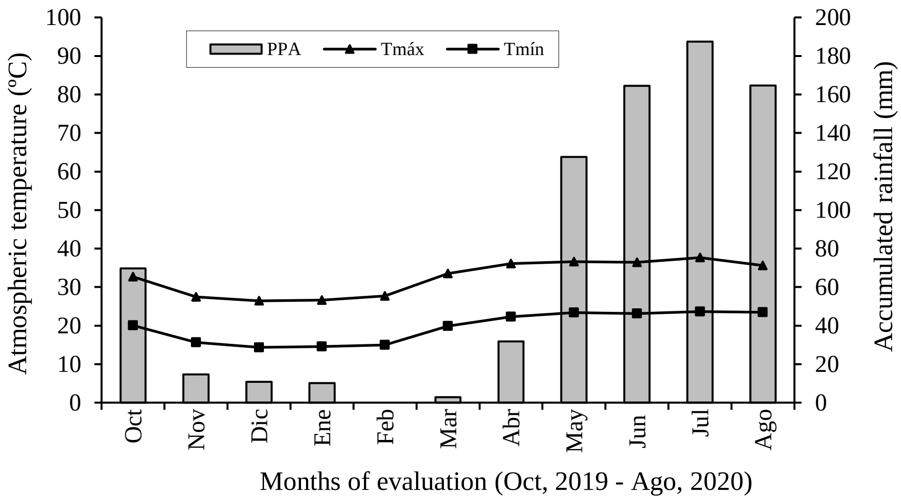

Figure 1. Climograph of the experimental site with the accumulated rainfall (PPA) and the average monthly maximum (Tmáx) and minimum (Tmín) temperatures that were recorded during the evaluation period.

Experimental design

The study factor was the sugarcane varieties IMMEX 91-589, XMMEX 91-917, IMMEX 95-25, MEX 95-59, ATEMEX 96-40, MEX 96-60 and IMMEX-98-13, and CP 72-2086 was added as a control for being the most used in the sugarcane region of the state. The evaluation was conducted under a randomized complete block design, with four repetitions and considering the varieties as a treatment.

The experimental unit consisted of eight furrows with 12 m long and 1.4 m apart. The useful furrows were only the two central ones and of these, a linear meter of each end was discarded, in order to avoid the edge effect.

Establishment of experimental units

The soil was prepared by fallow, double crossed harrow and furrowing, and planting was carried out on October 01, 2019, using vegetative material (stalks) and the traditional method of the region, double chain with overlap between the tip and base of the stalks. Similarly, an edaphic fertilization was carried out with 217, 124, 44, 135 and 2 kg ha^{-1} of nitrogen, phosphorus, potassium, sulfur and zinc, respectively, and it was divided into two applications, one at the time of planting and another five months after the first. In addition, supplemental irrigations to field capacity were applied during dry periods and weeds were controlled with the pre-emergent application of Ametryn + Atrazine at a rate of 1 146 g of each ai ha^{-1} and three months later, with post-emergent application of Ametryn + 2.4-D 765 g and 392.7 g, respectively of ai ha^{-1}.

Agro-industrial yield

In the field, the yield was evaluated based on the processable stalks (PSY, t ha^{-1}) at the beginning of the maturation of the control variety (CP 72-2086), which occurred nine months after planting. To do this, only the stalks that were in the eight linear meters considered useful in each of the two central furrows of each plot were harvested and weighed fresh, but not before removing the green and dry leaves and removing the tips between sections 8 and 10. With the data obtained, the calculation was made using the following formula: $PSY\left(t\ GM\ ha^{-1}\right)=\frac{\left(\frac{HSW\ (kg)}{HA\ (m^2)}\right)\times 10000}{1000}$. Where: HSW= is the harvested stalk weight; HA= is the harvested area, which, in this case, was 22.4 m^2; 10 000= corresponds to the m^2 that a hectare has; and 1 000= the kg that a ton has.

Industrial yield was evaluated according to sugar production, which was estimated using the following formula: $SY\left(t\ ha^{-1}\right)=\frac{PSY\left(t\ GM\ ha^{-1}\right)\times S\ (\%)}{100}$. Where: PSY= is the processable stalk yield; S= the percentage of sucrose; and 100= the conversion factor.

Juice quality

In this case, the evaluation was made based on degrees Brix, sucrose content (%), purity (%), reducing sugars (%), moisture (%) and fiber (%) in the processable stalks. For these determinations, of the stalks harvested in the estimation of the yield, 10 that were representative of each variety and plot were chosen and sent for processing and analysis to the laboratory of Ingenio El Mante SA de CV, owned by Grupo Pantaleón and located in the municipality of El Mante, Tamaulipas, Mexico. In the laboratory, the analyses were carried out following the methodologies of the Official Mexican Standards established for the Sugar Industry.

Statistical analysis

The data obtained from the evaluated variables were analyzed using a randomized complete block design, with four repetitions and using the statistical analysis software SAS version 9.0 (SAS Institute, 2002). In the case of the variables that presented significant statistical differences between treatments (varieties), the Tukey test was applied with a significance level of 5% ($p\leq 0.05$) in the comparison of means.

Results and discussion

Agro-industrial yield

According to the analysis of variance, the difference observed in the response of the varieties was significant ($p\leq 0.05$) in both (Table 1). The maximum value of processable stalk yield (PSY) was obtained by the variety MEX 95-59 with 90.8 t ha^{-1} and the minimum by IMMEX 98-13 with 68.51 t ha^{-1}, with significant differences between both ($p\leq 0.05$) and the rest of the varieties. This was reflected in the significant increase and decrease ($p\leq 0.05$) of the yield by 20 and 9.5% with respect to the control (CP 72-2086), respectively, while the varieties IMMEX 91-589 and XMEX 91-917, statistically ($p> 0.05$), were similar to each other, as well as IMMEX 95-25 and MEX 96-60 and they increased yield between 6.4 and 10.7%. In the case of ATEMEX 96-40, it increased 2.8% in yield with respect to the control.

Table 1. Agro-industrial yield at the beginning of maturity of seven varieties of sugarcane (*Saccharum officinarum* L.) and the control CP 72-2086, in the sugarcane region of El Mante, Tamaulipas, Mexico.

Varieties	PSY (t GM ha^{-1})	SY (t ha^{-1})
CP 72-2086	75.67 e	8.62 ab
IMMEX 91-589	81.87 c	7.73 bc
XMEX 91-917	80.49 c	8.44 ab
IMMEX 95-25	83.74 b	9.1 a
MEX 95-59	90.8 a	6.44 c
ATEMEX 96-40	77.76 d	7.29 bc
MEX 96-60	83.57 b	7.73 bc
IMMEX 98-13	68.51 f	7 c
MSD	1.4	1.36

Within the same column, means with different literals (a, b, c, d, e, f) indicate a significant statistical difference between sugarcane varieties (Tukey; $p\leq 0.05$). MSD= minimum significant difference; PSY= processable stalk yield; SY= sugar yield.

As for the sugar yield (SY), it showed a totally different and opposite response to the previous variable, since the highest yield corresponded to IMMEX 95-25 with 9.1 t ha^{-1} on average; while the lowest value corresponded to MEX 95-59, variety that obtained the highest PSY, and to IMMEX 98-13 with 6.44 and 7 t ha^{-1}, respectively. However, the yield of IMMEX 95-25 did not differ significantly ($p>0.05$) from that of CP 72-2086 and XMEX 91-917, which obtained values of 8.62 and 8.44 t ha^{-1}, with no statistical difference ($p>0.05$) from IMMEX 91-589, ATEMEX 96-40 and MEX 96-60 nor from those that obtained the minimum values.

Overall, the control (CP 72-2086) only differed significantly ($p\leq 0.05$) from IMMEX 98-13 and MEX 95-59, which was reflected in yield with a decrease of 18.8 and 25.3%, respectively. According to the results obtained, the highest field yield in terms of processable stalks was produced by MEX 95-59; however, in industrial yield, it presented the minimum values. Contrary to this, the varieties CP 72-2086, XMEX 91-917 and IMMEX 95-25 had an industrial yield superior to that of MEX 95-59, despite obtaining a lower field yield than this variety. As for IMMEX 91-589, ATEMEX 96-40, MEX 96-60 and IMMEX 98-13, they obtained medium yields, except for IMMEX 98-13, in sugar yield. This is consistent with what Gilbert *et al*. (2006) reported, who found that the genotype of sugarcane varieties has a great influence on the accumulation of sucrose in the stalks, which is due to the variability in the maturation time of each variety (Da Silva *et al*., 2012).

The behavior of the variety MEX 95-59 indicates that it has a high rate of biomass accumulation, therefore, greater water demand compared to the rest of the varieties (Coale *et al*., 1993), which is why a water deficit originated, which in turn caused a reduction in the sucrose content (Singels *et al*., 2005; Singels *et al*., 2010), in addition to the fact that field yield is closely related to industrial yield (Jackson, 2005; Vera-Espinosa *et al*., 2016).

In this regard, Méndez-Adorno *et al*. (2016) point out that there are varieties of sugarcane that are sensitive to water deficit; however, Inman-Bamber and Smith (2005) reported that water restriction or deficit is beneficial in this crop, but not at the beginning of maturation, but when the maturation stage is advanced or weeks before harvest, since it induces a decrease in vegetative growth and an increase in accumulation of sucrose in stalks.

On the other hand, the field yield obtained in the evaluated varieties was higher than that reported by other authors in some of these varieties, such as CP 72-2086, which, when harvested at eleven months, produced 64.69 t of biomass per hectare, with an industrial yield of 9.13 t ha^{-1} (Pérez *et al*., 2019), although, in the latter case, it was higher than what was obtained in this study. These variations in yield can be attributed to the agronomic management and the edaphoclimatic conditions of each experimental site, in addition to the number of harvests that the crop has undergone (Salgado-García *et al*., 2016) and the period between planting and harvesting (Gilbert *et al*., 2006).

Juice quality

The varieties showed significant effects ($p\leq 0.05$) in all variables considered in the evaluation of the quality of sugarcane juice, except for moisture (M) and fiber (F) (Table 2). The degrees Brix (Brix) and sucrose (S) showed the maximum values in CP 72-2086, but statistically it was similar ($p> 0.05$) to the varieties XMEX 91-917, IMMEX 95-25 and IMMEX 98-13 and these, in turn, did not differ significantly ($p> 0.05$) from IMMEX 91-589, ATEMEX 96-40, MEX 96-60 and IMMEX 98-13. In these same variables, the variety ATEMEX 96-40 had values statistically ($p> 0.05$) similar to MEX 96-60 in sucrose content, with 9.4 and 9.26%, respectively. A similar effect was observed in purity (P), where the variety MEX 95-59 had the lowest value (77.29%) and differed significantly ($p\leq 0.05$) from the others, which were statistically similar ($p> 0.05$) to each other.

Table 2. Quality of the juice at the beginning of maturity of seven varieties of sugarcane (*Saccharum officinarum* L.) and the control CP 72-2086, in the sugarcane region of El Mante, Tamaulipas, Mexico.

Varieties	ºBrix*	Sucrose*	Purity*	Reducing sugars*	Moisture*	Fiber*
CP 72-2086	13.3 a	11.4 a	86.36 a	0.81 b	83.75 a	12.19 a
IMMEX 91-589	11.19 b	9.45 b	84.45 a	0.82 b	82.25 a	11.88 a
XMEX 91-917	12.3 ab	10.49 ab	85.25 a	0.94 ab	81.75 a	11.63 a
IMMEX 95-25	12.64 ab	10.87 ab	86 a	0.95 ab	84.25 a	11.75 a
MEX 95-59	9.19 c	7.1 c	77.29 b	1.14 a	85 a	11.19 a
ATEMEX 96-40	11.28 b	9.4 b	82.92 a	0.97 ab	83.25 a	11.63 a
MEX 96-60	10.95 bc	9.26 b	84.58 a	0.92 ab	84 a	12.5 a
IMMEX 98-13	11.94 ab	10.22 ab	85.56 a	0.99 ab	83 a	12.19 a
MSD	1.8	1.79	3.68	0.23	5.66	1.6

*= means expressed as a percentage. Within the same column, means with different literals (a, b, c) indicate a significant statistical difference between sugarcane varieties (Tukey; $p\leq 0.05$). MSD= minimum significant difference.

As for reducing sugars (Rs), the minimum values were obtained in CP 72-2086 and IMMEX 91-589 and the maximum values in MEX 95-59, so they differed significantly ($p\leq 0.05$) from each other, although statistically ($p> 0.05$), the three were similar to the rest of the varieties. Regarding the variables M and F, no significant statistical differences ($p > 0.05$) were detected between varieties; however, the values obtained ranged between 81.75 and 85 and 11.19 and 12.5%, respectively, for each variable.

In Mexico, the quality of sugarcane juice is considered adequate, ºBrix range between 12 and 18, the sucrose content is equal to or greater than 12.5%, purity between 79 and 89%, while the concentration of reducing sugars must be less than 1% (Salgado *et al*., 2003). In this regard, all the varieties evaluated had sucrose values lower than the percentage considered ideal for good quality, despite the fact that in the rest of the parameters they were within the ranges, with the exception of MEX 95-59, which had a purity below 79% and exceeded 1% of reducing sugars, which was due to the phenological phase in which the evaluation was carried out.

Nevertheless, the varieties CP 72-2086, XMEX 91-917 and IMMEX 95-25 were close to the quality ranges, in the case of CP 72-2086, it is attributed to the fact that it is a variety of early maturity (Pérez *et al*., 2019) and therefore, it is usually harvested at eleven months of age or regrowth, period in which it reaches commercial maturity and quality. In addition to the above, these varieties had an inverse relationship between the content of sucrose and reducing sugars, characteristic of early varieties because they have maximum levels of neutral invertase activity compared to late varieties (Cardozo and Sentelhas, 2013), such as MEX 95-59, which showed a behavior of this type and that could be influenced by the time the stalk takes to mature (Da Silva *et al*. al., 2012), reflected in the amount of reducing sugars, which are mainly composed of the monosaccharides glucose and fructose (Begum *et al*., 2012).

Regarding moisture, in the sampled sections, it was higher than 80% and did not showed differences between varieties or relationship with the reducing sugars, as mentioned by Salgado-García *et al*. (2016), who, when evaluating the varieties CP 72-2086 and Méx 69-290 during five cultivation cycles (first planting-ratoon five), found that the lower the moisture, the lower the amount of reducing sugars. Similarly, these authors mention that the stalk should have a moisture content between 68 and 70% at the time of maturity.

Fiber is a dry and insoluble component in the water of the stalk that is important in measuring cane quality due to its inverse relationship with juice extraction and milling efficiency (Islam *et al*., 2021), therefore, acceptable levels are between 10 and 14% (Gravois and Milligan, 1992), since, otherwise, for each 1% increase in fiber content, a decrease in the theoretical values of recoverable sucrose is caused, which ranges from 1.51 to 3.02 g kg^{-1} of cane (Glaz *et al*., 2010). In this component, the varieties did not show differences from each other, attributed to the chemical stability that this crop has in the components of the cell wall, formed mainly by hemicellulose, cellulose and lignin, which together provide support to the stalks (Waclawovsky *et al*., 2010; Figueiredo *et al*., 2019).

On the other hand, the findings obtained in some varieties were similar to what was reported by other authors who, when evaluating and harvesting the varieties CP 72-2086 and MEX 79-431 at eleven months after planting, found that there is no significant difference in the content of sucrose, ºBx, purity and reducing sugars between varieties and that the averages were 14%, 15.83º, 88.61% and 0.31%, respectively (Pérez *et al*., 2019). Similarly, Córdova-Gamas *et al*. (2016) found that, when harvesting MEX 79-431 at 10 months, the content of sucrose, ºBx, purity and reducing sugars was 9.46%, 18.8, 50% and 0.97%, respectively, lower values compared to the results obtained in the present study.

Conclusions

Under the conditions in which the experiment was developed and in the phenological phase in which the evaluation was carried out, it was found that there are varieties that-can equal or even exceed the commercial variety (CP 72-2086) of the sugarcane region of Tamaulipas in yield and juice quality, and among the most promising are XMEX 91-917 and IMMEX 95-25, which stood out for their agro-industrial yield and low values of undesirable parameters in the juice.

Acknowledgements

The authors thank the Mante Multidisciplinary Academic Unit of the Autonomous University of Tamaulipas for the arrangements made before Grupo Pantaleón for the processing and analysis of samples in the Laboratory of Ingenio El Mante SA de CV.

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