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Adaptability and phenotypic stability of sugarcane clones in the state of Mato Grosso do Sul using multi-information methodology

Adaptabilidade e estabilidade fenotípica de clones de cana-de-açúcar no estado de Mato Grosso do Sul utilizando metodologia multi-informação

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ABSTRACT

The adaptability and stability of different genotypes are crucial for recommending cultivars effectively. To achieve this, several methods have been proposed and the use of these methodologies simultaneously appears to allow the extraction of more consistent information than the use of each methodology separately. Therefore, the present study aimed to evaluate the adaptability and stability of sugarcane genotypes in terms of tons of sugarcane per hectare (TCH) in four environments in Mato Grosso do Sul and identify the superior genotypes through criteria multi-information. The TCH data were collected in the 2018/2019 harvest, in third-cut crops, from the experimentation phase of the Sugarcane Improvement Program of the Interuniversity Network for the Development of the Sugarcane Sector. The experiment followed a randomized block design with three replications, evaluating six early-maturing clones (G1, G2, G3, G4, G5 and G6) and two commercial varieties (G7 - RB855156 and G8 - RB966928) were evaluated in four environments (1 - Ivinhema, 2- Rio Brilhante, 3- Nova Andradina Fazenda "N.O." and 4- Nova Andradina Fazenda "E". The joint analysis of variance was obtained from the data. The adaptability and stability of the genotypes was evaluated using multi-information, which included 10 parameters, being: the general average, average potential in different environmental conditions, plasticity, measure of the relative contribution to the interaction, Annicchiarico recommendation index, percentage adaptability, stability percentage, J pattern of genotype response, champion pattern and centroid recommendation index. The results revealed that genotypes G3, G4, G6, G7 and G8 demonstrated high stability and specific adaptation to high yield environments, such as environments 1 and 3. Genotype G6 surpasses commercial genotypes in yield. Genotypes G1, G2 and G5 present high stability, specific adaptation to low yield environments such as 2 and 4.

KEYWORDS: Genotype x environment interaction, improvement of semi-perennial species, *Saccharum officinarum*.

RESUMO

A adaptabilidade e estabilidade de diferentes genótipos são importantes para auxiliar na recomendação de cultivares. Para conseguir, vários métodos têm sido propostos e a utilização destas metodologias em simultâneo parece permitir a extração de informação mais consistente do que a utilização de cada metodologia separadamente. Portanto, o presente trabalho tem como objetivo estudar a adaptabilidade e estabilidade de genótipos de cana-de-açúcar em termos de toneladas de cana por hectare (TCH) em quatro ambientes de Mato Grosso do Sul e identificar os genótipos superiores através de critérios multi-informação. Os dados do TCH foram coletados na safra 2018/2019, em culturas de terceiro corte, da fase de experimentação do Programa de Melhoramento da Cana-de-Açúcar da Rede Interuniversitária de Desenvolvimento do Setor Canavieiro. O delineamento utilizado foi o de blocos com três repetições em que foram avaliados seis clones de maturação precoce (G1, G2, G3, G4, G5 e G6) e duas variedades comerciais (G7 - RB855156 e G8 - RB966928) em quatro ambientes (1 - Ivinhema, 2- Rio Brilhante, 3- Nova Andradina Fazenda “N.O.” e 4- Nova Andradina Fazenda “E”. A análise conjunta de variância foi obtida a partir dos dados. A adaptabilidade e estabilidade dos genótipos foram avaliadas por meio de multi-informação, que incluiu 10 parâmetros, sendo: média geral, potencial médio em diferentes condições ambientais, plasticidade, medida da contribuição relativa para a interação, índice de recomendação Annicchiarico, percentual de adaptabilidade, percentual de estabilidade, padrão J de resposta genotípica, padrão campeão e recomendação centróide Os genótipos G3, G4, G6, G7 e G8 apresentaram alta estabilidade e adaptação específica a ambientes de alta produtividade, como os ambientes 1 e 3. O genótipo G6 supera os genótipos comerciais em produtividade. Os genótipos G1, G2 e G5 apresentam alta estabilidade, adaptação específica a ambientes de baixa produtividade como 2 e 4.

PALAVRAS-CHAVE: Interação genótipo x ambiente, melhoramento de espécies semiperenes, *Saccharum officinarum*.

INTRODUCTION

Brazil is the largest sugarcane producer in the world, with a focus on the Southeast and Midwest regions. Most of the production is concentrated in the São Paulo region (CONAB 2023). Part of this result is due to genetic improvement programs that develop more resistant, productive, and suitable varieties for cultivation in different environments. For this purpose, it is necessary to test a new variety in different environments before launching a new variety (CARNEIRO et al. 2023). This is because genotypes can exhibit more effective behavior in certain environments than in others (CRUZ et al. 2014), which characterizes the interaction between genotypes and environments (G x E) (MONTES et al. 2021).

The G x E interaction is a problem faced by plant enhancers, not only in sugarcane, but also in other species (CARDOSO et al. 2021, CARNEIRO et al. 2023, GUIMARÃES et al. 2018, OTOBONI et al. 2022) . To mitigate this influence of interaction, it is necessary to recommend cultivars with wide adaptability and stability (ANTUNES et al. 2016, REGIS et al. 2018), the first of which can be defined as the ability of genotypes to respond advantageously to environmental stimuli, and the second, defined as the ability of genotypes to present highly predictable behavior in the face of environmental stimuli (CRUZ et al. 2014, REZENDE et al. 2020).

Several researchers have developed different concepts and statistical methods to evaluate adaptability and phenotypic stability (CARNEIRO et al. 2023, FERNANDES JÚNIOR et al. 2013). The methods can be classified based on the following: a) variance analysis (WRICKE 1965), the stability parameter is called ecovalence and is estimated by the decomposition of the sum of the squares of genotype and environmental integration in the parts due to isolated genotypes, b) linear regression, composed of the coefficient of regression (estimating adaptability) and regression deviation (estimating stability), they have general or broad adaptability (EBERHART & RUSSELL 1966), with regression deviation equal to zero, bi-segmented regression, which allows a specific parameter for adaptability to unfavorable environments and unfavorable environments, in addition to the regression deviation (CRUZ et al. 1989), and, d) non-parametric statistics, determine the stability through the mean square of the distance between the average genotypes and the maximum average response for all environments (LIN & BINNS 1988, ANNICCHIARICO 1992, NASCIMENTO et al. 2010).

To be more assertive in the selection of sugarcane genotypes and considering adaptability and stability, it is interesting to use a recommendation proposal based on a multiinformational sheet, which considers several methodologies rather than just one when deciding which genotype to recommend for each site, enabling extracting information that could not be obtained individually (PONTES 2020).

Therefore, the aim of this work was to evaluate the adaptability and stability of sugarcane genotypes in terms of tons of sugarcane per hectare (TCH) in different environments in Mato Grosso do Sul and to identify higher genotypes using the multiinformation criterion.

MATERIAL AND METHODS

The experiments were conducted in four environments in the state of Mato Grosso do Sul (Table 1), referring to the experimental phase of the Sugar Cane Genetic Improvement Program provided by RIDESA/UFSCar. Climatic data for each environment are shown in Figure 1.

Six initial clones (G1, G2, G3, G4, G5 and G6) and two commercial controls were used: RB855156 (G7) and RB966928 (G8). The clones used were obtained from the RIDESA/UFSCar Genetic Cane Improvement Program. The design used was that of casualized blocks with three repetitions. The plots were composed of 4 8-m thresholds in Ivinhema – MS, 4 15 meter thresholds in Rio Brilhante, and 5 10-m thresholds in Nova Andradina – MS, using 20 cm deep thresholds. The spacing between plants was 1.5 m, resulting in 25 plants per plot. The clones were planted and the third cut collected, respectively, in Rio Brilhante, on April 15, 2016 and August 8, 2019; in Ivinhema, on July 1, 2016 and June 5, 2019; in Nova Andradina Fazenda "E", on 15 June 2015 and 3 May 2018; and in Nova Andradina Fazenda "NO", on 15 June 2015 and 24 May 2018.

Table 1. Description of the four environments in which the experimental phase of the RIDESA/UFSCar sugar cane genetic improvement program was implemented.

Environment	Municipality	Altitude (m)	Latitude	Longitude	Environment *	Climate*
1	Ivinhema, MS	350	22° 29' 13"	53° 59' 13"	E	Am
2	Rio Brilhante, MS	337	21° 30' 53"	54° 43' 80"	A	Af
3	Nova Andradina, MS – Fazenda "N.O."	374	22° 11' 72"	53° 23' 70"	D	Am
4	Nova Andradina, MS - Fazenda"E"	433	22° 06' 72"	53° 23' 59"	B	Am

* The environment and climate were classified according to BERTOLANI et al. (2015) and FIETZ & FISCH (2008) for soils with sugarcane productivity potential: A, better potential; B: has lower potential than class A; D: has greater potential than class E; E: lower potential. Am (humid or subhumid tropical climate), Af (humid or superhumid tropical climate, without dry season, with the average temperature of the warmest month above 18 oC).

In the third cut, the characteristic tons of the cane per hectare (TCH) was evaluated using cane mass 30, which was obtained by cutting three beams with cane 10 and weighing the beams individually on a manual scale. Subsequently, we obtained 1 hectare of straw. For this, the formula described by ZAMBON & DAROS (2005) was used: TCH= (M10C/10) x (NSP/10) x (10000) /(LS) / (1000), where: M10C: mass of 10 stems (kg); NSP: number of stems in the plot; LS: spacing between lines.

After obtaining the data, statistical analyses were performed. Initially, a joint analysis of the data was conducted to detect significant interactions between genotypes and environments. The homogeneity between the residual variances was verified by the ratio of the largest to the lowest average square of the residue. In this study, we found that the ratio between the largest and smallest square residues was less than seven. Estimates lower than seven indicate error homogeneity of errors (GOMES & GARCIA 2002).

The statistical model used is: $Yijk= \mu + Gi + Bk + Ej + GEij + eijk$. Where: Y_{jik}: phenotypic value in the k-third block, evaluated in the i-third genotype and in the j-third environment; µ: fixed effect of the general average; Gi: random effect of genotype i; Bk: fixed effect of block k; Ej: fixed effect of the environment j; GEij: effect of the interaction between genotype i and the environment j; eijk: random effect of the experimental error associated with the portion of block k that received genotype j in condition i. ˙eijk ~ NID (0, σ^2).

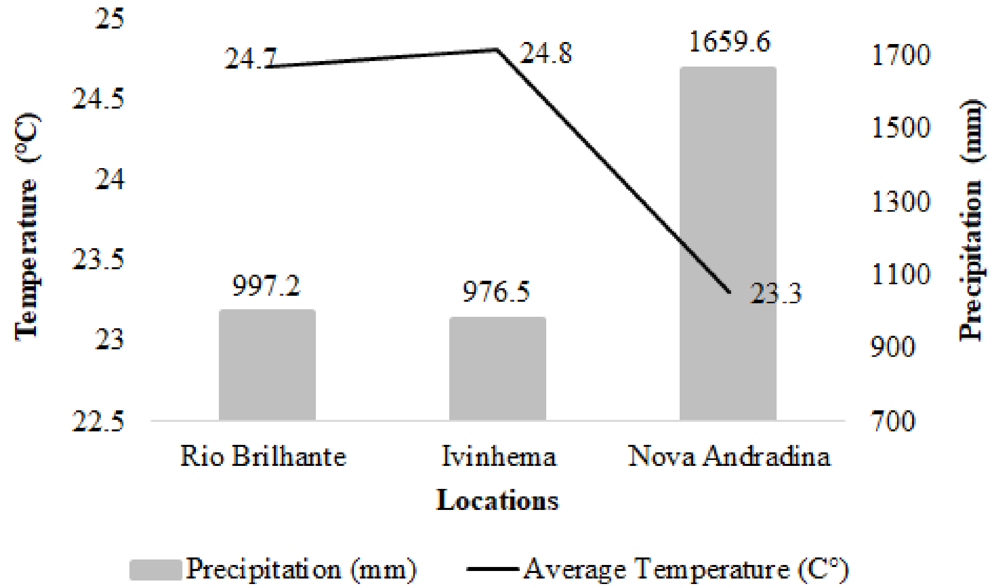

Figure 1. Average temperature (°C) and precipitation (mm) collected in the third cutting period, being considered the dates of Rio Brilhante from April 15, 2018 to August 8, 2019, Ivinhema from July 1, 2018 to July 5, 2019, and Nova Andradina from June 16, 2017, to April 24, 2018. Source: National Institute of Meteorology (INMET 2022).

To complement the analysis of variance, the mean TCHs of the eight sugarcane genotypes were grouped using the method of SCOTT & KNOTT (1974) at 5% and 1% probability.

To evaluate the adaptability and stability of the genotypes, the multiinformation criterion was used based on the evaluation of nine parameters: average potential in different environmental conditions, plasticity, measurement of the contribution relative to the G x E interaction, Annicchiarico recommendation index, percentage adaptability, percentage stability, J pattern of genotype response, champion pattern, and centroid recommendation index according to PONTES (2020). All genetic-statistic analyses were performed using the Genes software (CRUZ 2016).

RESULTS AND DISCUSSION

The study was analyzed together in the environments to verify whether the studied genotypes exhibit the same behavior among themselves for the characteristic tons of cane per hectare (TCH). From the result of the joint variance analysis, it was found that there was a significant difference for the character TCH at 1% probability ($p \leq 0{,}01$) by the F test for the genotypes by The study was analyzed in the environments together to verify whether the studied genotypes present the same behavior among themselves for the character tons of cane per hectare (TCH). From the result of the joint variance analysis, it was found that there was a significant difference for TCH character at 1% probability ($p \leq 0{,}01$) by test F for genotype interaction by environment (Table 2).

This result indicates that the eight assessed sugarcane genotypes exhibit differentiated behaviors due to environmental changes. Therefore, a more detailed study of this interaction is needed to ensure that it does not negatively interfere with the recommendation of the best genotypes. The homogeneity ratio of the medium square of the largest residue divided by the medium square of the smallest residue was 7, allowing us to continue with the analysis of adaptability and stability.

Table 2. Summary of the analysis of combined and average general variance of tons of sugarcane per hectare (TCH) of eight sugarcane genotypes obtained in the third cut in the experimental phases, conducted at four locations in the 2018/19 crop.

Source of Variation	GL	QM
Block	02	25.84
Genotypes (G)	07	1653.39**
Environments (E)	03	17796.95**
Interaction G x E	21	323.88**
Error	62	
Average ($t.ha^{-1}$)	62.49	
C.V.(%)	20.93	

** significant in probability p<0.01 using test F.

The overall experimental average for the TCH characteristic was 62.49 $t.ha^{-1}$ (Table 2), a value considered low considering that the national average for the harvest 2023/2024 is 72.35 t.ha -1 (CONAB 2023) and experiments in two cuts and 24 environments in the states of São Paulo and Paraná in Brazil and in 30 genotypes with averages of 92.03 t.ha -1 (REGIS et al. 2018).

It should be noted that the mean overall experimental value was reduced by the TCH mean observed in the eight clones when evaluated in environments 2 and 4. This result can be observed in Table 3, where environments 2 and 4 presented negative environmental index values (Ij), indicating that they are unfavorable environments. This may have occurred due to adverse soil and climate conditions, the seed season, and the presence of pests and diseases, among others. For example, the ideal temperature for the development of crops is around 30°C (MONTES 2018), and precipitation between 1500 and 2000 mm per year (DOORENBOS & KASSAM 1979) or 1000 mm well distributed throughout the year can ensure satisfactory productivity (ALMEIDA et al. 2008). Therefore, in this study, the sugarcane genotypes studied may have been less favorable in environments 2 and 4.

In this experiment, the mean TCH may have been reduced by the poor distribution of precipitation in ambient 2 and the presence of cigar lines in ambient 4. The high incidence of cigars (*Mahanarva fimbriolata*) was caused by the favorable environmental conditions for insects and the difficulty of controlling this pest. *M. fimbriolata* is considered the main type of cigarette that attacks sugarcane in Brazil (VALVERDE et al. 2018). The attacks of both nymphs and adults cause yellowing of the leaves, reducing chlorophyll content and consequently photosynthesis, which can contribute to the reduction of growth, dehydration, and dryness of the columns, significantly reducing productivity (MELO et al. 2018, VALVERDE et al. 2018). In colms, there is a reduction in the content of soluble solids and sucrose and an increase in the total phenolic compounds and acidity of the juice (MADALENO et al. 2008).

Table 3. Average environmental and environmental index (Ij) of four sites used in the experimental phase for the evaluation of eight sugarcane genotypes of tons of sugarcane per hectare (TCH) in the 2018/19 crop.

Environments	Average ($t.ha^{-1}$)	Environmental Index (Ij)
1 Ivinhema, MS	92.21	32.72
2 Rio Brilhante, MS	30.12	-32.37
3-Nova Andradina, MS	69.49	7.00
4-Nova Andradina, MS	55.15	-7.34

Environments 1 and 3 presented the highest TCH averages, highlighting environment 1, which produced 92.21 t.ha^{-1} (Table 3). Environments 1 and 3 were rated favorable with Ij positivity. Positive Ij values are possibly associated with appropriate edafoclimatic conditions for cultivation and use of high-tech agricultural production, with adequate inputs in routine culture controls (CRUZ et al. 2014). This affirmation of positive values is consistent with work with sugarcane on different genotypes in 10 cities in the state of São Paulo, Brazil (FERNANDES JÚNIOR et al. 2013). BERRES (2018), as observed in bean culture, in studies in different environments and cultures in the state of Mato Grosso do Sul, obtained positive values and indicated that the genotypes presented good average performance, a fact that was confirmed by positive environmental indices.

Regarding the overall averages of each of the eight genotypes evaluated in the four environments, it can be observed that G6 and G8 presented the highest mean estimates of TCH, respectively 85 t.ha^{-1} and 75 t.ha -1 (Figure 2). The other genotypes were grouped in group b and were inferior to the G6 and G8 genotypes allocated to group a.

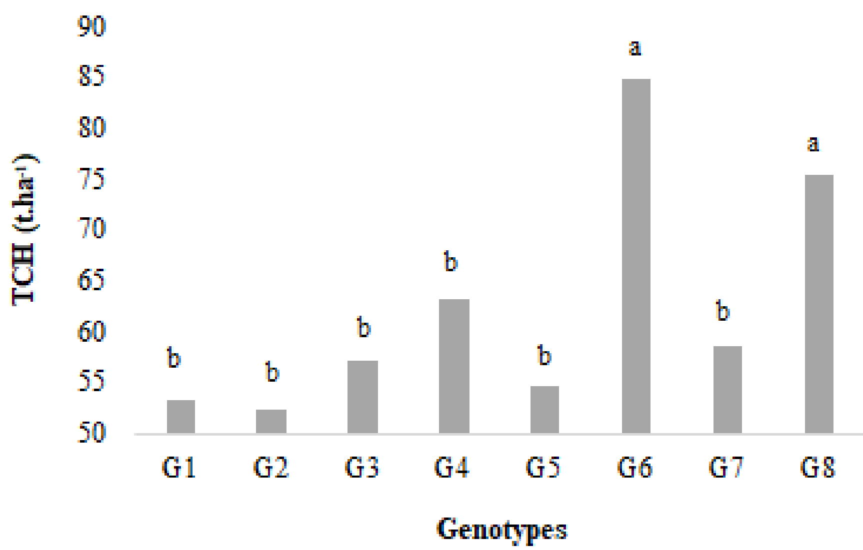

Figure 2. Average tons of sugarcane per hectare (TCH) obtained from eight sugarcane genotypes evaluated in four environments in Mato Grosso do Sul, harvested in 2018/19, grouped according to test by SCOTT & KNOTT (1974). Values followed by the same letter belong to the same group.

After identifying the presence of G x E interaction in the assessed tests, classifying the environments as favorable or unfavorable and obtaining the overall averages of the eight sugarcane genotypes, we decided to conduct a multigenetic research based on 10 parameters to verify the adaptability and stability of the eight sugarcane genotypes of tons of sugarcane per hectare (TCH). A sheet of information on each genotype is presented in Table 4.

Table 4. Genotypic recommendation sheet based on the multi-information analysis of eight sugarcane genotypes regarding the characteristic tons of sugarcane per hectare (TCH) evaluated in four environments of Mato Grosso do Sul.

Parameter		Genotype 1		Genotype 2		Genotype 3		Genotype 4		References	
		Value	*Rank*	Value	*Rank*	Value	*Rank*	Value	*Rank*	Min	Max.
Average potential	General environment	53.38	7	52.48	8	57.14	5	63.15	3	52.48	85.01
	Favorable environment	70.19	7	66.27	8	84.57	4	87.4	3	66.27	105.93
	Unfavorable environment	36.57	7	38.69	4	29.7	8	38.91	3	29.7	64.1
Plasticity		1289.95	3	1098.2	1	4046.49	8	3980.36	7	1098.2	4046.49
Contribution to interaction (Wi%)		21.04	8	16.45	7	12.23	3	16.38	6	0.48	21.04
Recommendation index Annicchiarico	General environment (%)	70.43	5	60.11	7	47.61	8	77.3	3	47.61	117.88
	Favorable environment (%)	78.26	3	53.88	6	27.53	8	77.81	4	27.59	129.34
	Adverse environment (%)	59.59	8	74.63	6	96.7	3	78.57	5	59.59	124.25
Adaptability	$\beta 1$	0.68*	-	0.66*	-	1.34*	-	1,31^{ns}	-	0.66	1.34
Stability (%)	S^2_d	11,69 ^{ns}	-	35,19 ^{ns}	-	100,00 ^{ns}		26,47 ^{ns}	-	11.69	100
	R^2 (%)	80.32	-	88.96	-	99.81	-	96.1	-	80.32	99.94
Standard J response	Adaptability $\beta 1$	0.82ns	-	0.60*	-	1.37*	-	1,20^{ns}	-	0.6	1.37
	Adaptability $\beta 1 + \beta 2$	0.11**	-	0.99ns	-	1,21^{ns}	-	1.93*	-	-0.11	1.93
	Stability (%) S^2_d	99,58^{ns}	-	92,69^{ns}	-	99,97^{ns}	-	99,92^{ms}	-	91.59	99.99
Standard Champion	General environment	608.8	7	624.43	8	443.28	5	296.66	3	1.71	624.43
	Favorable environment	765.01	7	787.55	8	228.75	4	226.64	3	0	787.55
	Unfavorable environment	452.59	5	461.31	6	657.8	8	366.67	3	3.42	657.8
Recommendation Index Centroid	4 Centroid		IV		IV		II		II	-	-
	7 Centroid		IV		IV		V		V	-	-

Parameter		Genotype 5		Genotype 6		Genotype 7		Genotype 8		References	
		ue	*Rank*	ue	*Rank*	ue	*Rank*	ue	*Rank*	*Min*	Max.
Average potential	General environment	54.67	6	85.01	1	58.58	4	75.47	2	52.48	85.01
	Favorable environment	72.12	6	105	1	79.99	5	92.27	2	66.27	105.93
	Unfavorable environment	37.22	5	64.1	1	37.17	6	58.66	2	29.7	64.1
Plasticity		1281.05	2	2524.88	4	2972.49	6	2843.68	5	1098.2	4046.49
Contribution to interaction (Wi%)		16.21	5	0.48	1	3.68	2	13.51	4	0.48	21.04
Recommendation index Annicchiarico	General environment (%)	70.99	4	117.88	1	67.61	6	99.85	2	47.61	117.88
	Favorable environment (%)	65.35	5	129.34	1	50.37	7	108.77	2	27.59	129.34
	Adverse environment (%)	68.32	7	124.25	1	88.61	4	101.66	2	59.59	124.25
Adaptability	$\beta 1$	0.70^{ns}	-	1,06^{ns}	-	1,15^{ns}	-	1,07^{ns}	-	0.66	1.34
Stability (%)	S^2_d	22,36 ^{ns}	-	100,00 ^{ns}	-	100,00 ^{ns}	-	8.33 ^{ns}	-	22.36	100
	R^2 (%)	86.33^{s}	-	99.94^{s}	-	98.88^{s}	-	89.62	-	80.32	99.94
Standard J response	Adaptability $\beta 1$	0.80^{ns}	-	1,05^{ns}	-	1,13^{ns}	-	1.0ns	-	0.6	1.37
	Adaptability $\beta 1 + \beta 2$	0.14*	-	1,12^{ns}	-	1,24^{ns}	-	1,45^{ns}	-	-0.11	1.93
	Stability (%) S^2_d	95.75^{ns}		99.99^{ns}	-	98.99ns	-	91,59^{ns}	-	91.59	99.99
Standard Champion	General environment	556.14	6	1.71	1	377.44	4	77.68	2	1.71	624.43
	Favorable environment	649.65	6	0	1	337.61	5	102.19	2	0	787.55
	Unfavorable environment	462.63	7	3.42	1	417.27	4	53.16	2	3.42	657.8
Recommendation Index Centroid	4 Centroid		IV		I		IV		I	-	-
	7 Centroid		V		I		V		VII	-	-

.**,*, ns: significant (p<0,01), significant (p<0,05) and non-significant by test F. I: High general adaptability; II: Specific adaptability to favorable environments; III: Specific adaptability to adverse environments IV: Poorly adapted; V: Average general adaptability; VI: Average specific adaptability to favorable environments; VII: Average specific adaptability to environments.

Through the ranking of genotypes, it was found that the G6 genotype stood out in terms of the Average Potential parameter, staying first in the general environment (85,01 $t.ha^{-1}$), favorable (105,93 t.ha -1) and unfavorable (64,10 t.ha -1), demonstrating to be the best genotype in all environments. G8 also stands out for presenting second place in the general environment, favorable and unfavorable, 75,47 $t.ha^{-1}$, 92,2 t.ha-1, and 58,67 t.ha -1 , respectively. G1 was ranked seventh in the general environment (53.38 $t.ha^{-1}$), favorable (72.12 t.ha -1) and unfavorable (37.22 t.ha -1). The eighth place was obtained by G2 in the general environment (52,48 $t.ha^{-1}$), favorable (66,27 t.ha -1) and by G3 in the unfavorable environment (29,7 t.ha -1).

When analyzing the results obtained using the plasticity parameter, genotypes G2 and G5 presented lower estimates of the mean square of the interaction G x E, which indicates lower phenotypic plasticity. Based on this parameter, these genotypes probably showed less variation in their physiology and/or morphology in the four assessed environments, indicating stability. Genotypes 6 (G6) and 8 (G8) are in the fourth and fifth positions and are considered to have medium plasticity.

The Parameter Relative Contribution to Interaction, also called Ecovalence (Wi%), indicates how much a given genotype contributed to the interaction G x E. Genotype G6 had an estimate of 0.48%, being the genotype that contributed the least to the interaction G x E, followed by G7 (3.68%) and G3 (12.23%). G1 and G2 contributed the most to the G x E interaction, representing 21,04% and 16,45%, respectively.

The results obtained by the recommendation index or the Annicchiaric Confidence Index showed that G6 presented the best behavior, i.e., the improver will have a high level of confidence in recommending this genotype in a general, favorable, and unfavorable environment. G8 presented a similar result to G6, with a second position for the general environment, favorable, and unfavorable compared to the other selected genotypes.

When analyzing the Adaptability parameter, the values of the regression coefficient ranged from 0.66 for G2 to 1.34 for G3. Large variations in the coefficient of regression reveal that genotypes respond differently to environments. PFAHLER and LINSKEN (1979) demonstrated that the greatest utility of the coefficient of regression is to identify the response of a given parameter to variability between environments.

In addition, it was observed that 62.5% of the genotypes (G4, G5, G6, G7 and G8) presented non-significant estimates, indicating that they obtained statistically equal regression coefficients to one ($\beta1=1$) and therefore presented broad adaptability to the evaluated environments. It is worth noting that genotypes G7 and G8 are commercial varieties and are listed among the most planted materials in Mato Grosso do Sul, occupying the sixth and first positions, respectively, and in the Center-South region, occupying the sixth and second positions. Among these genotypes, only G6 and G8 obtained averages higher than the general experimental average.

Regarding adaptability, genotypes G1 and G2 had regression coefficient estimates lower than one ($\beta1<1$), indicating adaptability to adverse environments. G3, on the other hand, presented an estimated coefficient of regression greater than one ($\beta1>1$), indicating adaptability to favorable environments.

Regarding the stability parameter, it was observed that the eight evaluated genotypes presented a non-significant regression deviation ($S^2_d=0$), allowing us to infer that the genotypes present predictable behavior in relation to TCH in the conditions and environments tested in this study. In addition to estimating the deviations from the regression, the determination coefficient (R^2) was used. Thus, genotypes that presented a non-significant regression deviation ($S^2_d=0$) and R^2 near 1 did not vary TCH depending on the environment, i.e., they presented stable behavior. Second Birth et al. (2010) classified genotypes in two ways: as stability or high predictability, when R^2 is greater than 70%; and with low stability or predictability, when R2 is less than 70%. Therefore, all genotypes exhibit high stability, but the G6 genotype stands out from the others, showing constant behavior in different environments.

In relation to the Standard J, which is based on the methodology of CRUZ et al. (1989), it was found that the genotypes G1, G4, G5, G6, and G7 did not differ from each other ($\beta1=1$), and they did not respond to environmental variations in adverse conditions. Under the same conditions, the genotypes of G2 and G3 genotypes are little ($\beta1<1$) and very demanding ($\beta1<1$), respectively.

Regarding the linear response to favorable environments (ß1+ß2), the genotypes G2, G3, G6, G7, and G8 did not differ significantly from one (ß1+ß2=1), indicating that they increase TCH as the environment improves. G4 had a significantly higher score than one (ß1+ß2>1), indicating that it was adapted to favorable environments. However, because its average was lower than the experimental average, it did not respond to environmental improvement. Genotypes G1 and G5 presented significantly lower estimates than one (ß1+ß2<1), suggesting that they are adapted to unfavorable environments.

Regarding phenotypic stability or predictability of the genotypes in terms of linear response to environmental improvement, evaluated by regression deviations, it was found that all genotypes presented an estimate equal to zero (S^2_d=0). Therefore, they can be classified as stable in both favorable and undesirable environments.

Based on the Centroid Recommendation Index for the four centroids, genotypes 6 and 8 were classified as having high overall adaptability, indicating maximum production in favorable and unfavorable environments. For the seven centroids, there was high general adaptability for G6 and average specific adaptability to adverse environments (average production in favorable environments and maximum in adverse environments) for G8.

Among the 10 parameters evaluated, the G6 genotype was closest to the ideal genotype due to its high average TCH (92.21 t.ha^{-1}), wide adaptability, and predictable behavior in the considered environments.

CONCLUSION

The genotypes of sugarcane 1, 2, and 5 showed high stability and specific adaptation to low productivity environments, as demonstrated in Rio Brilhante (environment 2) and Farm “E” in Nova Andradina, MS (environment 4).

Genotypes 3, 4, 7, and 8 present high stability and specific adaptation to high productivity environments, such as Ivinhema-MS (environment 1) and Fazenda “N.O.” in Nova Andradina – MS (environment 3).

Genotype 6 exhibited superior performance, showing high sugarcane seed productivity per tonne per hectare, high stability, and broad adaptability.

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