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Three New Promising Highly Productive Sugarcane Clones for Farming and the Industry

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Abstract

Context: At present, high-potential agricultural and industrial sugarcane clones are critical at the beginning of the harvest to replace the cultivars that have reduced their productivity after years of exploitation and resistance to the major pests and diseases that attack the crop.
Aim: To evaluate the agro-industrial potential of three new promising sugarcane clones in dryland.
Methods: A randomized experimental block design with five treatments and three replicas was used. The treatments were three promising clones (C13-369, C13-370 and C13-383), and two commercial cultivars (C86-12 y C1051-73) used as controls. The agro-botanical characteristics and crop yields, along with the juice quality parameters at the beginning of the harvest (December), at 12 months of plant's age.
Results: Clones C13-383 and C13-370 demonstrated a better performance than the controls, reaching higher crop yields than 195 t ha^{-1} of millable sugarcane, and 30 t Pol ha^{-1}. The crop yields of C13-369 (164.48 t sugarcane t ha^{-1}) and industrial yields (25.53 t Pol ha^{-1}) were similar to cultivar C86-12 and higher than C1051-73.
Conclusions: The three promising clones have a high genetic potential for sugar production, confirming its possible use as early-maturation cultivars to be harvested at the beginning of production.

Keywords: juice quality, agro-botanical features, early-maturation.

Introduction

Sugarcane is a versatile and one of the highest solar energy-converting crops in terms of dry matter. Worldwide, it is cultivated in approximately 24.5 million hectares, with an annual production of 1 850 tons yielding 75.5 t ha^{-1}, on average. This crop is highly demanded for several other uses, such as forage, fiber, biofuels, and power generation (Mishra, 2019).

The highest production of sugarcane and harvested area by hectares is in Africa, followed by South

America and Asia. Although more than 100 countries participate in the world's sugar supply, the major production levels are concentrated in a few countries, of which Brazil and India stand out (Food and Agriculture Organization of the United Nations [FAOSTAT], 2016).

The principal mission of the Sugarcane Research Institute (INICA), in Cuba is to develop and recommend new highly-productive sugarcane varieties for farming and the industry, which can be resistant to pests, diseases, and insect plagues that harm the crop. They should also be able to adapt to the main edaphoclimatic conditions (soil climate) of the main sugarcane areas in Cuba. Accordingly, there is a network of experimental stations that perform different stages of the selection scheme, and conduct a comprehensive process of evaluations of thousands of genotypes from hybridization (crossings). The transference of each individual to the next stage will depend on the requisites established for their future release commercially. Consequently, the development of new varieties of sugarcane that improve and ensure long-term sustainable production requires years of evaluations. In Cuba, and most countries, this period varies between 10 and 12 years (INICA, 2019).

To speed up the selection and recommendation of sugarcane, in 2013, the Mid-Eastern Genetic Breeding Department of ETICA in Camaguey set out to select the group of plantlets from individuals that stood out from the rest of the population according to their phenotypical characteristics. The genotypes were named elite clones, which were reproduced quickly into the next stage of the selection scheme for sugarcane in Cuba (clone batch I). Accordingly, between 5 and 10 cuttings from every elite clone were planted. At selection, clone batch I met all the criteria established in the Standards and Procedures of the Sugarcane Genetic Breeding Program in Cuba (Jorge, González, Casas & Jorge, 2011). After evaluations, the outstanding clones (which kept their features) were planted in an area named Original Elite Clone Seed Bed.

In the 2013 series, 26 clones from the bank were established, which were evaluated according to the same criteria in place for the final stages of the selection scheme (Jorge *et al*., 2011). Following a rigorous evaluation, a number of 22 clones were rejected and the study continued with four genotypes. One of them was considered for animal nutrition due to the high production of biomass and the regular sugar content. The other three clones showed good farming and industrial performance in dryland, with high sugar contents. Accordingly, this research aims to evaluate the agro-industrial potential of three new promising sugarcane clones in drylands.

Materials and Methods

The study was done at the Mid-Eastern Territorial Sugarcane Research Station (ETICA), in Camaguey, located in the municipality of Florida, on the following coordinates: 21º 30' north latitude and 78º 15' west longitude, 57.47 m above sea level. The field experiment was conducted in brown soil with carbonates, according to Hernández, Pérez, Bosch & Castro (2015).

The climatic variables were recorded at the Agrometeorological Station in Florida, 300 m away from the field experiment. The relative humidity during the study had a mean of 75.91%; the maximum, minimum, and average temperatures were 31.9, 22.0, and 26.4, respectively. The total of precipitations was 1 302.7 mm in 137 days of rain.

The research was based on a randomized experimental block design with five treatments and three replicas. The treatments evaluated were three promising clones (C13-369, C13-370 and C13-383), and two commercial cultivars (C86-12 and C1051-73) used as controls. Clones C13-369 and C13-370 were the progenies from a two-parent crossing between C86-12 x Mex66-1235 and C13-383, which produced C97-446 x Mex66-1235.

Each experimental unit consisted of two 7.5 m long rows, 1.50 x 0.60 m distant from each other, covering 45 m^2 by plot. The study was planted in dryland, on December 21st, 2018. The agrotechnical work was done according to the standards set for the crop (Santana *et al*., 2014).

The evaluations were performed in the second half of December 2019, 12 months following plantation. The variables evaluated were number of stems by linear meter, stem length, stem diameter, crop yield in tons of sugarcane by hectare (TCH), and the Brix, juice Pol, purity, sugarcane fiber, sugarcane Pol, and Pol tons by hectare (TPH).

The calculations and measurements were made according to the method described by Martins & Landell (1995):

- ✓ The number of stems by linear meter was estimated by counting only the millable stems in the two central rows.
- ✓ The stem length measurements consisted of five millable stems by plot, from the stem base to the last visible dewlap. A 5 m measure tape was used.
- ✓ The stem diameter of five millable stems was measured using a gauge caliper on the lower third.

These data permitted the estimation of the crop yields in tons of sugarcane by hectare (TCH), using the following mathematical equation:

$$TCH=D^2 \times C \times H \times (0.007854/E)$$

Where:

D= Mean stem diameter (cm); **C**= Number of stems by linear meter; **H**= mean stem length (cm); **E**: Distance between rows (1.5 m).

The sugarcane fiber content was determined through the hydraulic press method, and the other juice quality parameters were determined according to the standards of the International Commission for Uniform Methods of Sugar Analysis [ICUMSA] (2011).

STATGRAPHICS Centurion for Windows, version 15.1, was used for statistical analysis. (2006). Simple analyses of variance were conducted to compare the variables evaluated through the F test. In cases where statistically significant differences were observed, the Tukey's test ($p<0.05$) was performed to establish the differences between the means.

Results and discussion

The morphological characteristics may undergo broad variations between cultivars of the same species (Casler, Vogel, Taliaferro & Wynia, 2004), so understanding the growth and productivity components is essential for the selection of existing cultivars (Nyadanu & Dikera, 2014). Under the proper conditions for development, including the ideal humidity and temperature, the plants are able to express all their genetic potential, standing out from other cultivars (Almeida *et al*., 2008; Silva, Jifon, Silva, Dos Santos & Sharma, 2014; Santos, Oliveira, Sousa, Silva & Sarmento, 2014). Therefore, the morphological and productive criteria can assist breeders in the selection and recommendation of promising cultivars (Maia Júnior *et al*., 2018).

Due to the island conditions of Cuba, precipitations and temperatures are the most influential variables in terms of growth and development of sugarcane (Ramírez-Gonzáles, Rodríguez-Moreira, Ramírez-Gonzáles & Barcia-Sardiñas, 2019). The behavior of these variables is essential to interpret the results achieved by the genotypes evaluated throughout this research. Fig. 1 shows the variants of monthly temperature, and the precipitations that took place during the plant cycle.

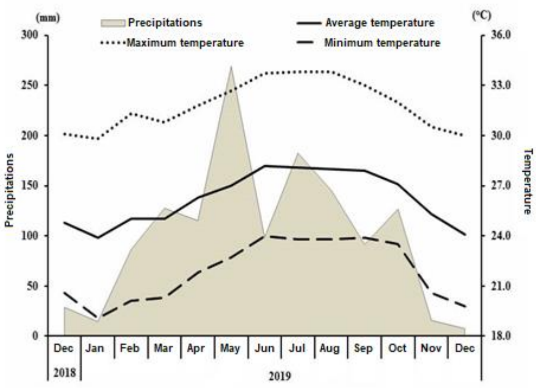

Fig. 1. Monthly means of temperature and precipitation throughout the research.

In the first two months, coinciding with the shooting stage (30-60 days) proper soil humidity was hard to achieve due to the scarce rainfall values. However, the precipitations were distributed, with eight and six rain days, respectively. Hence, the soil humidity content was the minimum needed for the process to occur. The average temperature was 24.6 ºC, within the range (20-32 ºC) where shootings remain unaffected. During the stage (61-120 days), the precipitation record (242.9 mm) and rain days (22), along with mean temperatures between 25 and 26.3 ºC, provided favorable conditions to the phenotypes to show their potential for this necessary agro-botanical characteristic. After the vegetative phase, the momentum or maximum growth stage took place (121-270 days) where the climatic conditions were favorable. A total of 787.4 mm of rain occurred along 76 days, while the average temperature ranged between 27 and 28.2 ºC, with an average maximum value of 33.4 ºC. During the crop maturation phase (271-360 days), 150.2 mm of rain occurred throughout 21 days; 84.42% of the precipitation values was in October. During the same period, the average temperature was 25.5 ºC, with an average minimum of 21.3 ºC. The low rainfall values, especially in the last two months, and the reduction of temperatures produced favorable conditions for maturation of the experimental genotypes.

Table 1 shows the results observed through the analysis of variance of the sugarcane cultivars studied, at 12 months of age. As observed, there were statistically significant differences between the cultivars for the four variables cultivated. A behavior that coincides with the findings of Santana *et al.* (2017), who pointed out that the agro-botanical features are inherent to every particular genotype, an expression influenced by the climate and the farming practices.

Regarding stem length, clone C13-383 and commercial cultivar C86-12 showed the best mean values of the study, which differed statistically from the rest. The lowest value was found in the control cultivar C1051-73. The values observed in the study were above 270 cm, with an average monthly growth between 22.61 and 29.08 cm. These values demonstrated the satisfactory development reached by the genotypes, which were favored by the climatic conditions that prevailed during all the vegetative phases of the crop (Fig. 1).

Table 1. Behavior of the agro-botanical characteristics evaluated in the study

Cultivars	LT (cm)	DT (cm)	Population (Stems m^{-1})	TCH (t ha^{-1})
C13-369	295.00^{bc}	3.17^{a}	10.61^{c}	164.48^{bc}
C13-370	297.33^{b}	3.23^{a}	12.11^{b}	196.62^{ab}
C13-383	349.00^{a}	2.98^{ab}	14.52^{a}	235.46^{a}
C86-12	324.67^{a}	2.95^{ab}	11.37^{bc}	168.38^{b}
C1051-73	271.33^{c}	2.69^{b}	11.97^{bc}	123.48^{c}
Sig.	***	**	***	***
X̄	**307.47**	**3.00**	**12.11**	**177.69**
SE	**7.45**	**0.05**	**0.05**	**10.57**

LT: Stem length **DT:** Stem diameter **TCH:** Sugarcane tons per hectare

Note: Means with different scripts on the same column differ significantly, according to (ANOVA, Tukey, significant ******* p <0.001, ****** p <0.01).

Similar results were achieved in Ecuador, by Ramón (2011), upon evaluation of three cultivars of sugarcane from Cuba, compared to the Cristalina variety. The above author found stem length values of 279 and 360 cm. Santana *et al*. (2017) also found values between 220.1 and 327.6 cm in a study of six sugarcane cultivars in Brazil. In the two studies made by the previously cited authors, the crop was established under irrigation conditions.

Lower results were published by Arreola-Enríquez *et al*. (2019) by evaluating 12 sugarcane cultivars in Mexico, and found values between 212.6 and 284.3 cm, and by Tesche, Ragghianti, de Pauli & Marques (2014), in Brazil, where the sugarcane cultivars reached 190.33 and 241.67 cm.

The results found in the clones are promising and relevant, considering the findings of Singels & Savage (2003), and Capone, Lui, Silva, Dias, & Melo (2011), who noted that this trait is fundamental for the crop's development, which mainly occurs depending on the genetic characteristics of the material, and can be used as a base in the characterization and selection of promising cultivars.

Barbosa, Prado, Vale, Avalhães & Fonseca (2012) pointed out that there is a positive correlation between stem length and productivity; that is, higher cultivars would tend to have more mass per stem, and consequently, more productivity. Reis *et al*. (2019) also found positive correlations to the green biomass yields (r=0.80), and dry mass (r=0.78), which evidenced the significance of this morphological characteristic in relation to the reproductive aspects of the cultivars.

Regarding stem diameter, the elite clones C13-369 and C13-370 showed the highest mean values, over 3 cm thick. These results did not differ statistically from C13-383 and the commercial cultivar C86-12, but did differ from C1051-73, which had the lowest experimental values.

Similar results were found by Ramón (2011) and Arreola-Enríquez *et al*. (2019), who reported mean values that varied between 2.8 and 3.6 cm. On the contrary, Tesche *et al*. (2014) and Santana *et al.* (2017) found mean values between 2.31 and 2.68 cm, lower than in this study.

De Souza *et al.* (2011) and Tesche *et al.* (2014) reported that the differences found in this important character were mainly given by the intrinsic genetic factors of each cultivar. Moreover, they highlighted their relevance due to the positive correlations with the stem weight, suggesting that it can be a good parameter for crop breeding.

Clone C13-383 showed the greatest number of stems per linear meter in the experiment. It differed statistically from the other genotypes. Clone C13-369 showed the lowest value of the variable, though in sugarcane, the genotypes with the greatest stem diameter showed the lowest tillering. In that sense, Oliveira *et al*. (2007) and Maia Júnior *et al*. (2018) found significant negative correlations between the stem number and diameter. This clone reached over 3 cm stem thickness (valued defined as thick), coinciding with the previous remarks.

The mean values found in the study were similar to the ones published by Ramón (2011); Tesche *et al.* (2014); Santana *et al*. (2017) and Arreola-Enríquez *et al.* (2019), who found a number of stems ranging between 9 and 14 per linear meter.

Particularly, the three promising clones showed a mean value of 12.41 stems per linear meter, which is significant, considering that this agro-botanical characteristic is one of the most influential yield components in this crop (Rincón, 2005; Baracat-Neto, Scarpare, Araðjo & Scarpare-Filho, 2017).

Clone C13-383 reached its highest agricultural mean yield value in the research. It differed statistically from the other genotypes, except C13-370. Cultivar C1051-73 showed the highest farming productivity. The average productivity reached in the study (177.69 t ha^{-1}) was high, and it can be attributed largely to proper crop management, from soil preparation through to harvest, and the favorable climatic conditions so that the genotypes could express their genetic potential. These results were better than the mean farming yields in Cuba (40 t ha^{-1}), and the world (75.50 t ha^{-1}).

Particularly, the three promising clones showed high farming productivity, with an average value of 198.85 t ha^{-1}. Clone C13-383 stood out due to its excellent shooting, spread tillering, and proper development through the vegetative stages. These results corroborated the reports of Rincón (2005); Milanés *et al.* (2013) and Baracat-Neto *et al*. (2017), who along with other factors that define the farming yields of sugarcane, the cultivar, age, type of stump, edaphoclimatic conditions and plantation management, play a major role as well.

Lower results were published by Castro, Andrade, Botrel & Evangelista (2009); Ramón (2011); Benett *et al*. (2013); Tesche *et al*. (2014); Pereira *et al.* (2017); Santana *et al.* (2017); Arreola-Enríquez *et al.* (2019) and Cervantes-Preciado, Milanés-Ramos & Castillo (2019), who found mean farming yields between 95.70 and 141.07 t ha^{-1}, in their research. Higher productivity values were published by Camus *et al.* (2019) in Peru, which reached a mean farming yield of 189.94 t ha^{-1} in 12 sugarcane cultivars, but harvested at an older age (18.5 months) than in this study.

As to the juice quality parameters, Table 2 shows statistically significant differences between cultivars.

Table 2. Behavior of juice quality parameters evaluated

Cultivar	ºBrix	PJ	Purity (%)	Fiber (%)	PC (%)	TPH (t ha^{-1})
C13-369	20.53^{b}	17.78^{b}	86.57^{c}	12.72^{b}	15.51^{b}	25.53^{bc}
C13-370	20.67^{ab}	18.77^{a}	90.84^{a}	14.18^{a}	16.11^{a}	31.67^{ab}
C13-383	20.53^{b}	18.51^{a}	90.16^{ab}	12.36^{b}	16.23^{a}	38.18^{a}
C86-12	20.90^{a}	18.71^{a}	89.52^{b}	12.70^{b}	16.24^{a}	27.50^{b}
C1051-73	20.80^{ab}	18.81^{a}	90.42^{ab}	13.66^{a}	16.33^{a}	20.05^{c}
Sig.	*	***	***	***	**	***
$\bar{X}$	**20.69**	**18.52**	**89.50**	**13.13**	**16.08**	**28.59**
SE	**0.04**	**0.10**	**0.41**	**0.19**	**0.08**	**1.72**

PJ: Pol in juice **PC:** Pol in sugarcane **TPH:** Pol tons per hectare

Note: Means with different scripts on the same column differ significantly, according to (ANOVA, Tukey, significant *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$).

Commercial cultivar C1051-73 reached the mean Brix value, which except for C86-12 and C13-370, differed statistically from the other two genotypes. The promising clones did not show statistically significant differences between them.

The Brix values found in the study were within the ranges published by Ramírez, Insuasty & Viveros (2014), who indicated that that juice Brix grades must normally fluctuate between 16 and 24. Also, Cobeña & Loor (2016) said that the concentration of soluble solids in the juice of the mature plant of sugarcane that is sent to the industry in dry times was 19-22 Brix. Rodrigues & Santos (2011) noted that when the sugarcane starts to mature, a very close relation takes place between the percentage of soluble solids and the sucrose content seemingly in the solution, which is considered mature, with a minimum Brix of 18º, among other factors. Therefore, the three promising clones evidenced maturity at the beginning of harvest, a major characteristic of Cuba, due to the need to have highly-productive genotypes with high sugar contents that can be used to program the harvest.

Lower results were published by Ramón (2011), using three Cuban sugarcane cultivars and the Cristalina variety. The author found between 16.15 and 18.74 Brix. Besides, Vera-Espinosa *et al.* (2016) found values between 15.94 and 19.51, lower than in this study. Cobeña & Loor (2016) reported 18.66 and 21.9 ºBrix in 12 cultivars, similar to this research.

Clone C13-369 showed the lowest mean value of the Pol in juice, which differed statistically from the other genotypes in the study. According to Checa (2010), the values achieved in the study were classified according to the parameters to determine the quality of sugarcane as excellent, except for C13-369, which was classified as good, staying below 18 g/100g sugarcane.

Clone C13-370 purity showed the best mean values, which did not differ statistically from C13-383 and C1051-73, but differed from the other genotypes studied. Clone C13-369 had the lowest mean purity value. According to Rein (2012), good quality, clean, and fresh sugarcane produces juice with about 90% purity. Fernández, Trigo & Fernández (2015) noted that the percentage of purity helps determine the time of sugarcane maturity, above the readiness range (75%). Hence, promising clones C13-370 and C13-383 were classified into early-maturation genotypes, showing very similar values to cultivar C1051-73. Clone C13-369 could be considered as a mid to early-maturation genotype, similar to C86-12, which was the female parent used in the crossing (C86-12 x

Mex66-1235) through hybridization, producing this genotype and clone C13-370.

Clone C13-370 and commercial cultivar C1051-73 showed the highest mean values of fiber percentage in sugarcane. These results differed statistically from the other three genotypes in the study. Clone C13-383 was the one with the lowest fiber content. The values achieved in the study were within the reference range (11-18%) for clean sugarcane, published by Rein (2012). Larrahondo (1995) noted that 12% of fiber is the ideal content to send to the industry internationally, 12.5% is the value accepted for the millable stem. Santana *et al*. (2017) also stressed that the content of fiber in sugarcane depends on the cultivar, the climate (precipitations and temperature), the soil (humidity and fertility), age, and harvest cycle. Dias, Corsato, Santos & Santos (2012) remarked that the fluctuation in the content of fiber among cultivars is a genetic characteristic, and that the genotypes with a high sugar content have the lowest fiber content.

Similar values were published by Abreu, Silva, Teodoro, Holanda & Sampaio (2013) and Silva, Arantes, Rhein, Gava & Kolln (2014). Fernández *et al.* (2015) said that a mean value over 14.5% of fiber content was above the mean found in this research.

The sucrose percentage in sugarcane (Pol) is, undoubtedly, the most relevant and interesting variable; the higher its value at harvest, along with the field yields and industry efficiency, the greater the volume of sugar produced (Cervantes-Preciado *et al.*, 2019). Clone C13-369 had the lowest mean purity value. However, considering the parameters for the determination of sugarcane quality (Checa, 2010), the value (>15 %) can be considered as excellent.

Similar results to this study were published by Vizcaíno & Flores (2007); Carrillo-Ávila, Vera-Espinosa, Alamilla-Magaña, Obrador-Olán & Aceves-Navarro (2008) and Cervantes-Preciado *et al*. (2019), with values between 14 and 17% Pol in sugarcane. Moreover, Ramon (2011); Arreola-Enríquez *et al.* (2019) and Camus *et al.* (15.79%) found average values between 11.66 and 15.79%, lower than in this study.

Clone C13-383 reached the highest mean value of TPH (sucrose per hectare), which did not differ statistically from C13-370, but it differed from the other genotypes. Although the commercial cultivar C1051-73 reached its highest values of Pol percentage in the sugarcane, it showed the lowest value of this indicator. This result evidences the significance of crop yields. Camus (2019) noted that sugarcane productivity should have more relevance than the sucrose content, due to the direct relation it has with the total sugar to produce per surface unit.

Lower results were published by Ramón (2011); Arreola-Enríquez *et al.* (2019) and Camus *et al.* (2019), who found mean values that varied between 9.86 and 23.67 t Pol ha^{-1}, evidencing the high agro-industrial potential of the new promising clones and the cultivars used as controls in the study.

Conclusions

The three promising sugarcane clones were characterized by high crop productivity and elevated sugar content, similar to, and even higher than, the controls C86-12 and C1051-73. These results demonstrated their high genetic potential for sugar production, confirming their possible use as early-maturation cultivars to be harvested at the beginning of production.

Author contribution statement

Yoslen Fernández Gálvez: research planning, template process, analysis of the results, redaction of the manuscript, proof-reading.

Isabel Torres Varela: research planning, experimental mounting and evaluation, analysis of the results, final review.

Joaquín Montalván Delgado: experimental mounting and evaluation, analysis of the results, redaction of the manuscript, final review.

Yusvel Hermida Baños: experimental mounting and evaluation, analysis of the results, redaction of the manuscript, final review.

Héctor García Pérez: analysis of the results, redaction of the manuscript, final review.

José M. Mesa López: analysis of the results, redaction of the manuscript, final review.

Conflicts of interests

The authors declare the existence of no conflicts of interest

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