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Association technological and agronomic traits sugarcane for the quantitative and qualitative production of brown sugar

Patricia Jesus de Melo[1], Alessandro Dal'Col Lúcio[1], Elisangela Marques Jeronimo Torres[2], Sidinei José Lopes[1], Darlei Michalski Lambrecht[1]*, Maria Inês Diel[3]

[1] Universidade Federal de Santa Maria, Santa Maria, RS, Brasil. E-mail: patty_de_melo@yahoo.com.br; adlucio@ufsm.br; sjlopes2008@gmail.com; darleilambrecht@gmail.com
[2] Agência Paulista de Tecnologia dos Agronegócios, URPD Bauru, Bauru, SP, Brasil. E-mail: elisangela.torres@sp.gov.br
[3] Universidade Federal do Pampa, Itaqui, RS, Brasil. E-mail: mariaines.diel@hotmail.com

ABSTRACT: Despite the growing demand for the consumption of brown sugar, there is little study on sugarcane cultivars and harvesting times more propitious for the production of brown sugar. In this sense, the objective of this study was to identify linear relationships between agronomic and technological variables of different genotypes and harvest times, to identify direct and indirect effects on the quantitative and qualitative production of brown sugar. For this, an experiment was carried out in a split-plot scheme (genotypes × growing seasons), in a randomized block design with four replications. The variables analyzed were stem height, the number of internodes, apparent sucrose in sugarcane, apparent sucrose from broth, soluble solids content of cane, fiber, purity, total recoverable sugars, average stem mass, the volume of broth extracted, content of soluble solids in the broth, frown sugar apparent sucrose, instrumental color, mass of brown sugar per ton of cane and the amount of broth per ton of cane. The statistical analyzes performed were path analysis and canonical correlation. The amount of juice per ton of cane and ºBrix of the juice can be selected for greater brown sugar production, both had a greater direct effect. With different responses in the three harvests, the canonical correlation showed interdependence between groups of variables, inferring those agronomic variables can be used in the selection of better-quality brown sugar cultivars. If the objective is greater sugar production, season 1 proved to be more promising in relation to the others.

Key words: canonical correlation; harvest season; multivariate analysis; path analysis

Associação de características tecnológicas e agronômicas da cana-de-açúcar para produção quantitativa e qualitativa de açúcar mascavo

RESUMO: Apesar da crescente demanda pelo consumo de açúcar mascavo, há pouco estudo sobre cultivares de cana-de-açúcar e épocas de colheita mais propícias para a produção de açúcar mascavo. Neste sentido o objetivo deste estudo foi identificar relações lineares entre variáveis agronômicas e tecnológicas de diferentes genótipos e épocas de colheita, para identificar efeitos diretos e indiretos na produção quantitativa e qualitativa de açúcar mascavo. Para isso, realizou-se um experimento em esquema de parcelas subdivididas, (genótipos × épocas de cultivo), em delineamento blocos ao acaso com quatro repetições. As variáveis analisadas foram altura do caule, número de entrenós, sacarose aparente na cana-de-açúcar, sacarose aparente do caldo, teor de sólidos solúveis da cana, fibra, pureza, açúcares totais recuperáveis, massa média do caule, volume de caldo extraído, teor de sólidos solúveis no caldo, açúcar carranca sacarose aparente, cor instrumental, massa de açúcar mascavo por tonelada de cana e a quantidade de caldo por tonelada de cana. As análises estatísticas realizadas foram análise de trilha e correlação canônica. A quantidade de caldo por tonelada de cana e o ºBrix do caldo podem ser selecionados para maior produção de açúcar mascavo, pois ambos tiveram maior efeito direto. Com respostas diferentes nas três safras, a correlação canônica mostrou interdependência entre os grupos de variáveis, inferindo que essas variáveis agronômicas podem ser utilizadas na seleção de cultivares de açúcar mascavo de melhor qualidade. Caso o objetivo seja maior produção do açúcar, a época 1 mostrou-se mais promissora em relação às demais.

Palavras-chave: correlação canônica; temporada de colheita; análise multivariada; análise de trilha

* Darlei Michalski Lambrecht - E-mail: darleilambrecht@gmail.com (Corresponding author)
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Introduction

The culture of sugar cane (*Saccharum* spp.), of the family Poaceae, has great worldwide importance, economic and social, its main derivatives are ethanol and sugar (CONAB, 2020). Among the derivatives of sugar cane is brown sugar, which had its rediscovery and growing demand for presenting characteristics of a healthy product and with numerous health benefits (Okabe et al., 2009). In view of the importance of the crop, brown sugar consumption and the current growth in preference for the consumption of brown sugar in the search for healthier foods, there is still a lack of information about the most suitable cultivar for the production of brown sugar. Besides that, so that a breeding program can carry out the selection of characters in certain genotypes, the researcher needs to know the impact that his selection will have on brown sugar production.

This way, there is a need for a more in-depth investigation of the possible relationships between the variables measured in experiments that evaluate the productivity of sugarcane the yield and quality of processed brown sugar. The selection of traits of interest for genetic improvement can be performed by statistical analysis, these help the researcher to make the correct decision about which trait to select, to increase brown sugar production, for example. Among the multivariate data analysis methodologies, Pearson's linear correlation allows identifying the correlation between two variables (Pearson, 1920).

After estimating the linear correlation coefficients, path or cause and effect analysis can be performed, which unfolds Pearson correlation coefficients into direct and indirect effects of independent variables on a main dependent variable (Wright, 1934), making it possible to identify how independent variables, directly and indirectly influence a main dependent variable (Cruz et al., 2012).

Beyond track analysis, canonical correlation analysis can contribute to the researcher work, when it faces two groups of traits. In this approach, we seek to identify and quantify the relationships between two groups of agronomic traits, so that their maximized correlations (Cruz et al., 2012).

Studies have already been carried out with the cultivation of sugarcane, aiming to contribute to the genetic improvement of the culture, with the application of canonical correlation and path analysis techniques, but none was directed to the production of brown sugar, among them are Masri et al. (2015), Barbosa et al. (2017), and Ali et al. (2018, 2019). In view of the above, seeking to contribute to the study of the improvement of the sugarcane culture for the production of brown sugar, this work aims to identify linear relationships between agronomic and technological variables of different genotypes and harvest times, to identify direct effects and indirect in the quantitative and qualitative production of brown sugar.

Materials and Methods

Cultivation conditions and the study area

The experiment was carried out in the city of Jaú - São Paulo, Brazil, located at 22° 17' S and 48° 34' W with 580 m of altitude. Based on Köppen classification, the climate in this region, is Aw-dry type (Alvares et al., 2013), with an annual temperature average of 21.6 °C, annual rainfall average of 1,344 mm. Fertilization throughout the experiment followed soil analysis, with applications according to the technical recommendations for the crop (Lorenzi et al., 1997). The planting was carried out in the first fortnight of April 2013, with planting carried out in furrows, was planted in the rows at a density of 18 buds per meter.

Experimental design

The experiment was conducted in a split-plot scheme, having in the plots the genotypes and in the subplots the season, in a randomized block design with four replications. The study consisted of ten sugarcane genotypes, characterized in Table 1, with their parents, origin, maturation group and percentage of the cultivated area in Brazil in the 2017/2018 harvest, where data were collected from 6.8 million hectares and in the state of São Paulo, data were collected a cultivated area was 3.8 million hectares in the 2018/2019 harvest (Braga Junior et al., 2019). Three harvesting seasons, namely 15 (Season 1(S1)), 17 (Season 2(S2)), and 19 (Season 3(S3)) months

Table 1. Classification of sugarcane genotypes according to the maturation group, source, cultivated area, and its parents.

Genotype	Code	Ripening group	Source	Area cultivated in the 2017/2018 harvest in Brazil%	Area cultivated in the 2018/2019 harvest in the state of SP%	Parenting	
IACSP04-656	G1	No/Inf	IAC[1]	No/Inf	No/Inf	IACSP93-3046	SP77-5181
IACSP04-704	G2	No/Inf	IAC[1]	No/Inf	No/Inf	IACSP95-3028	SP77-5181
IACSP93-3046	G3	Medium/late	IAC[1]	No/Inf	No/Inf	SP79-1011	NA
IACSP95-5000	G4	No/Inf	IAC[1]	No/Inf	1.8	SP84-2066	SP80-185
IACSP95-5094	G5	Medium	IAC[1]	No/Inf	No/Inf	SP80-3280	NA
IACSP96-3060	G6	Medium/late	IAC[1]	No/Inf	No/Inf	SP82-6108	NA
IACSP97-4039	G7	Precocious	IAC[1]	No/Inf	No/Inf	RB835486	RB855453
RB867515	G8	Medium/late	RIDESA[2]	26	18.3	RB72454	NA
RB966928	G9	Precocious	RIDESA[2]	9.2	15.1	RB855156	RB815690
SP81-3250	G10	Medium	Copersucar	5.7	2.1	CP70-1547	SP71-1279

[1] IAC - Instituto Agronômico de Campinas; [2] RIDESA - Rede Interuniversitária para o Desenvolvimento do Setor Sucroenergético; SP - São Paulo.

after planting were allocated in the sub-plots corresponding to moment before and after the sugarcane harvest, that is, at the most common season of harvesting sugarcane grown in the year and a half and after the cultivation of sugarcane. The experimental plot was composed of five 8 m length cropping rows spaced by 1.5 m, making a total useful area of 60 m² (2.400 m² of experimental area).

Traits evaluated

In each harvest, a sample of 62 stems was collected in the subplot, referring to 1/3 of the main portion. This sample was separated into two subsamples. An, with 12 stems was used to measure the traits stem height (SH in cm), the number of internodes (NI in nº), apparent sucrose in sugarcane (ASS cane in %), apparent sucrose from broth (ASS broth in %), soluble solids content of cane (ºBrix cane in %), fiber (F in %), purity (%) e total recoverable sugars (TRS in kg ton^{-1}). The other sub-sample with 50 stems, was used to measure the average stem mass (ASM in kg), the volume of broth extracted in a small mill, (BV in L) and content of soluble solids in the broth (ºBrix of the broth in %) to be used for brown sugar processing.

Eight liters of broth, of the broth extracted from the 50 stems, were directed towards the production of brown sugar, at atmospheric pressure, in semi-industrial high-pressure gas stove. The temperature throughout the process was around 90 to 100 ºC and with a temperature of 115 ºC at the end of the concentration and obtaining the mass, the moment called brown sugar obtaining point, which is immediately removed from the fire for the manual tapping and sugar crystallization.

For each day of analysis, four batches of brown sugar were produced per day, where each batch came from the eight liters per pot. The sequence of analyzes lasted ten consecutive days. The samples were analyzed for instrumental color, using a Minolta portable colorimeter, model CR400, scale CIELAB. The device measures the coordinates L*, representing the luminosity on a zero scale (black) a hundred (White); a* represents a scale of shades of red (0 + a) the green (0 – a); and b*, which represents a scale of shades of yellow (0 + b) the blue one (0 – b).

The chroma trait (Hue angle) was measured by converting the values of a* and b* obtained, setting the color intensity (0 in the center and increases with the distance of this). The soluble solids content was measured in an automatic bench refractometer, mark Reichert, model I300, and the readings of brown sugar apparent sucrose (ASS BS %) were performed in Polarimeter, mark Anton Paar, model MCP 200. The mass of brown sugar per ton of cane was calculated (BSTC in kg) and the amount of broth per ton of cane (BTC in %).

Statistical analysis

Statistical analyzes were performed for each harvest season. Pearson correlation coefficients were initially estimated, after checking the degree of multicollinearity in groups of traits, consecutively, the split into direct and indirect effects was carried out utilizing the path analysis (Wright, 1934). The trait used as the main dependent was the production of brown sugar per ton of sugarcane (BSTC in kg).

Canonical correlation analysis was also performed between the two groups of traits, in which group 1 was composed of agronomic traits SH, NI, BSTC, BTC, ASM and group 2, was formed by technological traits: Fiber, ºBrix cane, ASS broth, purity, ASS cane, TRS, °Brix broth, ASS BS, "L", "a", "b" and chroma.

To identify the multicollinearity between the traits, for both path analysis and canonical correlation analysis, the variance inflation factor was estimated (VIF) $VIF = 1/ (1 – r^2)$, as described by Montgomery et al. (2012) and, also by the condition number (NC). According to Montgomery et al. (2012), multicollinearity is considered weak when VIF < 10 and NC ≤ 100, moderate to severe when 100 < NC ≤ 1,000 and severe when NC > 1,000. When the variance inflation factor VIF superior to 10 or NC superior to 100 indicates moderate to severe multicollinearity, and so it will be removed.

For the interpretation of the canonical correlation analysis, the coefficients of the crossed canonical loads were used. The significance of canonical correlations was tested using the t-test and the chi-square test with 5% significance. Statistical analyzes were performed using the software R (R Core Team, 2019).

The correlation matrix was obtained by the *color* function and the path analysis utilizing the *pathanalysis* function, both carried out through the package *biotools*, versão 3.1 (Silva et al., 2017). To perform the canonical correlation analysis, the *cca* function of the *yacca* package was used (Butts, 2018). In multicollinearity, for identifying the condition number, the *cond* function of the *pracma* package was used (Hans et al., 2019) and for the VIF of traits the *vif* function of the *faraway* package (Faraway, 2016).

Results and Discussion

In the multicollinearity test performed on the correlation matrix, results were obtained with VIF > 10 and NC > 100, therefore, the traits that presented VIF above 10 were excluded, such that the NC of the group of traits, presented value below 100. After it was deleted traits BV, Fiber, TRS, ASS broth, and CHROMA that were causing multicollinearity for canonical correlation analysis. Then the traits were excluded NI, VC, Fiber, TRS, ASS broth, and SH that were causing multicollinearity for the track analysis. After removing these characters, the other traits and group of traits have low values for the VIF and NC, indicating weak multicollinearity (Table 2). In the path analysis, the traits CHROMA, "L", "a", "b" and the ASS BS were eliminated before analysis because they are traits obtained after obtaining brown sugar.

In the path analysis, the groups formed in the three harvest seasons presented low NC and VIF, indicating low multicollinearity. Different groups were formed at different harvest seasons (Table 2) because if the same traits are kept, multicollinearity would be high, thus, the selection was made according to the degree of multicollinearity.

Table 2. Traits average stem mass (ASM in %), cane soluble solids content (°Brix cane in %), purity (%), the soluble solids content of the broth (°Brix broth in %), amount of broth per ton of cane (BTC in %), stem height (SH in cm), brown sugar apparent sucrose (ASS BS in %), apparent sucrose in the broth (ASS broth in %), the number of internodes (NI in nº) and color parameters "L", "a", "b" and CHROMA after reducing multicollinearity, variance inflation factor (VIF) and condition number (NC) for path analysis and canonical correlation, for three sugarcane harvest seasons (S1, S2, and S3).

Path Analysis					
S1		S2		S3	
Trait	VIF	Trait	VIF	Trait	VIF
ASM	5.27	ASM	1.26	ASM	1.29
°Brix cane	3.76	°Brix cane	2.74	°Brix cane	4.72
Purity	2.47	Purity	1.82	Purity	5.79
°Brix broth	3.66	°Brix broth	2.50	°Brix broth	1.93
BTC	1.78	BTC	1.76	BTC	1.85
SH	4.58	-	-	-	-
NC 27.13		NC 10.42		NC 24.70	
Canonical correlation					
Trait	VIF	Trait	VIF	Trait	VIF
Technological traits					
°Brix cane	1.50	Fiber	1.58	Fiber	1.46
Purity	1.14	°Brix cane	1.53	°Brix cane	2.17
°Brix broth	1.54	Purity	1.22	Purity	1.83
ASS BS	1.39	°Brix broth	2.06	°Brix broth	1.50
"L"	4.96	"L"	8.13	"L"	4.20
"a"	2.24	"a"	2.4	"a"	1.70
"b"	3.97	"b"	6.54	"b"	3.58
-	-	Chroma	2.93	ASS broth	1.79
-	-	ASS BS	1.67	ASS BS	1.67
NC 22.49		NC 47.03		NC 26.0	
Agronomic traits					
BSTC	2.54	BSTC	3.38	BSTC	1.71
ASM	2.45	ASM	1.75	ASM	2.57
SH	1.69	SH	2.07	SH	2.10
NI	1.34	NI	1.32	NI	1.61
BTC	2.90	BTC	3.50	BTC	1.70
NC 12.33		NC 12.33		NC 9.0	

In path analysis and canonical correlations, the diagnosis of multicollinearity is of great importance, because when they have high multicollinearity, correlations can be inaccurate. When this occurs, the exclusion of traits that are causing multicollinearity is one of the alternatives to reduce the bias of the results obtained (Montgomery et al., 2012).

For the results of the path analysis of the first harvest season, the direct effect of dependent traits on the main trait ranged from -0.0620 to 0.9695 (Table 3). There was a direct effect of the trait broth per ton of cane on brown sugar production, with a value of 0.9695 and a significant correlation of 0.8686, indicating cause and effect relationship between the traits. The greater the amount of broth obtained, the greater the brown sugar production (Table 3). In other traits, no direct or indirect effect was significant in brown sugar production. The determination coefficient obtained was 0.8845 and the residual effect of 0.3398.

The direct effect found by the path analysis at season 1 of the BTC trait (0.9695) proves the influence of the amount of broth per ton of sugarcane on brown sugar production, this result was already expected, since the more broth is used, the greater the production. These results were repeated for the second harvest season. The highest sugar production occurs due to the amount of sucrose in the broth (Santos et al., 2018).

For the second harvest season, a direct effect variation was from -0.4326 to 0.7755. The BTC trait had a direct effect on the main trait (Table 3), a result similar to that obtained in the first harvest season. The determination coefficient obtained was 0.7816 and residual effect of 0.4674. In the third harvest season, the direct effect of the dependent traits on the main trait varied from -0.6733 to 0.8764. The BTC trait had a direct effect on brown sugar production (0.8764), as well as the °Brix do broth showed high direct effect (0.6738) and with significant correlation, indicating that these traits directly influence the production of brown sugar (Table 3).

In the third harvest season, the amount of broth is no longer the trait that most influenced the amount of sugar produced, becoming the °Brix broth (0.6738), that due to the cane maturation curve being with the °Brix high (greater accumulation of sugars) which may be due the longer permanence of sugarcane in the field of cultivation (Table 3).

Ali et al. (2019) used indirect character selection, for sugar production, and according to the authors, it can be determined by agronomic factors, morphological or physiological with associations and interrelationships, sugar production was influenced by the °Brix broth. For Gravois et al. (1991) in his studies obtained a direct effect of °Brix broth in 0.48 and indirect of 0.43, results close to those observed in this study, the mentioned authors did not describe the season of cultivation of sugarcane in the field.

The groups of traits formed to determine the canonical correlations had low NC and VIF, indicating weak multicollinearity (Table 2). The groups formed at different harvest seasons did not show the same traits, because in some seasons when using the same traits, multicollinearity would be high, so the selection was different in each group. In Table 4, it was only chosen to present only the first two canonical pairs, aiming at better visibility of the results, since only the first canonical pair was significant in the first and third harvest times.

The results of the canonical correlation analysis for the first harvest season, presented the first significant canonical pair (0.80), indicating interdependence between groups of agronomic and technological characters (Table 4). The other canonical pairs did not present a significant correlation. Through the canonical R^2 found, the explained variance was 65% between the independent and dependent canonical traits of the first group of canonical traits.

The group I, the instrumental color traits ("L" and "b") presented the highest values 0.63 and 0.71 respectively, while for group 2 (independent), the trait SH presented the highest value (-0.79), showing a correlation between the mentioned traits and indicating that, stems with smaller size allow the

Table 3. Direct effects of variable production of brown sugar per ton of cane (BSTC in kg) and indirect effects and correlation coefficient (r) for the three sugarcane harvest seasons, according to the groups formed in Table 2, for the average stem mass traits (ASM in %), stem height (SH in cm), soluble solids content (°Brix cane in %), purity (%), soluble solids content of the broth (°Brix broth in %), amount of broth per ton of cane (BTC in %). Diagonal and bold values indicate a direct effect.

	ASM	°Brix cane	Purity	°Brix broth	BTC	SH	r
Harvest season 1							
ASM	**-0.0620**	0.0066	0.0819	0.0345	-0.3675	0.0754	**-0.2311**
°Brix cane	-0.0024	**0.1674**	-0.0396	0.1593	-0.1209	0.0208	**0.1846**
Purity	-0.0265	-0.0346	**0.1917**	-0.0173	-0.4091	-0.0026	**-0.2983**
°Brix broth	-0.0104	0.1297	-0.0161	**0.2057**	0.0741	0.0102	**0.3931**
BTC	0.0235	-0.0209	-0.0809	0.0157	**0.9695**	-0.0383	**0.8686***
SH	-0.0461	0.0343	-0.0048	0.0207	-0.3665	**0.1013**	**-0.2611**
Determination coefficient: 0.8845							
Residual effect: 0.3398							
Harvest season 2							
ASM	**-0.0515**	0.0782	0.054	-0.0882	-0.3088	-	**-0.3163**
°Brix cane	0.0093	**-0.4326**	0.0662	0.3408	0.1316	-	**0.1152**
Purity	0.0137	0.1408	**-0.2034**	0.0177	0.3753	-	**0.3441**
°Brix broth	0.0093	-0.3024	-0.0074	**0.4875**	0.3179	-	**0.5049**
BTC	0.0205	-0.0734	-0.0984	0.1998	**0.7755**	-	**0.8239***
Determination coefficient: 0.7816							
Residual effect: 0.4674							
Harvest season 3							
ASM	**-0.1866**	-0.1383	0.1863	0.0900	-0.0507	-	**-0.0993**
°Brix cane	0.0422	**0.6115**	-0.5434	0.4000	-0.0583	-	**0.4520**
Purity	0.0516	0.4935	**-0.6733**	0.3882	0.2975	-	**0.5575**
°Brix broth	-0.0249	0.363	-0.388	**0.6738**	0.0089	-	**0.6328***
BTC	0.0108	-0.0407	-0.2286	0.0068	**0.8764**	-	**-0.6247**
Determination coefficient: 0.8934							
Residual effect: 0.3266							

* Significant 5% probability of error by the F test.

Table 4. Canonical loads crossed for the three seasons of harvest sugar cane for the production of brown sugar, according to the groups formed in Table 2, for the cane soluble solids content traits (°Brix cane in %), purity (%), soluble solids content of the broth (°Brix broth in %), apparent sucrose content of brown sugar (ASS BS in %), "L", "a", "b", fiber (%), CHROMA, apparent sucrose content of the broth (ASS broth in %), brown sugar per ton of sugarcane (BSTC in kg), average stem mass (ASM in %), stem height (SH in cm), number of internodes (NI in nº) and amount of broth per ton of cane (BTC in %).

Group 1	Harvest season 1		Harvest season 2		Harvest season 3	
	Canonical pair					
	CV 1	CV2	CV 1	CV2	CV 1	CV2
°Brix cane	-0.13	-0.06	0.09	0.13	0.30	0.33
Purity	0.05	0.09	0.24	0.12	0.44	0.09
°Brix broth	0.04	0.10	0.33	-0.07	0.43	0.26
ASS BS	0.05	-0.41	0.44	-0.45	0.58	0.27
L	0.63	-0.13	-0.05	-0.05	0.01	0.29
a	-0.07	0.05	-0.32	0.05	0.34	0.21
b	0.71	0.05	0.06	0.09	0.31	0.26
Fiber	-	-	-0.12	0.10	-0.18	0.53
CHROMA	-	-	0.10	0.16	-	-
ASS broth	-	-	-	-	0.38	0.05
Group 2	**CV 1**	**CV2**	**CV 1**	**CV2**	**CV 1**	**CV2**
BSTC	0.26	0.32	0.60	-0.01	0.68	-0.36
ASM	-0.48	0.14	-0.30	-0.43	-0.09	0.00
SH	-0.79	0.05	-0.21	-0.01	-0.19	0.22
NI	-0.20	0.42	0.14	0.12	0.21	0.02
BTC	0.24	0.32	0.30	0.12	0.16	-0.56
Corr	0.80	0.55	0.74	0.65	0.81	0.68
R^2 canonical	0.65	0.30	0.55	0.42	0.66	0.46
Degrees of freedom	35	24	45	32	45	32
χ^2	120.2	102.4	119.4	101.2	119.4	101.17
Pr(>F)	0.02*	0.67^{ns}	0.06^{ns}	0.30^{ns}	0.00*	0.12^{ns}

* Significant at 5% probability of error by F test; ns not significant.

production of brown sugar with yellow color in light shade (Table 4).

In the first harvest season, smaller culms were obtained, showed a positive correlation with instrumental color traits, "L" and "b", sugar being produced with a lighter color at this season. As this qualitative response was observed only in the first harvest season, it can be associated with the maturation point of sugar cane, because among the studied genotypes, there were the precocious, medium and late.

Consumer preference for purchase may be affected by color, Verruma-Bernardi et al. (2011) in the study of different qualitative parameters in brown sugar, obtained greater preference for sugars of intermediate brown color and uniform appearance.

Vicentini-Polette et al. (2019) in their studies on the quality of different brands of brown sugar about color, obtained greater preference for the brown coloration with a dark tint. The color of brown sugar can be influenced by different factors, among them the composition of sugarcane broth about sucrose levels, glucose and fructose, causing caramelization reactions, and Maillard reaction, due to temperature variation versus cooking season and pot material. Elevated temperatures can lead to compounds called caramels, which promotes the darkening of sugar, use of stainless-steel equipment instead of carbon steel, the presence of large amounts of polyphenols and amino acids in the broth that promotes the darkening of sugar (Verruma-Bernardi et al., 2011).

For the second harvest season, there was no significant correlation pair, thus, it is not possible to infer about the relationships between the traits of the first group, with the traits of the second group (Table 4). For the third harvest season, the first pair of canonical correlations obtained was significant, the explained variance was 66% between the independent and dependent canonical traits of the first group of canonical traits. The traits ASS BS, ºBrix broth, and purity of group 1 presented high values (0.58, 0.43 and 0.44 respectively), just like the trait BSTC (0.68) in group 2, indicating that the largest amount of °Brix broth and purity in the broth provides the largest brown sugar production.

For the third harvest season, after 19 months of growing sugarcane, positive purity interrelationships were obtained, °Brix broth, ASS BS, and BSTC. For this harvest season, it is observed that the higher concentration of soluble solids content and greater purity of the broth provides greater brown sugar production (r = 0.81). The ASS BS is directly related to the BSTC because it is evaluated after the brown sugar production. Similar results were found by Oliveira et al. (1999) where the values of °Brix broth, ASS cane, ASS broth, and purity were increasing in terms of cultivation season.

Anjos et al. (2007) in his studies with organic and mineral fertilization in the cultivation of sugar cane for the production of brown sugar in three different growing seasons, obtained the highest values of ASS and °Brix in the second and third season. The greater the purity of the broth, the greater the amount of brown sugar produced because it is related to the maturation of sugar cane (Viana et al., 2017).

Hagos et al. (2014) studying different sugarcane harvest seasons in Ethiopia, also found a greater accumulation of ºBrix and ASS the longer the growing period, the author observed an increase in the accumulation of these traits, harvesting season from 10 to 14 months, he understands that the explanation may be due to the effect of diluting the sugarcane enzymes, modifying reducing sugars and converting substances such as fiber to sucrose or it may be due to the positive impact of harvest age on yield components, allowing the greater accumulation of soluble solids and sucrose at the season of harvest, after 14 months of cultivation the quality parameters dropped.

Ahmed et al. (2016) in his study conducted in Egypt, also obtained higher values of accumulation of ºBrix according to longer cultivation season, where the greatest accumulation occurred at 14 months of cultivation, beyond the ºBrix the author also obtained the broth with the highest percentage of purity, until the period close to 14 months, after there was a significant reduction that the author justifies by the rapid increase in the content of total soluble solids.

Conclusions

The results found in this study indicate the influence of the growing season on the production of brown sugar. We saw that the variables can present different behaviors according to the growing season, and as we saw in the first two harvests, the variable broth per ton of cane had the greatest direct effect on the production of brown sugar, while in the third it was observed a greater direct effect of the soluble solids content of the broth. In addition, the height variable influences the color of the brown sugar, if cultivated in season 1, while in the third season the variable °Brix of the juice and the purity influence the higher production of brown sugar per ton of cane.

These results indicate that the variables juice per ton of cane, the soluble solids content of the juice, height, °Brix of the juice and purity can be selected in genetic improvement programs, seeking genotypes with higher production and quality of brown sugar. Also, if the researcher's objective is greater sugar production, season 1 proved to be more promising in relation to the others. More studies are needed to elucidate the influence of the growing season on the variables of production and quality of brown sugar.

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Compliance with Ethical Standards

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