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Phenotype adaptability and stability of sugarcane genotypes in the sugarcane belt of the State of Pernambuco, Brazil

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ABSTRACT. We assessed the agroindustrial performance of 25 sugarcane genotypes adapted to the edaphoclimatic conditions of the State of Pernambuco, Brazil, within the microregions Mata Norte, Mata Sul, Região Central, Litoral Norte, and Litoral Sul. The variables analyzed were POL tonnage per hectare, sugarcane tonnage per hectare, fiber and total recoverable sugar tonnage per hectare, using a randomized block design with four repetitions. Combined variance of experiments, genetic parameter estimates, decomposition of the genotype-environment interaction, and environment stratification were analyzed. Phenotype adaptability and stability were also analyzed. The various genotypes presented great potential for improvement and a similar response pattern to the microregions Centro and Mata Sul of the state of Pernambuco. Genotypes RB863129, RB867515, RB92579, RB953180, SP81-3250, RB75126, and RB942520 were better in productivity and phenotype

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adaptability and stability compared to genotypes RB892700, RB943365, SP79-1011, Q138, RB943538, SP78-4764, RB953281, RB943066, RB928064, RB93509, RB72454, RB952675, RB952991, RB943161, RB942898, RB872552, RB952900, and RB942849. These genotypes are recommended as cultivation options in the sugarcane belt in the state of Pernambuco, since they stand out in terms of phenotype adaptability and stability as evaluated using the method by Annicchiarico, Lin and Bins, and the method by Eberhart and Russel.

Key words: Genotype-environment interaction; Plant improvement; Productivity; *Saccharum* spp

INTRODUCTION

Sugarcane is one of the crops of greatest economic relevance, contributing approximately to 2% of the Brazilian gross domestic product (BIOSEV, 2013). The species provides raw material for the manufacture of an array of products, such as schnapps, yeasts, proteins, pharmaceutical drugs, sugar, and alcohol, and it is used in the production of cattle feed (Mendonça et al., 2004). In this context, Brazil is the largest sugarcane producer in the world, accounting for over 490 million tons sugarcane in the 2011/2012 harvest. The country also enjoys the first place in sugar production, with a 25% share in global figures, and it holds 50% of the world's sugar exports (ÚNICA, 2013).

More specifically, the State of Pernambuco, in the country's northeast region, stands out in the Brazilian economic scenario, producing 14.90 million tons sugarcane addressed to the sugar and alcohol industry and ranking as the second highest producer in the region (CONAB, 2013). However, the mean productivity is relatively low, with roughly 45 tons sugarcane per hectare. The main reason hampering improvements in sugarcane productivity is the genotype-environment interaction, which is expressed mainly as diversity in soil characteristics, sloped terrains, and irregular rainfall patterns, in which long drought periods are common.

Koffler et al. (1986) were the first researchers to characterize the sugarcane belt in Pernambuco. In their pioneer study, the authors systematically gathered a body of environmental information in an effort to afford researchers devoted to genetic improvement studies a wider panorama of their fields of interest. They subdivided the state sugarcane belt into five distinct microregions: Mata Norte (MN), Mata Sul (MS), Região Central (RC), Litoral Norte (LN), and Litoral Sul (LS). For each microregion, the geology, geomorphology, climate, hydrology, natural vegetation, soils, and ecological zoning were characterized.

These regional units were studied separately, taking into account a set of edaphic and climatic parameters that influence sugarcane production as raw material. The investigations revealed that environmental distinctions may either promote or hamper these microregions' specific capabilities regarding soil and climate interactions with sugarcane culture. Expressed in practical crop improvement terms, it was concluded that the agroindustrial performance of a given cultivar in one microregion may not be reproduced in another. Additionally, the environment may facilitate or obstruct the expression of particular characteristics of economic interest. According to Bressiani et al. (2002), when the genotype-environment interaction is too robust, the selection of superior cultivars is made more difficult.

Therefore, it became clear that the development of new cultivars with excellent po-

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tential to respond more advantageously to environment improvements (that is, adaptability) and with only slight variations in overall behavior when exposed to a different environmental setting (stability) is essential to any strategy to increase sugarcane production in Pernambuco. As a result, these improvement strategies should be conceived or perfected to develop new cultivars adapted to these microregions' specific settings. In other words, these new cultivars genetically superior should express economically interesting characteristics that are the result of genetic effects and not the interactions with edaphoclimatic conditions observed in cultivation sites (Vendruscolo et al., 2001).

Several methodologies have been described to study adaptability and stability, including variance analyses (Yates and Cochran, 1938; Plaisted and Peterson, 1959; Wricke, 1965; Annicchiarico, 1992), non-parametric analyses (Lin and Binns, 1988; Huehn, 1990; Nascimento et al., 2010), and simple linear regression (Theil, 1950; Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; Tai, 1971). According to Cruz and Regazzi (1994), the method chosen by crop improvement researchers is defined by the number of environments involved, the class of the information required, and the experimental accuracy desired.

In sugarcane research, several studies address the genotype-environment interaction and phenotype adaptability and stability. These efforts, such as the relevant investigations carried out by Rea and Sousa-Vieira (2002), Kumar et al. (2004), and Bastos et al. (2007), are attempts to shed more light on productivity improvement based on the selection of superior cultivars that may be more significantly added to this target.

In this background, this study evaluates the agroindustrial performance of selected sugarcane genotypes that are adaptable to the edaphoclimatic conditions observed in the sugarcane production microregions in the state of Pernambuco, Brazil.

MATERIAL AND METHODS

The experiments were carried out in the cultivation areas held by the sugarcane processing plants taking part in the sugarcane genetic improvement program (Programa de Melhoramento Genético da Cana-de-açúcar) of the Universidade Federal de Pernambuco. The program is part of a university network established to promote the development of the sugar and alcohol sector (Rede Interuniversitária para o Desenvolvimento do Setor Sucroalcooleiro (PMGCA/UFRPE/RIDESA). The plants were Usina Santa Tereza, Usina Una Açúcar e Energia, Usina Petribú, and Usina União e Indústria e Usina Central Olho d'Água, representing the microregions LN, LS, RC, MS, and MN, respectively, in accordance with the classification proposed by Koffler et al. (1986). Experimental data were obtained using samples collected at two development stages in the sugarcane production cycle: adult plants and sprout after the first harvest.

The following genotypes were analyzed: RB92579, SP81-3250, RB867515, RB953180, RB863129, RB942520, RB75126, RB892700, RB943365, SP79-1011, Q138, RB943538, SP78-4764, RB953281, RB943066, RB928064, RB93509, RB72454, RB952675, RB952991, RB943161, RB942898, RB872552, RB952900, and RB942849. A randomized block design with four repeats was used. Experimental parcels were defined as a set of five 8-m rows interspaced by 1-m passages. Plantations were grown according to the traditional method (Stolf, 1986). Soil pH corrections and fertilization techniques were carried out following the system adopted by each agroindustrial company.

The variables analyzed were POL tonnage per hectare (TPH), sugarcane tonnage per hectare (TCH), fiber (FIB), and total recoverable sugar tonnage per hectare (ATR/tha). In the estimates of TPH, TCH, and ATR/tha, the methodologies described by Dutra Filho et al. (2013) were used. FIB was calculated according to the methodology introduced by Fernandes (2003).

Multiple-factor variance analysis of experiments and genetic parameter estimates (Cruz, 2006) were used. Means were clustered using the Scott and Knott (1974) test at 5% probability. The genotype-environment interaction was decomposed following the methodology developed by Cruz and Castoldi (1991). The environments were stratified according to the square sum method between genotypes and paired environments by using the method of Cruz and Regazzi (1994).

The methods developed by Annichiarico (1992), Lin and Binns (1988), and Eberhart and Russel (1996) were used to analyze the phenotype adaptability and stability. All data were processed using the GENES program (Cruz, 2006).

RESULTS AND DISCUSSION

The variance analysis revealed significant differences between means of the variables studied for all genotypes (Table 1). This result shows the occurrence of genetic variability across the genotypes that were evaluated based on these characteristics that, according to Bastos et al. (2003), are among the most important elements in sugarcane production. In addition, significant differences were observed between the sugarcane microregions that were evaluated, indicating that they are contrasting environments due to edaphoclimatic factors that affect the expression of characteristics considered in selection processes (Rosse et al., 2002).

Table 1. Summary of the combined variance analysis of experimental groups carried out during the competition phase of sugarcane genotypes at the beginning of harvest in the sugarcane belt, State of Pernambuco, Brazil.

Variables	d.f.	Mean squares			
		TPH	TCH	FIB	ATR/tha
Genotypes	24	24.35**	1250.43**	1.87*	24.63**
Environments	4	580.81**	17,012.59**	17.21**	614.15**
G x E	96	7.99**	315.96**	1.10*	8.91**
Residuals	360	2.62	94.67	0.79	2.88
Means		11.51	88.32	13.60	11.78
CV (%)		14.06	11.01	6.53	14.40
>MSQ/<MSQ		2.30	2.76	6.51	2.81

TPH = POL tonnage per hectare; TCH = sugarcane tonnage per hectare; FIB = fiber; ATR/tha = total recoverable sugar tonnage per hectare. ** and * Significant at 1 and 5% probability, respectively, in the F test. G-E = interaction genotype-environment.

Concerning the genotype-environment interaction, significant differences were recorded for all variables. According to Silva (2008), these significant interactions are the result of the distinctive manner in which genotypes react in different environments. Furthermore, the differences reveal that the genotypes performed differentially across the environments in which they were grown.

Means clustering (Scott and Knott, 1974) (Table 2) allowed the placement of genotypes that performed better in the microregions. In the analysis of TPH, genotypes RB92579, SP81-3250, and RB867515 clustered and formed group a. The analysis of THC clustered genotypes RB92579, SP81-3250, and RB867515 along with genotypes RB953180, RB863129, RB942520, and RB75126 into group a. Concerning FIB, no superior group was formed, suggesting that all genotypes exhibited the same potential. Finally, in the ATR/tha analysis, genotypes RB92579, SP81-3250, and RB867515 performed better than other genotypes and were ranked in group a.

Table 2. Clustering of means of characters evaluated during the competition phase of genotypes at the beginning of harvest in the sugarcane belt, State of Pernambuco, Brazil.

Genotypes	Variables			
	TPH (t/ha)	TCH (t/ha)	FIB (%)	ATR (t/ha)
RB92579	14.45[a]	106.45[a]	13.48[a]	14.69[a]
SP81-3250	14.10[a]	105.80[a]	13.55[a]	14.32[a]
RB867515	13.10[a]	98.05[a]	13.97[a]	13.55[a]
RB953180	12.29[b]	94.40[a]	13.44[a]	12.48[b]
RB863129	12.18[b]	96.95[a]	13.33[a]	12.42[b]
RB942520	11.92[b]	89.25[a]	13.31[a]	12.21[b]
RB75126	11.89[b]	97.80[a]	12.71[a]	12.20[b]
RB892700	11.83[b]	86.05[b]	14.17[a]	12.05[b]
RB943365	11.78[b]	86.25[b]	13.41[a]	12.00[b]
SP79-1011	11.55[b]	85.85[b]	13.13[a]	11.96[b]
Q138	11.47[b]	86.05[b]	13.55[a]	11.68[b]
RB943538	11.41[b]	85.60[b]	13.81[a]	11.67[b]
SP78-4764	11.41[b]	88.30[b]	13.68[a]	11.67[b]
RB953281	11.28[b]	85.65[b]	13.87[a]	11.54[b]
RB943066	11.27[b]	82.00[b]	13.64[a]	11.56[b]
RB928064	11.11[b]	86.45[b]	13.52[a]	11.36[b]
RB93509	10.90[b]	96.05[b]	13.64[a]	11.27[b]
RB72454	10.84[b]	84.10[b]	13.33[a]	11.14[b]
RB952675	10.69[b]	83.05[b]	13.75[a]	10.88[b]
RB952991	10.67[b]	84.65[b]	13.49[a]	10.85[b]
RB943161	10.59[b]	80.90[b]	13.72[a]	10.82[b]
RB942898	10.57[b]	81.40[b]	13.96[a]	10.85[b]
RB872552	10.56[b]	80.20[b]	13.65[a]	10.81[b]
RB952900	10.14[b]	76.75[b]	13.88[a]	10.37[b]
RB942849	9.816[b]	80.20[b]	13.84[a]	10.15[b]

Means followed by the same letter in a column are in the same group, according to the Scott & Knott test, with 5% probability.

Regarding the estimated genetic parameters (Table 3), the predominance of the genotype-environment interaction is observed over the genetic variance components for all characteristics, confirming that this interaction is quite strong in the sugarcane belt of the state of Pernambuco. This result requires that the genotype-environment interaction is decomposed to observe whether the nature of this interaction influences the selection and recommendation of cultivars. In Tables 4 and 5, the decomposition of the genotype-environment interaction shows that the interactions of genotypes with sugarcane microregions in the state of Pernambuco are complex, considering all of the variables investigated.

Table 3. Estimated genetic parameters of the characters assessed during the competition phase of genotypes at the beginning of harvest in the sugarcane belt, State of Pernambuco, Brazil.

Characters	Genetic parameters				
	φ^2_g	$\hat{\sigma}^2_{ga}$	h^2	CV_g	CVg / CVe
TPH	0.82	1.28	67	7.85	0.55
TCH	46.72	53.10	75	7.73	0.70
vFIB	0.03	0.07	41	1.43	0.22
ATR/tha	0.79	1.45	65	7.52	0.52

φ^2_g = Genetic variance component; $\hat{\sigma}^2_{ga}$ = Genotype-environment interaction variance component; h2 = Genotypical determination as means; CVg = Genetic coefficient variation; CVg/CVe = b index. For other abbreviations, see legend to Table 1.

Table 4. Coefficients of the genotype-environment interaction (%CI) for paired environments (microregions) according to Cruz and Castoldi (1991) for variables TPH (upper diagonal) and TCH (lower diagonal) of 25 sugarcane genotypes evaluated in five environments [Mata Norte (MN), Mata Sul (MS), Região Central (RC), Litoral Norte (LN), Litoral Sul (LS)], State of Pernambuco, Brazil.

Environments	LN	LS	RC	MN	MS
LN		88.12	77.04	88.93	82.75
LS	83.31		61.54	62.90	82.48
RC	77.16	61.14		58.83	77.76
MN	90.13	68.26	72.17		87.55
MS	73.33	69.86	59.78	81.86	

Table 5. Coefficients of the genotype-environment interaction (%CI) for paired environmens (microregions) according to Cruz and Castoldi (1991) for variables FIB (upper diagonal) and ATR/tha (lower diagonal) of 25 sugarcane genotypes evaluated in five environments [Mata Norte (MN), Mata Sul (MS), Região Central (RC), Litoral Norte (LN), Litoral Sul (LS)], State of Pernambuco, Brazil.

Environments	LN	LS	RC	MN	MS
LN		69.10	77.29	97.15	95.48
LS	88.59		61.29	69.44	75.79
RC	79.13	62.46		96.59	90.04
MN	90.60	66.81	62.23		93.31
MS	81.03	78.43	73.48	85.10	

According to the methodology proposed by Cruz and Castoldi (1991), coefficients over 50% are a consequence of complex interactions, while values under 50% represent simple interactions. In this study, the genotype-environment interactions between paired environments were shown to be complex, considering the four variables that were analyzed. These interactions pose difficulties in improvement strategies, especially in the identification of superior genotypes. In this sense, the stratified analysis of environments is recommended to identify sets of environments where this interaction is not significant; in this case, the genotypes' performances are essentially identical.

Environment stratification (Table 6) reveals the similarity pattern in the genotypes' response to the microregions Centro and Mata Sul for TPH, THC, and ATR/tha. As a rule, the recommendation is that commercial plantations of the genotypes evaluated are located in the two microregions that were the most homogeneous, which were Centro and Mata Sul. According to Silva and Oliveira et al. (2004), environments should be chosen based on the specific needs defined in cultivation programs. The authors also stated that criteria such as the availability of research centers, easy access, and relevance of production centers (microregions) should be adopted. This result also reveals the need for phenotype adaptability and stability to identify genotypes that prove to be adaptable to other microregions. Tables 7 and 8 present the phenotype adaptability and stability parameters for TPH, THC, FIB, and ATR/tha.

From Amorim et al. (2006), the method proposed by Annicchiarico considers an ideal genotype that with the highest percent mean and the highest recommendation index. Based on these considerations, it is concluded that, genotypes RB863129, RB867515, RB92579, RB953180, and SP81-3250 exhibited higher general adaptability in terms of

TPH, which entitles them to be recommended for growth in the five environments surveyed. In turn, genotypes Q138, RB75126, RB942520, and SP78-4764 presented specific adaptability to favorable environments, herein identified as Litoral Norte, Litoral Sul, and Mata Norte (Table 9). Finally, the genotypes RB943161 and RB943365 were considered adaptable to unfavorable environments (Centro and Mata Sul, respectively). For THC, genotypes RB863129, RB867515, RB92579, RB93509, RB953180, and SP81-3250 exhibited better general adaptability. Genotype Q138 was characterized as adaptable to favorable environments. Genotypes RB942520 and RB943365 were identified as adaptable to unfavorable environments. Concerning ATR/tha, genotypes RB863129, RB867515, RB892700, RB92579, RB953180, and SP81-3250 revealed higher general adaptability. The genotypes characterized as adaptable to favorable environments were Q138, RB75126, and RB942520, while those considered adaptable to unfavorable settings were RB93509, RB943161, and RB943365.

Table 6. Stratification of sugarcane microregions in the state of Pernambuco, Brazil, based on the similarity pattern of response of genotypes, for each environment.

Variable	QMI/r	F calculated	F tabulated (5%)	Environments
TPH	0.97	1.47	1.54	3 and 5
TCH	32.77	1.38	1.54	3 and 5
FIB	0.20	1.00	1.32	2, 3, 1, and 4
ATR/tha	0.85	1.18	1.54	3 and 5

For abbreviations, see legend to Table 1.

Table 7. General adaptability Wi estimates (g) to favorable Wi(+) and unfavorable Wi(-) environments according to Annichiarico (1992) for the variables TPH and TCH of 25 genotypes assessed in the sugarcane belt of the state of Pernambuco, Brazil.

Genotype	Variables/Adaptability					
	TPH/Wi (g)	TPH/Wi(+)	TPH/Wi(-)	TCH/Wi(g)	TCH/Wi(+)	TCH/Wi(-)
Q138	95.91	101.2	88.61	93.94	100	86.91
RB72454	91.94	92.79	90.29	93.33	93.04	93.375
RB75126	98.23	104.8	89.46	108.7	111.1	105.5
RB863129	104.92	104.7	105.3	108.6	106.1	113.5
RB867515	108.7	110.1	107.3	107.7	107.5	109.3
RB872552	90.66	91.69	88.94	89.27	90.92	86.7
RB892700	100.9	99.52	102.2	96.08	97.91	93.55
RB92579	119.2	126.3	108.6	116.4	119.4	111
RB928064	94.18	92.77	96.01	95.58	97.31	93.9
RB93509	92.98	89.95	98.69	105.8	97.78	122
RB942520	98.94	101.3	94.3	97.85	95.56	101.5
RB942849	84.1	79.16	95.2	88.98	84.74	97.27
RB942898	90.85	89.22	93.48	90.79	89.97	91.74
RB942991	91.81	88.83	98.67	94.78	92.04	99.5
RB943066	93.8	93.6	95.4	89.55	90.43	89.1
RB943161	89.91	82.97	102.4	89.47	85.12	96.31
RB943365	99.08	88.35	119.8	94.26	85.78	109.5
RB943538	95.75	97.01	93.72	93.72	96.81	90
RB952675	89.62	92.27	84.92	92.04	93.52	89.14
RB952900	83.61	90.22	76.67	83.86	88.6	78.68
RB953180	104.5	100.1	113.7	104.3	103	106.1
RB953281	94.12	95.12	92.17	93.85	96.31	90.9
SP784764	94.44	100.1	88.45	96.63	99.54	92.46
SP791011	95.92	98.83	91.15	94.09	96.29	91.3
SP813250	120.6	118.4	125.2	118.3	117.2	119.8

For abbreviations see legend to Table 1.

Table 8. General adaptability Wi estimates (g) to favorable Wi(+) and unfavorable Wi(-) environments according to Annichiarico (1992) for the variables FIB and ATR/tha of 25 genotypes assessed in the sugarcane belt of the State of Pernambuco, Brazil.

Genotype	Variables/adaptability					
	FIB/Wi(g)	FIB/Wi(+)	FIB/Wi(-)	ATR/tha Wi(g)	ATR/tha Wi(+)	ATR/tha Wi(-)
Q138	99.45	99.22	99.75	95.39	100.6	88.2
RB72454	96.74	97.76	95.6	92.21	93.51	90.03
RB75126	92.78	92.21	93.52	98.77	104.6	91.07
RB863129	97.72	98.01	97.29	104.3	104.3	104.3
RB867515	102.2	101.2	104	109	111.2	106.8
RB872552	99.93	99.39	100.8	90.7	92.06	88.65
RB892700	103.3	104.6	101.4	100.4	98.84	102
RB92579	98.61	97.62	100.3	118.7	125.4	108.8
RB928064	98.84	99.35	97.9	94.06	92.72	95.9
RB93509	98.5	97.44	100.2	94.24	90.31	101.9
RB942520	96.77	95.61	98.74	99.73	100.4	97.41
RB942849	100	103	96.99	85.06	79.7	98.06
RB942898	101.9	100.5	104.5	90.93	89.66	92.79
RB942991	98.45	100.3	96.13	91.14	87.97	98.14
RB943066	98.57	96.33	101.7	93.55	93.8	94.68
RB943161	100.4	100.5	100	89.72	82.64	102.5
RB943365	97.39	99.27	94.82	98.81	88.16	119.7
RB943538	100.9	100.7	101.1	95.48	96.95	93.33
RB952675	100.1	101	98.52	89.4	91.72	85.23
RB952900	101.6	101.1	102.3	83.46	90.05	76.63
RB953180	97.13	101.7	92.35	103.7	99.12	112.8
RB953281	101	99.47	103.9	94.01	95.49	91.48
SP784764	99.72	98.88	101.6	94.47	99.94	88.68
SP791011	95.49	94.26	97.17	96.37	99.88	90.91
SP813250	98.8	97.05	102.3	119.7	117	124.9

For abbreviations, see legend to Table 1.

Table 9. Classification of sugarcane microregions in the State of Pernambuco, Brazil, according to Annichiarico (1992), Lin and Binns (1988), and Eberhart and Russel (1966).

Microrregions	Variable	Mean	Index	Class
Litoral Norte	TPH	12.70	1.19	Favorable
	TCH	90.19	1.87	Favorable
	FIB	13.55	-0.03	Unfavorable
	ATR/tha	12.89	1.11	Favorable
Litoral Sul	TPH	12.40	0.88	Favorable
	TCH	95.84	7.52	Favorable
	FIB	14.04	0.42	Favorable
	ATR/tha	12.95	1.16	Favorable
Região Centro	TPH	9.61	-1.90	Unfavorable
	TCH	73.67	-14.65	Unfavorable
	FIB	12.92	-0.67	Unfavorable
	ATR/tha	9.76	-2.02	Unfavorable
Mata Norte	TPH	14.37	2.86	Favorable
	TCH	104.9	16.63	Favorable
	FIB	13.80	0.20	Favorable
	ATR/tha	14.64	2.85	Favorable
Mata Sul	TPH	8.48	-3.03	Unfavorable
	TCH	76.95	-11.37	Unfavorable
	FIB	13.60	0.08	Favorable
	ATR/tha	8.66	-3.11	Unfavorable

For abbreviations, see legend to Table 1.

The results obtained for the phenotype adaptability and stability analysis using the method described by Lin and Binns (1988) are shown in Tables 10 and 11. The methodology allows the decomposition of the Pi estimator into the sections assigned to favorable and unfavorable environments. The general superiority of a genotype increases and the deviation in the maximum productivity decreases with decreasing Pi values. In this sense, genotypes

RB92579, SP81-3250, RB867515, RB863129, and RB953180 were considered to present general adaptability in TPH. Genotype RB942520 was characterized as adaptable to favorable environments, while RB943365 was adaptable to unfavorable settings. For THC, general adaptability was observed for genotypes SP81-3250, RB92579, RB75126, RB867515, RB863129, and RB953180. RB943365 and RB943538 were considered adaptable to unfavorable and favorable environments, respectively. Finally, for ATR/tha, RB92579, SP81-3250, RB867515, RB942520, and RB863129 exhibited general adaptability, and SP79-1011 and RB953180 were adaptable to favorable and unfavorable environments, respectively.

Table 10. Estimated general adaptability Pi(g) based on Lin and Binns (1988) to favorable Pi(f) and unfavorable Pi(d) environments, considering the variables TPH and TCH of 25 genotypes assessed in the sugarcane belt of the State of Pernambuco, Brazil.

Genotype	Variables/Adaptability					
	TPH/Pi(g)	TPH/Pi(+)	TPH/Pi(-)	TCH/Pi(g)	TCH/Pi(+)	TCH/Pi(-)
Q138	10.26	11.15	8.93	379.1	357.0	412.1
RB72454	11.69	14.24	7.85	386.1	457.3	279.2
RB75126	8.82	9.64	7.58	124.4	137.3	105.1
RB863129	6.97	9.03	3.88	142.7	206.2	47.45
RB867515	4.61	5.47	3.32	130.2	163.2	80.65
RB872552	13.86	17.16	8.92	530.8	611.5	409.9
RB892700	9.13	12.15	4.60	354.1	399.2	286.5
RB92579	1.07	0.32	2.19	32.47	15.30	58.14
RB928064	11.79	15.35	6.44	350.5	391.5	289.1
RB93509	13.42	18.57	5.69	239.1	393.5	7.57
RB942520	7.20	8.45	5.33	282.3	361.9	162.8
RB942849	19.45	27.96	6.68	574.9	827.3	196.2
RB942898	13.91	18.38	7.20	491.8	611.3	312.5
RB942991	13.49	18.92	5.34	414.8	572.4	178.5
RB943066	9.71	11.65	6.79	447.8	492.2	381.2
RB943161	16.62	24.68	4.54	584.7	820.3	231.2
RB943365	12.84	20.67	1.11	516.6	810.6	75.62
RB943538	8.99	10.20	7.17	344	337.1	354.3
RB952675	13.21	16.14	8.81	447	522.3	334.1
RB952900	15.97	17.21	14.11	640.7	653.8	621.0
RB953180	7.14	10.19	2.55	190.6	233.3	126.5
RB953281	10.18	11.86	7.67	352.5	362.4	337.6
SP784764	11.22	12.53	9.24	359.6	401.8	296.3
SP791011	8.40	9.37	6.95	335.3	344.2	321.9
SP813250	1.88	2.92	0.32	26.2	39.04	6.95

For abbreviations, see legend to Table 1.

The adaptability and stability parameters for TPH, TCH, and ATR according to the method described by Eberhart and Russel (1966) are shown in Tables 12 and 13. The methodology considers genotypes with high productivity, high general adaptability (β_1 = 1, non-significant regression coefficient), and high stability (σ^2 = 0, non-significant regression deviation) as ideal. Genotypes adapted to favorable environments present $\beta_1 > 1$ (regression coefficient significantly higher than 1), while genotypes adapted to unfavorable environments show $\beta_1 < 1$ (regression coefficient significantly lower than 1). In this sense, only genotypes SP81-3250 and RB863129 could be considered ideal in terms of TPH; that is, genotypes that formed superior clusters according to the means clustering method by Scott and Knott were ideal genotypes. Apart from presenting coefficients of determination of 91.15 and 90.8%, respectively, these genotypes also met the requirements cited, showing excellent data adjustment to the linear regression model that was adopted. Genotypes RB92579 and RB942520 should be grown in favorable environments, similarly to RB867515 and RB953180, though under strict control in light of the low stability and not very favorable coefficient of determination.

Table 11. Estimated general adaptability Pi(g) based on Lin and Binns (1988) to favorable Pi(f) and unfavorable Pi(d) environments, considering the variables FIB and ATR/tha of 25 genotypes assessed in the sugarcane belt of the State of Pernambuco, Brazil.

Genotype	Variables/Adaptability					
	FIB/Pi(g)	FIB/Pi(+)	FIB/Pi(-)	ATR/tha Pi(g)	ATR/tha Pi(+)	ATR/tha Pi(-)
Q138	0.71	0.84	0.51	117.8	13.47	9.23
RB72454	1.08	0.99	1.20	130.0	16.28	8.08
RB75126	2.16	2.60	1.50	101.7	12.08	7.31
RB863129	1.04	1.14	0.89	84.81	11.38	4.12
RB867515	0.35	0.53	0.08	4.84	5.77	3.46
RB872552	0.69	0.90	0.38	155.9	19.86	9.19
RB892700	0.22	0.14	0.33	109.8	15.18	4.68
RB92579	0.91	1.22	0.43	1.46	1.00	2.14
RB928064	0.75	0.76	0.75	138.1	18.65	6.56
RB93509	1.09	1.55	0.40	146.8	21.27	4.78
RB942520	1.29	1.72	0.63	84.04	10.92	4.62
RB942849	0.54	0.26	0.97	211.4	31.30	5.89
RB942898	0.44	0.68	0.06	153.9	20.71	7.40
RB942991	0.80	0.67	0.99	15.81	22.67	5.51
RB943066	0.85	1.24	0.27	111.0	13.74	7.15
RB943161	0.58	0.67	0.45	191.2	28.85	4.54
RB943365	0.97	0.74	1.31	150.9	24.41	1.10
RB943538	0.47	0.58	0.31	102.6	12.17	7.41
RB952675	0.61	0.62	0.59	150.7	19.17	8.91
RB952900	0.37	0.47	0.22	182.4	20.74	14.49
RB953180	1.00	0.41	1.88	86.85	12.64	2.74
RB953281	0.61	0.95	0.10	118.5	14.40	8.02
SP784764	0.7	0.94	0.34	128.1	15.17	9.28
SP791011	1.54	1.99	0.86	88.54	10.02	7.10
SP813250	0.87	1.29	0.23	2.86	4.55	0.32

For abbreviations, see legend to Table 1.

Table 12. Estimated phenotype adaptability and stability (β_1: coefficient of linear regression; σ^2_{di} = variance of regression deviations, R^2 = coefficient of determination) according to Eberhart and Russel (1966) for variables TPH and TCH of 25 genotypes assessed in the sugarcane belt of the State of Pernambuco, Brazil.

Genotypes	TPH			TCH		
	β_1	σ^2_{di}	R^2(%)	β_1	σ^2_{di}	R^2(%)
Q138	1.12^{NS}	1.64*	80.88	1.22^{NS}	75.86**	77.39
RB72454	1.09^{NS}	-0.06^{NS}	94.03	1.13^{NS}	11.07^{NS}	89.29
RB75126	1.37*	1.22*	88.62	1.22^{NS}	12.23^{NS}	90.5
RB863129	1.03^{NS}	-0.43^{NS}	97.38	0.84^{NS}	-7.36^{NS}	90.8
RB867515	1.09^{NS}	6.17**	57.43	1.14^{NS}	135.81**	65.09
RB872552	0.95^{NS}	-0.48^{NS}	97.66	0.95^{NS}	-8.33^{NS}	93.1
RB892700	0.89^{NS}	0.38^{NS}	85.57	1.06^{NS}	-8.91^{NS}	94.57
RB92579	1.72**	1.54*	91.33	1.56**	102.0**	81.62
RB928064	1.02^{NS}	0.77^{NS}	84.99	1.20^{NS}	24.20^{NS}	87.26
RB93509	0.59*	-0.02^{NS}	81.39	0.23**	109.3**	8.74
RB942520	1.26^{NS}	1.60*	84.56	1.25^{NS}	102.5**	73.94
RB942849	0.43**	-0.55^{NS}	93.72	0.35**	2.43^{NS}	52.58
RB942898	0.76^{NS}	-0.16^{NS}	90.28	0.77^{NS}	14.54^{NS}	78.29
RB942991	0.73^{NS}	-0.40^{NS}	94.32	0.61*	-13.29^{NS}	89.18
RB943066	1.18^{NS}	2.70**	76.5	1.33^{NS}	49.89*	84.57
RB943161	0.44**	1.32*	43.22	0.39**	46.59*	33.98
RB943365	0.39**	3.90**	20.79	0.13**	160.4**	2.25
RB943538	1.17^{NS}	1.32*	84.37	1.46*	7.92^{NS}	93.88
RB952675	0.96^{NS}	0.94^{NS}	81.93	0.86^{NS}	32.06^{NS}	75.27
RB952900	1.30^{NS}	-0.07^{NS}	95.8	1.27^{NS}	15.46^{NS}	90.36
RB953180	0.63*	0.45^{NS}	73.75	0.92^{NS}	58.70*	70.42
RB953281	1.25^{NS}	1.75*	83.61	1.44*	17.20^{NS}	92.09
SP784764	1.24^{NS}	2.03**	81.75	1.00^{NS}	123.8**	60.53
SP791011	1.18^{NS}	2.09**	79.85	1.39*	25.77^{NS}	89.95
SP813250	1.07^{NS}	0.22^{NS}	90.98	1.14^{NS}	5.25^{NS}	91.15

**, * Significant at 1 and 5% error probability, respectively, according to the *t* test. (H0:β_{1i} = 1.0) and the F test (H0: σ^2_{di} = 0). NS = non-significant. For other abbreviations see legend to Table 1.

Table 13. Estimated phenotype adaptability and stability (β_1 = coefficient of linear regression; σ^2_{di} = variance of regression deviations; R^2 = coefficient of determination) according to Eberhart and Russel (1966) for variables FIB and ATR/tha of 25 genotypes assessed in the sugarcane belt of the State of Pernambuco, Brazil.

Genotypes	FIB			ATR/tha		
	β_1	σ^2_{di}	R^2(%)	β_1	σ^2_{di}	R^2(%)
Q138	0.80^{NS}	-0.18^{NS}	93.31	1.12^{NS}	1.58*	81.79
RB72454	1.18^{NS}	0.34*	37.24	1.11^{NS}	-0.14^{NS}	94.61
RB75126	1.15^{NS}	-0.04^{NS}	66.44	1.33^{NS}	1.43*	87.05
RB863129	1.14^{NS}	-0.16^{NS}	90.00	1.03^{NS}	-0.34^{NS}	95.86
RB867515	0.75^{NS}	-0.100^{NS}	57.98	1.19^{NS}	8.82**	55.08
RB872552	1.05^{NS}	-0.12^{NS}	78.80	0.96^{NS}	-0.57^{NS}	98.12
RB892700	0.86^{NS}	0.03^{NS}	42.91	0.87^{NS}	0.51^{NS}	83.49
RB92579	0.70^{NS}	-0.10^{NS}	56.30	1.72**	1.20*	92.66
RB928064	0.75^{NS}	-0.07^{NS}	52.10	1.00^{NS}	0.84^{NS}	83.99
RB93509	1.37^{NS}	0.88**	28.63	0.56*	-0.33^{NS}	87.34
RB942520	1.13^{NS}	0.22^{NS}	41.12	1.19^{NS}	1.49*	84.1
RB942849	1.62^{NS}	0.79**	38.01	0.40**	-0.70^{NS}	98.83
RB942898	0.76^{NS}	0.00^{NS}	40.61	0.80^{NS}	-0.05^{NS}	88.79
RB942991	1.72^{NS}	-0.16^{NS}	95.20	0.72^{NS}	-0.40^{NS}	93.15
RB943066	0.51^{NS}	0.85**	5.39	1.25^{NS}	3.13**	77.09
RB943161	0.82^{NS}	-0.12^{NS}	67.12	0.41**	1.43*	39.88
RB943365	1.23^{NS}	0.29^{NS}	41.40	0.35**	3.41**	19.82
RB943538	1.01^{NS}	-0.04^{NS}	60.78	1.20^{NS}	1.38*	85.04
RB952675	1.70^{NS}	0.00^{NS}	76.78	0.96^{NS}	0.65^{NS}	84.66
RB952900	0.66^{NS}	-0.14^{NS}	66.47	1.29^{NS}	0.13^{NS}	94.13
RB953180	2.29*	0.28^{NS}	71.36	0.65*	0.51^{NS}	73.91
RB953281	0.91^{NS}	0.16^{NS}	35.08	1.26^{NS}	1.74*	84.29
SP784764	-0.05*	-0.14^{NS}	1.02	1.22^{NS}	2.13**	81.09
SP791011	0.33^{NS}	0.11^{NS}	7.55	1.24^{NS}	3.23**	76.3
SP813250	0.49^{NS}	0.01^{NS}	20.92	1.04^{NS}	0.25^{NS}	90.11

**, * Significant at 1 and 5% error probability, respectively, according to the *t* test. (H0:β_{1i} = 1.0) and the F test (H0:σ^2_{di} = 0). ^{NS}Non-significant.

Regarding THC, SP81-3250, RB863129, and RB75126 are characterized as ideal genotypes for cultivation in sugarcane production microregions in the state of Pernambuco. RB92579, RB867515, RB953180, and RB942520 should be grown in favorable environments, Litoral Norte, Litoral Sul, and Mata Norte. For this variable, the data adjustment in the linear regression model was good, which affords more consistent decision-making concerning the allocation of cultivars to specific regions.

For ATR/tha, SP81-3250 is an ideal genotype for cultivation in the microregions that were assessed. It presented good perspectives of industrial performance since it has a high coefficient of determination. Genotype RB92579 had the best performance in ATR/tha, and its cultivation is recommended in favorable environments. As for RB867515, the same recommendation applies, which is suggested when TPH is taken into account, but it should be kept in a controlled environment because of its low stability and not very favorable coefficient of determination.

It should also be noted that the methodologies used is this report agreed in their classification of sugarcane microregions in the state of Pernambuco into favorable and unfavorable environments (Table 9). As a rule, the same applies for the identification of genotypes that were adaptable to edaphoclimatic conditions in the sugarcane belt in the state. In a study that tested adaptability and stability methodologies based on regression, variance, and nonparametric analyses, Silva e Oliveira et al. (2004) concluded that the methodology developed by Annicchiarico (1992) is among the best because it includes, under a single parameter, the concepts of adaptation, adaptability, and stability, which simplifies the interpretation of results. The methodology proposed by Lin and Binns (1998), according to De Fransceschi et al. (2010), was considered to be among the most reliable because, apart from addressing the genotype in question, it affords the assignment of genotypes with high and constant means to unfavorable environments, ranking them in terms of their response to environment improvements. In turn, although it does not identify genotypes specifically adapted to unfavorable environments, the methodology introduced by Eberhart and Russel (1966) should not be ruled out because it spots genotypes of high yield that are associated with adaptability and stability (De Fransceschi et al., 2010).

In sum, the results obtained in this study show that any methodology tested may be used, affording a more consistent recommendation of genotypes RB863129, RB867515, RB92579, RB953180, SP81-3250, RB75126, and RB942520 for commercial cultivation in the microregions of the state of Pernambuco that were assessed herein. Apart from standing out in terms of phenotype adaptability and stability, these genotypes exhibited the best agro-industrial performance.

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