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Stability analysis for cane and sugar yield of advanced sugarcane (*Saccharum officinarum*) genotypes

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ABSTRACT

The present investigation was undertaken to ascertain stable genotypes across nine environments. Ten advanced genotypes including three checks of themid-late group were evaluated for their adaptability in respect of cane yield, CCS yield and sucrose (%) for two crop seasons 2009-10 and 2010-11 under three locations with three cuttings. The stability of genotypes was worked out by using the model of Eberhart and Russell (1966). The regression coefficient (b_i) and deviation from regression ($S^2 d_i$) were used to define genotypic stability. Mean square due to G×E for all the characters was not significant. The genotypes CoBln 05502, CoP 05437 and CoP 9301 were stable and suitable for cane and CCS yield under favorable environments, while BO 91 was stable for CCS yield and sucrose per cent in juice under unfavorable environmental conditions. Apart from this, genotype CoP 05437 was on top and most stable and widely adaptable in cane and CCS yield across nine environments.

Key words: Genotype, G×E, Regression, Stability analysis, Sugarcane

Sugarcane (*Saccharum officinarum* L.) is grown extensively in tropical and sub-tropical India. The crop occupies over 5.05 million ha in the country with a total production of 348.18 million tonnes of which 66% is concentrated in the sub-tropical states (Dubey *et al.* 2017). Indeed, India is the second largest producer of sugar after Brazil. The crop is being used in making a large number of products including sugar and ethanol. In addition, the baggase residue obtained after juice extraction in the sugar factory has also gained paramount importance in the co-generation of electricity in the energy deficient country like India. The high demand of sugarcane products has forced the policy makers to give significant impetus to this crop in regard to its expansion. In sub-tropical India, the variation in the environmental condition is wide during the period of sugarcane growth and maturity owing to temperature ranges from 0-48 °C, photoperiod ranges from 4-8 hr and relative humidity from 8-100%. Climatic coefficient shifts are variable factors during the crop growth period which affect the yield and yield contributing traits of the crop. Hence, the yield of sugarcane is generally low in sub-tropical part of India (Tiwari *et al.* 2011). However, sugarcane is basically a tropical crop and capable of producing a high tonnage of cane under ideal conditions. But it is cultivated always in an erratic environment in sub-tropics, due to which varietal performance was noticed different over different locations/year/regions.

In sugarcane breeding programmes, the search for genotypes with high cane and sugar yield, adapted in the most varied environments is one of the most important objectives for breeders. Such situation forced the sugarcane breeders to develop stable and widely adapted genotypes over a variety of environments. Sugarcane breeding is highly complex because of its highly heterozygous nature, combined with higher polyploidy. In multi-year yield trials, the ranks of the genotypes vary from one location to another for yield and quality, thereby indicating a strong genotype (G) × environment (E) interaction. The importance of G×E interactions in sugarcane selection is widely recognized (Milligan *et al.* 1990).

Genotype × environment interactions are an important source of variation in the crop breeding programme and the term stability is used to characterize a genotype which exhibits a relatively constant cane yield across the environments under test. Based on this perception, genotypes with a minimal variance for cane yield across different environments are considered stable (Sabaghania *et al.* 2006). The knowledge on the components of genotype-environment (G×E) interaction is of great importance for breeding but provides no detailed information on the performance of each genotype under varying environmental conditions (Cruz *et al*. 2004). The analysis of stability and adaptability

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are, therefore, extremely important and necessary for the identification and recommendation of superior genotypes in different environments. Hence, there is utmost need to breed stable genotypes for awide range of environments. The understanding of genotypes × environment interaction is essential for such breeding programme since potentiality of a genotype and stability in its performance can be quantified by multi-environmental tests. Therefore, keeping above facts in view, the present investigation was undertaken to assess the stability and G×E interaction in some advanced genotypes of sugarcane across nine different environments.

MATERIALS AND METHODS

A set of seven advanced genotypes of sugarcane developed by different research centers of North Central Zone along with three standard checks (Mid-late group) were evaluated for cane yield and CCS (commercial cane sugar) yield and sucrose per cent in juice under the All India Co-ordinated Research Project on Sugarcane for three crops (I Plant crop, II Plant crop and ratoon) during 2009-2010 and 2010-11 at three locations, viz. ICAR-IISR, Regional Centre, Motipur (28°03' latitude 81°4' longitude), Sugarcane Research Institute, RAU, Pusa (25°9' latitude 85°7' longitude) and GSSBRI, Seorohi, Kushinagar (26°7' latitude 84°2' longitude).

The experimental material comprising Co 05018, Co 05019, Co 05020, CoP 05437, CoSe 05452, CoBln 05502 and CoBln 04174 along with three cultivars of sugarcane BO 91, CoP 9301 and CoSe 92423 as checks were taken. The experiments at three different locations over two crop seasons with three cuttings of crops constituted nine environments. The experiment was laid out in randomized block design (RBD) with three replications at all three locations. Plots were of 8 rows with 6.0 m length having 0.90 m spacing between rows. Three budded setts were used for planting with a seed rate of 12 buds per m^2 at all three locations. Six rows were harvested for measuring cane yield in each plot across replications and it was calculated as tonnes/ha. A 10 stalk sample was randomly taken from each plot and weighed. CCS (tonnes/ha) was computed as per standard formula. The clarified juice was analyzed with digital automatic saccrimeter Autopol 880 and J 57 Automatic refractometer for sucrose per cent juice. The phenotypic stability was estimated as per method outlined by Eberhart and Russell (1966). In this model of analysis sum of square due to G×E were partitioned into individual genotypes (X-i) regression of environmental mean (b_i) and deviation from regression ($S^2 d_i$). The regression coefficient (b_i) and mean square deviation from ($S^2 d_i$) were used to define genotypic stability. Mean is the general mean for the character of each genotype across nine environments.

Table 1 Pooled analysis of variance for genotype × environment interaction cane yield, CCS and sucrose per cent in sugarcane across nine environments

Source of variation	Mean sum of squares			
	df	Cane yield (tonnes/ ha)	CCS (tonnes/ ha)	Sucrose per cent in juice
Replication within environment	18	37.32	0.06	0.11
Genotypes (G)	9	170.30**	2.43**	1.83*
E + (G×E)	80	122.96**	2.17**	0.74**
Environments (E)	8	752.24**	14.78**	5.30**
G×E	72	53.04	0.77	0.23
Environments (Linear)	1	6017.94**	118.24**	42.45*
G×E (Linear)	9	120.73**	1.43**	0.55**
Pooled Deviation	70	39.04	0.61	0.17
Pooled Error	162	12.33	0.09	0.09
Total	89	127.75	2.19	0.85

Table 2 Stability parameters of ten advanced sugarcane genotypes for yield and quality traits

Genotype	Cane yield (tonnes/ha)			CCS (tonnes/ha)			Sucrose per cent in juice		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
Co 05018	54.57	1.15	20.74**	6.48	1.05	0.48*	17.07	0.92	0.11*
Co 05019	59.44	0.40	25.97**	7.00	0.62	0.48*	16.82	1.58	0.07
Co 05020	63.36	0.44	33.23**	7.28	0.54	0.45*	16.65	1.26	0.07
CoP 05437	70.02	1.10	4.34	8.15	1.16	0.17	16.93	1.23	0.09
CoSe 05452	60.21	1.49	44.97**	7.36	1.43	0.99**	17.45	0.19	0.03
CoBln 05502	54.72	1.56	2.28	6.32	1.44	0.16	16.88	1.06	0.04
CoBln 04174	61.08	0.79	54.69**	7.06	0.78	1.08**	16.69	0.95	0.19*
BO 91	59.26	1.02	10.76	6.96	0.89	0.30	17.21	0.89	-0.03
CoP 9301	61.25	1.51	5.67	7.57	1.40	0.31	18.17	1.00	0.23*
CoSe 92423	59.55	0.52	39.06**	7.22	0.67	0.72	17.24	0.99	-0.02
SE (Mean)	2.20			0.28			0.15		
SE of b_i		0.25			0.23			0.20	

The pooled error was used to test the hypothesis that the mean square deviation did not differ significantly from 0 at 0.05% and 0.01% probability levels. However, the t-test using the standard error of regression coefficient against the hypothesis that did not differ from 1.0, so it was assumed that genotypic effects were fixed and heritable while location and year effects were random and non-heritable.

RESULTS AND DISCUSSION

The pooled analysis of variance revealed that genotypes and environment were significant for all the three traits (Table 1). The higher value of pooled deviation than the pooled error indicated that there was a relationship between non-linear regression components and advanced genotypes for cane, CCS yield and sucrose per cent in juice. The relationship endorses the report that genotypes responded differently across the nine environments for cane and CCS yield (Tai *et al.* 1982, Queme *et al.* 2005) in sugarcane.

The mean performance of genotypes over several locations due to G×E interactions is not much reliable parameter alone for prediction of their stability for the traits. Therefore, under such condition genotypes should be screened individually in specific locations to maximize cane yield and CCS yield (Gauch 1990, Ebdon and Gauch 2002, Kumar *et al.* 2007).

The mean performance, regression coefficient (b_i) and deviation from regression ($S^2 d_i$) were presented in Table 2. The genotypes CoBln 05502, CoP 05437, CoP 9301 and BO 91 exhibited $S^2 d_i$ (deviation from the regression) non-significant and regression coefficient (b_i) greater than unity (b_i>1) for cane yield and CCS yield except BO 91. However, CoP 05437 and CoP 9301 showed higher mean value than the population mean indicating these two clones were suitable and stable under favorable environmental conditions for cane and CCS yield. On the other hand, genotypes CoBln 05502 and BO 91 exhibited their mean value lower than the population mean for CCS as well as cane yield. BO 91 also showed $S^2 d_i$ (deviation from the regression) non-significant and regression coefficient (b_i) less than unity (b_i<1) with mean value lesser than the population mean, thereby indicating its stability and suitability under the unfavourable condition for CCS (tonnes/ha) as well. However, a higher value of $S^2 d_i$ indicates unstability of genotypes over varied environments. Similar, results have earlier been reported Tahir *et al.* (2013), Guddadamath *et al.* (2014), Tiwari *et al.* (2011), Kumar *et al.* (2007) and Dubey *et al.* (2017). Whereas, the genotypes CoSe 92423, BO 91 and CoSe 05452 exhibited $S^2 d_i$ non-significant and regression coefficient (b_i) less than unity (b_i<1) with a mean value higher than the population mean indicated genotype stability and suitability under unfavorable environmental conditions for sucrose per cent in juice. While the clone CoBln 05502 showed $S^2 d_i$ (deviation from the regression) non-significant and regression coefficient (b_i) greater than unity (b_i>1) indicated its stability and suitability for sucrose per cent in juice under favorable environments (Table 2).

The genotypes CoBln 05502, CoP 05437, CoP 9301

Table 3 Performance of genotypes for cane yield (tonnes/ha) and their rank of stability across nine environments (E1-E9)

Genotypes	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand mean	b_i	S^2d_i	Rank
Co 05018	48.31	53.55	28.21	61.10	58.10	52.90	64.38	66.09	59.57	54.69		20.74	5
Co 05019	52.69	74.47	55.00	59.85	57.60	50.95	59.85	63.39	60.93	59.44		25.97	6
Co 05020	54.65	79.72	61.76	66.99	63.50	56.92	67.47	61.30	57.84	63.35		33.23	7
CoP 05437	59.41	72.22	48.20	80.85	78.40	71.03	80.85	68.33	60.93	70.02		4.34	2
CoSe 05452	48.43	54.17	28.63	73.61	71.36	63.08	73.60	70.17	58.83	60.21		44.97	9
CoBln 05502	42.87	59.43	27.39	68.71	67.50	50.80	68.71	60.68	46.37	54.72		2.28	1
CoBln 04174	71.85	78.79	44.80	63.75	59.36	50.25	64.08	60.80	55.50	61.04		54.69	10
BO 91	58.53	75.00	40.68	66.76	62.81	57.10	66.76	54.88	50.81	59.26		10.76	4
CoP 9301	54.32	68.70	32.96	74.72	74.27	60.75	74.72	57.81	53.03	61.25		5.67	3
CoSe 92423	64.39	52.53	42.95	61.48	59.20	57.00	61.65	71.53	65.24	59.55		39.06	8
Environmental index	-3.77	6.51	-19.30	7.43	4.86	-3.28	7.85	3.15	-3.45				
Mean	56.58	66.86	41.06	67.78	65.21	57.08	68.21	63.50	56.91				
CV	6.69	9.84	13.11	8.94	10.78	11.69	7.61	12.79	8.39				
SEm±	3.09	5.37	4.40	4.95	5.74	5.45	4.24	6.63	3.90				
CD (P=0.05)	6.49	11.28	9.24	10.40	12.06	11.44	8.90	--	8.19				

Table 4 Performance of genotypes for CCS (tonnes/ha) and their ranks in terms of stability across nine environments (E1-E9)

Genotypes	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand mean	b_i	S^2d_i	Rank
Co 05018	5.50	6.05	3.22	7.81	7.13	6.19	7.64	7.45	7.37	6.48		0.49	7
Co 05019	6.10	8.42	5.94	7.67	7.38	5.19	7.75	7.20	7.42	7.01		0.48	6
Co 05020	6.02	8.90	6.62	8.25	7.89	6.55	7.77	6.90	6.65	7.28		0.45	5
CoP 05437	7.53	8.35	5.47	10.66	9.71	7.65	8.63	8.13	7.21	8.15		0.17	2
CoSe 05452	5.84	6.40	3.34	9.32	8.38	7.42	9.90	8.46	7.20	7.36		0.99	9
CoBln 05502	4.81	6.54	3.13	8.55	8.48	5.11	7.40	7.26	5.65	6.33		0.16	1
CoBln 04174	8.49	8.90	4.99	8.15	7.40	5.41	7.73	6.28	6.22	7.06		1.09	10
BO 91	6.97	8.47	4.70	8.50	7.92	6.44	7.12	6.53	5.98	6.96		0.30	3
CoP 9301	6.61	8.44	4.13	9.75	10.19	6.93	7.91	7.29	6.87	7.57		0.31	4
CoSe 92423	7.67	6.11	4.79	7.84	7.52	6.57	8.24	8.34	7.94	7.23		0.72	8
Environmental index	-0.59	0.52	-2.51	1.51	1.06	-0.80	0.87	0.24	-0.29				
Mean	6.55	7.66	4.63	8.65	8.20	6.35	8.01	7.39	6.85				
CV	6.68	4.15	3.52	7.24	9.98	9.62	6.34	5.10	9.62				
SEm±	0.36	0.26	0.13	0.51	0.67	0.50	0.42	0.31	0.54				
CD (P=0.05)	0.75	0.55	0.28	1.07	1.40	1.05	0.87	0.65	1.13				

Table 5 Performance of genotypes for sucroseper cent in juice and their ranks in terms of stability across nine environments (E1-E9)

Genotypes	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand mean	b_i	S^2d_i	Rank
Co 05018	16.12	16.06	16.48	18.47	17.48	16.89	17.42	17.02	17.77	17.08		0.12	8
Co 05019	16.36	16.26	15.64	18.18	18.76	14.99	17.05	16.47	17.66	16.82		0.07	6
Co 05020	15.66	15.90	15.54	18.00	18.30	16.44	17.19	16.25	16.59	16.65		0.07	5
CoP 05437	15.34	16.64	16.52	18.45	18.11	15.89	17.15	17.20	17.07	16.93		0.09	7
CoSe 05452	17.36	17.19	16.98	18.17	17.10	17.66	17.46	17.45	17.71	17.45		0.04	3
CoBln 05502	16.10	16.10	16.55	17.90	18.09	15.81	16.52	17.28	17.55	16.88		0.05	4
CoBln 04174	16.72	16.32	16.10	17.93	18.00	15.94	17.25	15.69	16.24	16.69		0.19	9
BO 91	17.02	16.60	16.76	18.09	18.28	16.44	17.25	17.35	17.06	17.21		0.03	2
CoP 9301	17.38	17.65	18.22	18.40	19.80	16.59	18.57	18.24	18.70	18.17		0.23	10
CoSe 92423	16.83	16.84	16.22	18.35	18.47	16.77	17.15	16.86	17.64	17.64		0.02	1
Environmental index	-0.62	-0.56	-0.61	1.08	1.13	-0.77	0.19	-0.13	0.29				
Mean	16.49	16.56	16.50	18.19	18.24	16.34	17.30	16.98	17.40				
CV	3.97	2.81	2.34	2.24	3.32	4.18	1.78	2.49	3.07				
SEm±	0.54	0.38	0.32	0.33	0.49	0.56	0.25	0.35	0.44				
CD (P=0.05)	1.12	0.80	0.86		1.04	1.17	528.00	0.73	0.92				

and BO 91 were found relatively suitable and stable across the environments. CoBln 05502 was most stable having the first rank, while the genotype CoP 05437 stood on the second rank in terms of stability has shown the ability to be performing better across low as well as high-yielding environments for cane yield (Table 3).

Genotype CoBln 05502 ranked first across the nine environments in terms of stability has mean value less than the population mean thereby indicating its performance suitable and stable under favorable environments. The CoP 05437 stood on the second rank had done well in both low and high-yielding environments with higher mean value compared to the population mean appeared to be most suitable and stable across varying environments for CCS (tonnes/ha). However, BO 91 and CoP 9301for CCS yield were relatively stable and suitable across the nine environments (Table 4).

The genotypes CoSe 92423, BO 91, CoSe 05432 and CoBln 05502 were relatively better in terms of stability for sucrose per cent. Interestingly the genotypes CoP 9301 had shown higher sucrose per cent in poor yielding and better yielding environments having a mean value greater than the population mean, but it was not found stable for this trait across the environments (Table 5).

The conclusion can be drawn from this investigation that genotypes CoBln 05502, CoP 05437 and CoP 9301 were found stable and suitable for cane yield and CCS yield under favorable environments while BO 91 was stable for CCS yield and sucrose per cent under unfavorable environmental conditions. Indeed, CoP 05437 was on a top pedestal in cane and CCS yield in low and high yielding locations across nine environments. These identified genotypes can be recommended in NCZ (Northern central zone) of India for commercial cultivation accordingly or they can be used as a parent in further crop improvement programme of sugarcane.

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