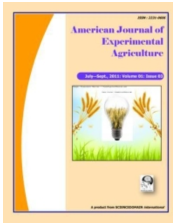

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Sugarcane Genotype Performance in Three Environments (Based on Crop Cycle) at Mardan, Pakistan

Mohammad Tahir[1*], Iftikhar Hussain Khalil[2], Per H. McCord[3] and Barry Glaz[4]

[1]Research Officer, Sugar Crops Research Institute, Mardan, Khyber Pakhtunkhwa, Pakistan.
[2]Department of Plant Breeding and Genetics, University of Agriculture, Peshawar, Pakistan.
[3]Research Geneticist, USDA-Agriculture Research Service, Canal Point, Florida, USA.
[4]Research Agronomist, USDA-Agriculture Research Service, Canal Point, Florida, USA.

Authors' contributions

Author MT Designed, and laid out the experiment; compiled the study results, followed by statistical analyses; wrote the first draft. Author IHK supervised the research project/relevant literature search. Author PHMC reviewed the first draft. Author BG critically reviewed and contributed to writing of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Sugarcane breeders often face significant genotype x environment interactions in their trials grown under multiple environments. Hence, genotypes need to be tested for their stability across different environments keeping in view the significant interactions. An experiment comprising 28 sugarcane genotypes (including 2 checks) was planted in two plant and one ratoon crops during 2010 to 2013 in a randomized complete block design with 3 replications. Data were recorded on cane, yield, and quality characters. Analyses of variance showed significant mean squares for crops, genotypes, and their interactions. The linear contrasts of two plant crops were found non-significant for tillering, vigor rate, stalk diameter, Brix, Pol, recovery, and cane yield. However, the contrast for plant crops versus ratoon was non-significant for stalk diameter only. Shukla's stability variances and yield stability indices (Ys_i) showed that no single genotype was stable for all characters. However, genotypes MS-2003-CP-209, MS-2003-CP-275,CoJ-76, MS-2003-CR2-131, and MS-2003-CR5-245 were stable for cane yield. The results of the study indicate the

**Corresponding author: Email: tasran@gmail.com;*

importance of genotype x environment interaction and stability in the ongoing varietal development program.

Keywords: Sugarcane; stability; Mardan; G x E interaction; Pakistan.

1. INTRODUCTION

Sugarcane genotypes in advanced evaluation stages need to be tested for their stability across different environments. Due to the varying interaction of genotypes with the environment the performance ranking of sugarcane genotypes is rarely the same across the environments they are tested in. Kang and Martin [1] reported that underlying genotype x environment interaction reduced the correlation between phenotypic and genotypic values. Non-significant genotype x location, genotype x year, and genotype x location x year interactions would indicate that little or no attention needs to be paid to locations and years in estimating genotypic effects and performance of the genotypes could be assessed based on one environment. However, if interaction of these sources of variation is significant, its causes, nature, and implications should be assessed. They further stated that a genotype would be regarded as stable if its associated interaction component is less than or equal to environmental variance (experimental error) and would be considered unstable otherwise.

Sugarcane is sensitive [2] to environmental changes, with special regards to commercial sugar per unit area. Jackson and Hogarth [3] reported that sugarcane clones interacted more with locations than crop-year in Australia. They suggested that for early stages of selection where many clones are under evaluation, testing only plant crops might be satisfactory. Comparatively larger genotypic mean squares showed that cultivars differed in their genetic potential for tons of cane per hectare (TCH) and Pol% of cane. Bissessur *et al*[4] studied 154 sugarcane genotypes belonging to four families at two sites under both plant and ratoon conditions. They found significant differences between families, genotypes, and sites in stalk height, stalk diameter, recoverable sucrose % cane, and TCH. Significant G × E interactions were also found for stalk and yield characters. They concluded that selection for each specific environment should be carried out separately.

Interaction of genotype, environment, and time of harvest and their implications for growers were studied by Gilbert *et al* [5]. The effect of these factors was assessed on kilograms of sugar per ton of cane (KST), TCH, and tons of sugar per hectare (TSH) for recently released cultivars in south Florida, USA. Cultivar, environment, time of harvest and their interactions significantly affected KST, TCH, and TSH. They concluded that significant cultivar x environment interactions supported continued multi-location evaluation of sugarcane germplasm both during genotype selection and following cultivar release. In the same way, Zhou *et al* [6] stated that genotype by environment interactions (G × E) complicated the selection process and hindered the true effects of the genotypes. They found significant differential responses of genotypes across locations for irrigated and coastal long-cycle programs, indicating that it was important to identify and characterize sites in South Africa. Genotype by crop-year interaction was found more significant and larger in rainfed than in irrigated cropping systems. These results led them to conclude that ratooning ability was important in rainfed regions. They recommended that separating the coastal hinterland and coastal average potential were good for reducing G × E.

The present study was planned to study the effect of different environments in the form of two plant and one ratoon crops on sugarcane genotypes across two years at Mardan, Pakistan, and attempt to identify genotypes that are stable across these environments.

2. MATERIALS AND METHODS

Twenty-six sugarcane genotypes and two checks were grown at Sugar Crops Research Institute (SCRI), Mardan, during 2010 to 2013. The experimental design was a randomized complete block with 3 replications. The first plant crop was planted in September 2010, while 2^{nd} plant crop was planted in September 2011. A ratoon crop was maintained in 2011 as well. Plot size for a genotype per replication was 6.7 x 10 meters (67 m^2). There were 7 rows per plot, 0.90 meters apart with a row length of 10 meters. The number of buds in the central row was kept at 150.All agronomic and cultural practices were kept uniform across all plots. Data were recorded on the following characters:

1. First Tillering: counting the number of tillers per 10 m central row, in the first week of April.
2. Second Tillering: counting the number of tillers per 10 m central row, one month after the first tillering.
3. Vigor Rate 1 (VR1): the difference of the two tillering counts divided by number of days of the month as per the formula below [7].
4. $$VR1 = \frac{(2ndTillering - 1stTillering)}{30}$$
5. First Growth: length of the standing plant from the ground to the top (rosette of leaves) in centimeters, recorded during the first week of July.
6. Second Growth: length of the standing plant from the ground to the top in centimeters, one month after the first growth.
7. Vigor Rate 2 (VR2): the difference of the two growth data divided by number of days of the month as per the following formula [7].
8. $$VR2 = \frac{(2ndGrowth - 1stGrowth)}{30}$$
9. Cane length: the length of the cane in centimeters to the point where tops were easily removable.
10. Number of internodes per cane: counting the number of internodes per cane stalk.
11. Internode length (cm): length of the internode in the center of the plant in centimeters.
12. Stalk diameter (cm): Diameter of the stalk in centimeters with a digital Vernier caliper.
13. Millable canes: counting the number of millable canes (i.e. excluding the tillers which have not developed into mature canes) in the central row of the plot.
14. Cane yield (tons per hectare): weighing the canes per plot without trash and converting to tons of canes per hectare as follows:

$CaneYield = \left(\frac{xX\,10000}{6.7\,X\,1000}\right)$; Where*x* = cane yield in kgs per plot.

15. Brix percentage: Five canes per sample were crushed using a cane crusher for estimation of Brix. Both Brix and temperature reading were taken with a hydrometer. Then, corrected Brix % was calculated using a Schmitz table [8] for a particular temperature.
16. POL %: Cane juice left from Brix reading was added with 1.5 g lead acetate and filtered. The filtered juice was then placed in a tube in a polarimeter. The reading taken was Pol% which was corrected for a particular Brix using Schmitz table [8] to obtain corrected Pol%.
17. Purity %: was calculated by the following formula:
18.

$$Purity\,\% = \frac{POL\,\%}{CorrectedBrix} X\,100$$

Where Corrected Brix was the Brix adjusted with the ambient temperature.

19. Recovery %: Calculated by the following formula:

Recovery %= [POL% - 0.5 (C. Brix – Pol%)] x 0.7

Data across 3 crops viz. 2 plant crops and 1 ratoon were analyzed to quantify genotype x environment interaction effects for all traits using PROCGLM of SAS 9.1 [9]. A fixed effect model was used for genotypes and crops. When a G x E interaction was significant, means were calculated across three crops and 'stability variances' were calculated. According to Shukla[10] a genotype is stable if its stability variance (σ_i^2) is equal to the environmental variance (σ_e^2) which means that σ_i^2=0. A relatively large value of σ_i^2 indicates greater instability of genotype i. As the stability variance is the difference between two sums of squares, it can be negative. These negative estimates of σ_i^2 may be taken as equal to zero [10]."Stability.par" procedure of the package "Agricolae" of R version 2.14 statistical software [11] developed by Kang [12] was used to calculate stability variances and YS_i values (which is determined by sum adjusted yield rank (Y) and stability rating (S) for each genotype). Genotypes having values for a character greater than mean YS_i and non-significant stability variance were judged as stable.

3. RESULTS AND DISCUSSION

Mean squares for crops were highly significant (P<0.01) for all the characters except vigor rate 1 which was significant at P<0.05, and stalk diameter was not significant (Table 1). Highly significant mean squares (P<0.01) for the contrast of plant crop 2011 versus plant crop 2012 were recorded for growth1, growth2, vigor rate 1, cane length, number of internodes, purity, and number of millable canes, while significant (P<0.05) for tillers2, and internode length, and non-significant for tiller1, vigor rate1, stalk diameter, brix, Pol, recovery, and cane yield. Mean squares of the contrast of plant crops versus ratoon were significant for all the characters except stalk diameter. Looking at the overall contribution of the contrasts mean squares to the crops it was noted that plant crops versus ratoon contributed a substantial amount to the crops mean squares.

Genotype mean squares were highly significant ($P<0.01$) for all characters. In the same way genotype x crop mean squares were highly significant ($P<0.01$) for the characters under study.Gilbert*et al* [5] also found significant cultivar, environment, and time of harvest interactions for sugar, cane yield, and sugar yield characters. Ramburan *et al* [13] reported that G × E interaction accounted for more variation than the main effect of genotype in sugarcane. In our study the order of importance of sources of variation was crop, genotypes and genotype x crop.

According to Kang and Martin [1], theoretically, if the interactions are found non-significant, performance of genotypes can be predicted from only one environment. However, practicing breeders/geneticists are aware that this situation rarely occurs in typical performance trials that examine large numbers of genotypes across many environments. Shukla [10] presented formulae for removing heterogeneity from the Gx E interaction variance, and partitioning the remainder of the Gx E interaction variance and assigning it to each genotype (parameter estimate). In our study, since the interaction component was significant, this method was used for calculating stability analysis.

3.1 Shukla's Stability Variances (Σ_i^2) and Yield stability (Ys_i's)

3.1.1 Tillers and growth

For tiller1, genotypes BF-162-166, MS-2003-CP-301, S-87-US-1767, MS-2003-CR2-131, and MS-2003-CR8-407, showed lower stability variances with mean values of 185.00, 167.83, 157.00, 147.33, and 192.50, respectively, while their yield stability values ranged from 12 to 30 which were above mean YS_i (11.68) (Table 2). For tiller2, genotypes MS-2003-CP-275, MS-2003-CP-378, CoJ-76, MS-2003-CR5-245, and MS-2003-CR8-407 showed mean values in the range of 312.5 to 342.06, lower and non-significant stability variances and higher values than mean YS_i (12.29). Vigor rate1 exhibited lower values of stability variances for genotypes MS-2003-CP-279, MS-2003-CP-300, MS-2003-CR1-50, MS-2003-CR2-129, and MS-2003-CR7-243, and means in the range of 4.13 to 5.13. YS_i values for vigor rate1 ranged from 13 to 29 which were above the mean YS_i.

The range of means for growth1 according to lower stability variances and higher values of YS_i values than mean was noted as 100.90 to 117.50 for genotypes MS-2003-CP-154, S-87-US-1767, CoJ-76, MS-2003-CR8-407, and MS-2003-CR9-451. For growth2 genotypes S-9883-CSSG-1139, MS-2003-CR1-50, MS-2003-CR2-131, MS-2003-CR5-245, and, MS-2003-CR9-451, showed non-significant stability variances and YS_i values in the range of 18 to 25 which were higher than means YS_i value (11.14). Genotypes MS-2003-CP-275, S-9883-CSSG-1139, MS-2003-CR1-50, MS-2003-CR2-129, and MS-2003-CR5-245, displayed lower and non-significant stability variances for vigor rate 1. Their YS_i values ranged from 20 to 25 and were higher than mean YS_i value (13.54).

Table 1. Analyses of mean squares, for 16 characters of 28 sugarcane genotypes analyzed in 2 plant-canes and one first-ratoon crop cycle

Source of variation	DF	Till1(number)	Till2(number)	VR1(ratio)	Gr1(cm)	Gr2(cm)	VR2(ratio)	Clength(cm)	Ninter(number)
Crops	2	531199.40**	1214753.69**	155.21**	123398.16**	104537.64**	4.54*	77399.40**	131.65**
Reps within crops	6	30.67	1323.19	1.09	59.95	166.70	0.18	291.88	0.33
PC 2011 vsPC 2012	1	2273.36	10465.93*	3.33	73246.20**	16656.31**	3.03**	9169.66**	113.31**
Plant crops vsratoon	1	1060125.45**	2419041.45**	307.10**	173550.11**	192418.98**	6.05**	145629.14**	150.00**
Genotype[a]	27	7770.20**	14322.62**	3.30**	1580.37**	4963.01**	1.43**	1484.59**	11.11**
Genotype × Crop	54	3425.92**	5175.41**	3.56**	649.53**	1372.15**	1.02**	582.31**	5.24**
Error	162	880.46	2007.62	1.08	116.73	280.22	0.34	283.75	1.52
Total	251								
	CV	18.90	15.82	24.66	10.47	9.06	20.43	9.87	8.48
	Mean	156.98	283.20	4.21	103.18	184.78	2.87	170.72	14.53

***, * = Significant at P=0.01 and P=0.05, respectively.*

Till= Tillers. Gr= Growth. VR= Vigor Rate. Clength= Cane Length. Ninter= Number of internodes.

[a]Mean squares for VR1, Cdia, Brix, Pol, Purity, Recovery, and Yield were tested against pooled error.

Table 1. (Contd.) Analyses of mean squares, for 16 characters of 28 sugarcane genotypes analyzed in 2 plant-cane and one first-ratoon crop cycle

Source of variation	DF	IntLen(cm)	Cdia(cm)	Brix (%)	Pol (%)	Purity (%)	Recovery (%)	M canes (number)	C yield (tonnes/ha)
Crops	2	188.08**	0.005	63.09**	122.53**	632.15**	78.83**	31473.91**	21695.05**
Reps within crops	6	3.69	0.010	1.45	4.14	64.15	3.60	114.46	661.83
PC 2011 vsPC 2012	1	14.08*	0.003	2.41	0.38	144.10**	1.40	23347.50**	174.05
Plant crops vsratoon	1	362.07**	0.006	123.77**	244.68**	1120.21**	156.26**	39600.31**	43216.05**
Genotype[a]	27	15.13**	0.021**	2.43**	4.51**	45.70**	3.31**	1078.40**	296.74**
Genotype × Crop	54	6.83**	0.013**	2.15**	2.89**	32.37**	2.05**	462.49*	276.84**
Error	162	2.80	0.004	0.72	1.12	12.23	0.81	289.63	104.77
Total	251								
	CV	12.31	6.62	4.38	6.58	4.22	8.90	21.54	15.31
	Mean	13.58	0.93	19.37	16.70	82.82	10.09	78.98	66.83

***, * = Significant at P=0.01 and P=0.05, respectively.*

IntLen= Internode Length. Cdia= Cand diameter. Mcanes= Number of Millable Canes. Cyield= Cane Yield.

[a]Mean squares for VR1, Cdia, Brix, Pol, Purity, Recovery, and Yield were tested against pooled error.

Table 2. Means, Shukla's stability variance (σ_i^2), and yield stability statistic (YS_i) of 28 genotypes for 16 traits analyzed in 2 plant-cane and 1 first-ratoon crop cycle

S.No.	Genotype	Till1(number)			Till2(number)			VR1(ratio)			Gr1(cm)		
		Means	σ_i^2	YS_i	Mean	σ_i^2	YS_i	Mean	σ_i^2	YS_i	Mean	σ_i^2	YS_i
1.	MS-2003-CP-154	133.83	2046.88	5	219.50	8177.92 *	-5	2.86	2.73	0	100.90	102.83	12 +
2.	BF-162-166	185.00	1320.69	23 +	331.17	3103.78	27 +	4.87	4.92 *	22 +	101.70	581.45 **	5
3.	MS-2003-CP-209	177.50	3889.90 *	17 +	294.67	5597.30	18 +	3.91	0.25	5	81.70	710.80 **	-9
4.	MS-2003-CP-275	192.67	2839.84 *	23 +	312.50	192.29	22 +	4.00	1.49	8	108.53	511.86 *	17 +
5.	MS-2003-CP-279	174.83	5310.77 **	12 +	307.67	9611.96 **	12	4.43	1.42	20 +	98.10	134.52	8
6.	MS-2003-CP-300	187.17	3271.21 *	20 +	331.83	10256.17 **	20 +	4.82	2.35	23 +	95.13	393.16 *	3
7.	MS-2003-CP-301	167.83	†-67.60	18 +	297.17	7716.77 *	15 +	4.31	7.15 **	10	94.23	926.60 **	-4
8.	MS-2003-CP-377	147.17	1021.35	11	269.67	649.46	10	4.08	1.38	11	79.97	655.61 **	-10
9.	MS-2003-CP-378	189.33	4013.82 *	21 +	310.83	2199.72	21 +	4.05	0.13	9	93.83	271.44	3
10.	S-87-US-1767	147.33	-31.45	12 +	231.83	62.08	2	2.81	0.40	-1	117.50	336.58	28 +
11.	S-87-US-2787	113.33	393.83	1	231.00	9389.11 *	-3	3.92	11.18 **	-1	100.73	101.71	11
12.	CoJ-76	195.67	12263.74 **	21 +	328.00	2837.63	25 +	4.41	7.49 **	11	112.53	391.55 *	22 +
13.	CPF-225	194.17	4058.51 *	24 +	351.50	6207.32 *	26 +	5.24	18.89 **	22 +	94.87	86.76	6
14.	S-9883-CSSG-1139	144.50	758.33	10	267.00	918.93	9	4.08	0.04	11	98.97	306.12	10
15.	MS-2003-CR1-50	97.83	4663.26 **	-10	221.83	7273.24 *	-4	4.13	0.21	13 +	108.33	101.56	20 +
16.	MS-2003-CR1-51	129.00	1071.00	3	237.00	6465.61 *	1	3.60	3.22	3	82.40	311.03	0
17.	MS-2003-CR1-79	136.50	5182.61 **	0	282.00	11099.63 **	4	4.85	2.67	25 +	107.00	553.65 **	11
18.	MS-2003-CR2-129	134.50	2157.20	7	284.00	4436.48	15 +	4.98	0.72	27 +	123.30	1135.25 **	22 +
19.	MS-2003-CR2-131	157.00	-34.65	15 +	290.67	6013.87	17 +	4.45	5.57 **	13 +	110.73	836.22 **	16 +
20.	MS-2003-CR2-132	131.50	1411.35	4	234.00	5234.22	4	3.42	2.19	2	109.43	155.18	22 +
21.	MS-2003-CR2-155	109.17	661.27	-1	233.17	1107.08	3	4.13	4.21 *	9	86.37	-12.17	2
22.	MS-2003-CR5-245	192.50	6285.40 **	18 +	318.33	2886.12	24 +	4.19	1.63	15 +	106.30	122.41	17 +
23.	MS-2003-CR6-295	159.67	2492.97	16 +	276.83	7581.72 *	7	3.91	1.75	5	98.73	442.14 *	5
24.	MS-2003-CR7-243	174.33	3038.09 *	15 +	328.17	6459.48 *	22 +	5.13	2.55	29 +	110.53	642.15 **	15 +
25.	MS-2003-CR8-407	196.60	1191.40	30 +	342.06	903.75	29 +	4.85	1.60	24 +	114.34	298.23	27 +
26.	MS-2003-CR9-451	163.73	2289.62	17 +	285.61	7269.48 *	12	4.06	1.44	10	103.66	227.26	16 +
27.	CP 77/400	139.33	13631.15 **	1	249.94	3573.57	7	3.69	9.04 **	-4	143.01	3981.60 **	23 +
28.	Mardan 93	123.33	10795.92 **	-6	261.72	7686.09 *	4	4.61	3.13	22 +	106.32	3881.30 **	10
	Means	156.98		11.68	283.20		12.29	4.21		12.25	103.18		11.00

***, * = Significant at P=0.1, 0.05 and 0.01, respectively, and also indicate that genotype was judged to be unstable.*
+ = Selected genotypes
Till= Tillers. Gr= Growth. VR= Vigor Rate
† negative values for stability variance may be taken as zero.

Table 2. (Contd.) Genotypes means, Shukla's stability variance (σ_i^2) and yield stability statistic (YS_i)

S.No.	Genotypes	Gr2(cm)			VR2(ratio)			Clength(cm)			Ninter(cm)		
		Means	**σ_i^2**	**YS_i**	**Means**	**σ_i^2**	**YS_i**	**Means**	**σ_i^2**	**YS_i**	**Means**	**σ_i^2**	**YS_i**
1.	MS-2003-CP-154	171.40	813.68	4	2.47	0.72	3	166.30	117.68	9	14.11	4.06	10
2.	BF-162-166	176.10	1817.79 **	-1	2.74	1.09 *	8	171.56	583.06	17 +	13.22	1.21	3
3.	MS-2003-CP-209	153.67	2460.35 **	-7	2.69	0.91	10	171.28	1192.56 *	12	14.28	0.89	12 +
4.	MS-2003-CP-275	188.73	124.53	20 +	2.97	0.00	20 +	176.89	847.98	20 +	13.05	-0.18	0
5.	MS-2003-CP-279	180.43	469.60	12 +	2.96	0.74	19 +	159.17	360.60	5	12.94	5.68 *	-5
6.	MS-2003-CP-300	168.00	16.70	3	2.65	0.32	7	166.00	90.65	8	14.33	1.01	13 +
7.	MS-2003-CP-301	176.17	1261.23 *	4	2.73	0.30	11	147.17	796.11	-1	13.05	3.00	0
8.	MS-2003-CP-377	141.40	294.95	-2	2.62	2.37 **	-2	152.20	-21.90	1	13.55	0.66	5
9.	MS-2003-CP-378	177.63	1341.17 **	1	2.77	0.01	13	154.26	444.39	2	16.61	2.22	30 +
10.	S-87-US-1767	193.63	904.61 *	17 +	2.65	0.27	8	170.61	192.29	13	13.17	10.96 **	-6
11.	S-87-US-2787	173.83	814.04	6	2.48	0.89	4	174.57	268.65	19 +	15.44	11.37 **	16 +
12.	CoJ-76	183.03	1003.53 *	9	2.44	0.25	2	166.30	53.41	9	14.00	1.57	8
13.	CPF-225	179.57	114.84	10	2.94	0.47	18 +	183.44	193.17	23 +	15.89	0.23	26 +
14.	S-9883-CSSG-1139	187.53	280.02	19 +	3.10	0.09	22 +	171.65	203.79	18 +	14.89	0.03	19 +
15.	MS-2003-CR1-50	195.77	260.05	22 +	2.98	-0.04	21 +	167.45	100.87	12	15.28	5.28 *	19 +
16.	MS-2003-CR1-51	145.23	602.39	-1	2.27	0.22	0	158.89	2873.35 **	-4	13.61	1.74	7
17.	MS-2003-CR1-79	184.87	1909.81 **	8	2.68	0.71	9	160.67	210.67	6	14.78	7.92 **	10
18.	MS-2003-CR2-129	215.70	1540.83 **	22 +	3.21	0.03	24 +	188.22	248.69	27 +	15.00	4.72 *	17 +
19.	MS-2003-CR2-131	198.57	175.72	25 +	3.15	0.47	23 +	187.72	428.62	26 +	16.67	11.82 **	23 +
20.	MS-2003-CR2-132	185.03	646.63	17 +	2.60	0.18	5	167.17	329.80	11	14.06	7.25 **	1
21.	MS-2003-CR2-155	145.27	1889.53 **	-8	2.10	1.72 **	-9	147.22	1088.99 *	-4	16.39	18.61 **	20 +
22.	MS-2003-CR5-245	198.47	370.35	24 +	3.24	0.20	25 +	189.33	2025.52 **	21 +	15.89	0.94	26 +
23.	MS-2003-CR6-295	180.00	2369.12 **	3	2.91	0.58	17 +	177.33	1072.61 *	18 +	15.22	6.54 *	18 +
24.	MS-2003-CR7-243	210.90	1353.00 **	19 +	3.25	0.96	26 +	191.03	280.90	30 +	14.61	12.35 **	9
25.	MS-2003-CR8-407	214.93	1322.16 *	25 +	3.45	0.62	28 +	189.22	471.49	28 +	14.21	7.97 **	3
26.	MS-2003-CR9-451	187.03	617.93	18 +	2.88	0.89	16 +	177.06	346.63	21 +	14.35	9.28 **	6
27.	CP 77/400	249.58	11051.87 **	23 +	3.67	13.14 **	21 +	162.42	180.91	7	13.22	9.14 **	-4
28.	Mardan 93	211.42	2594.15 **	20 +	3.68	0.43	30 +	185.13	1322.98 *	21 +	14.89	0.55	20 +
	Means	184.78		11.14	2.87		13.54	170.72		13.39	14.53		10.93

***, * = Significant at P=0.1, 0.05 and 0.01, respectively, and also indicate that genotype was judged to be unstable.*
+ = Selected genotypes
Gr= Growth. VR= Vigor Rate. Clength= Cane Length. Ninter= Number of internodes.
† negative values for stability variance may be taken as zero

Table 2. (contd). Genotypes means, Shukla's stability variance (σ_i^2) and yield stability statistic (YS_i).

S.No.	Genotypes	Int Len(cm)			Cdia(cm)			Brix(%)			Pol(%)		
		Means	σ_i^2	YS_i	**Means**	σ_i^2	YS_i	**Means**	σ_i^2	YS_i	**Means**	σ_i^2	YS_i
1.	MS-2003-CP-154	12.98	0.88	8	1.03	0.02 **	23 +	20.57	4.58 **	22 +	17.90	6.40 **	23 +
2.	BF-162-166	15.25	1.78	27 +	0.89	0.00	5	19.83	1.68	25 +	16.41	3.30	22 +
3.	MS-2003-CP-209	13.19	1.92	11	0.88	0.03 **	-8	18.23	0.93	-1	15.26	0.20	4
4.	MS-2003-CP-275	15.33	0.06	28 +	0.90	0.01	6	19.54	1.70	19 +	15.40	0.31	5
5.	MS-2003-CP-279	13.61	0.20	17 +	0.93	0.01	16 +	19.16	1.17	8	15.65	-0.04	7
6.	MS-2003-CP-300	12.44	0.83	3	0.92	0.00	13 +	19.72	0.65	24 +	16.42	8.70 **	15 +
7.	MS-2003-CP-301	12.78	1.91	7	0.93	0.00	14 +	19.89	1.63	26 +	16.31	0.62	21 +
8.	MS-2003-CP-377	12.22	1.86	1	0.98	0.01	24 +	19.47	1.97	17 +	15.80	3.06	9
9.	MS-2003-CP-378	11.14	7.01	0	0.91	0.01	10	19.42	0.23	14 +	15.94	0.01	12
10.	S-87-US-1767	15.11	4.89	26 +	0.93	0.08 **	6	19.45	1.72	15 +	15.87	0.68	11
11.	S-87-US-2787	12.55	0.28	5	1.02	0.01 *	24 +	19.59	4.72 **	12	16.84	5.90 **	17 +
12.	CoJ-76	13.41	0.87	13 +	0.94	0.02 **	13 +	19.68	6.70 **	15 +	16.98	10.37 **	19 +
13.	CPF-225	13.83	3.21	19 +	0.90	0.00	6	20.03	0.10	27 +	17.07	-0.06	28 +
14.	S-9883-CSSG-1139	13.89	1.53	20 +	0.93	0.00	20 +	19.46	1.75	16 +	16.31	2.01	20 +
15.	MS-2003-CR1-50	13.16	13.61 **	2	0.97	0.01	23 +	19.23	1.16	9	15.95	2.18	13 +
16.	MS-2003-CR1-51	13.08	38.78 **	1	0.90	0.05 **	0	19.59	2.97 *	16 +	16.13	0.11	17 +
17.	MS-2003-CR1-79	13.33	9.26 *	8	0.90	0.01	8	18.60	2.74 *	-3	15.48	0.04	6
18.	MS-2003-CR2-129	14.75	1.05	23 +	0.96	0.00	22 +	18.93	0.62	4	15.20	0.57	1
19.	MS-2003-CR2-131	12.64	1.10	6	0.91	0.01	10	18.97	5.19 **	-3	15.25	3.61 *	-1
20.	MS-2003-CR2-132	13.50	6.82	14 +	0.93	0.00	16 +	19.06	0.29	7	14.97	0.50	-1
21.	MS-2003-CR2-155	10.72	14.19 **	-10	0.88	0.01 *	-4	18.86	2.13	3	15.01	5.01 *	-4
22.	MS-2003-CR5-245	13.64	10.66 *	14 +	0.88	0.00	0	19.34	-0.03	11	16.23	0.13	19 +
23.	MS-2003-CR6-295	12.44	8.67 *	-1	1.01	0.00	27 +	18.99	2.92 *	2	16.14	7.95 **	10
24.	MS-2003-CR7-243	16.25	29.22 **	23 +	0.91	0.00	12 +	18.38	2.73 *	-4	15.72	0.95	8
25.	MS-2003-CR8-407	15.44	4.49	29 +	0.88	0.04 **	-8	19.53	1.11	18 +	15.95	0.11	13 +
26.	MS-2003-CR9-451	14.45	12.05 *	18 +	0.86	0.01	-1	19.27	3.61 **	2	15.81	7.40 **	2
27.	CP 77/400	14.93	9.34 *	21 +	1.02	0.00	28 +	19.61	0.59	22 +	16.77	2.49	24 +
28.	Mardan 93	14.18	4.88	21 +	1.00	0.01	26 +	20.16	4.77 **	21 +	17.15	8.19 **	21 +
	Means	13.58		12.64	0.93		11.82	19.38		12.29	16.07		12.18

***, * = Significant at P=0.1, 0.05 and 0.01, respectively, and also indicate that genotype was judged to be unstable.*

+ = Selected genotypes

IntLen= Internode Length. Cdia= Cand diameter. Mcanes= Number of Millable Canes. Cyield= Cane Yield.

† negative values for stability variance may be taken as zero.

Table 2 (contd). Genotypes means, Shukla's stability variance (σ_i^2) and yield stability statistic (YS_i)

S.No.	Genotypes	Purity(%)			Recovery(%)			Mcanes(number)			Cyield(tonnes/ha)		
		Means	σ_i^2	YS_i	Means	σ_i^2	YS_i	Means	σ_i^2	YS_i	Means	σ_i^2	YS_i
1.	MS-2003-CP-154	86.95	64.51 **	22 +	11.58	4.45 **	23 +	71.44	911.58 *	3	67.22	6.93	16 +
2.	BF-162-166	82.52	9.72	13 +	10.28	2.07	19 +	75.61	194.68	11	66.67	1.02	11
3.	MS-2003-CP-209	83.65	31.85	19 +	9.64	0.46	5	81.72	116.14	19 +	68.56	27.48	19 +
4.	MS-2003-CP-275	78.72	19.81	0	9.33	0.29	1	75.50	1247.48 *	6	67.78	-2.36	18 +
5.	MS-2003-CP-279	81.64	34.63	8	9.72	0.38	6	80.98	370.51	18 +	63.56	16.08	8
6.	MS-2003-CP-300	83.37	151.71 **	10	10.34	8.14 **	15 +	84.44	1223.28 *	17 +	67.56	1151.74 **	9
7.	MS-2003-CP-301	81.85	33.11	10	10.15	0.74	18 +	90.50	410.40	25 +	71.44	886.54 **	14 +
8.	MS-2003-CP-377	80.95	16.21	5	9.77	1.94	8	64.43	410.61	1	56.22	91.95	-1
9.	MS-2003-CP-378	82.01	16.81	11	9.96	0.26	12	76.11	115.22	12	57.89	473.57 *	-4
10.	S-87-US-1767	81.55	7.03	6	9.86	0.22	10	71.78	76.00	8	74.11	772.09 **	18 +
11.	S-87-US-2787	85.72	18.00	28 +	10.82	3.45 *	22 +	57.33	235.14	-1	59.34	360.02 *	0
12.	CoJ-76	86.12	24.94	29 +	10.93	6.21 **	20 +	87.42	52.31	23 +	75.44	25.65	29 +
13.	CPF-225	85.01	4.40	23 +	10.92	0.00	27 +	87.28	933.41 *	18 +	66.78	81.11	13 +
14.	S-9883-CSSG-1139	83.83	4.49	20 +	10.31	1.08	21 +	71.00	290.21	6	63.11	85.18	6
15.	MS-2003-CR1-50	82.69	8.65	14 +	10.02	1.46	13 +	70.92	4.81	5	64.45	334.68 *	5
16.	MS-2003-CR1-51	82.16	24.46	12	10.09	-0.05	15 +	60.37	761.88	0	69.78	43.72	21 +
17.	MS-2003-CR1-79	83.30	66.41 **	9	9.73	0.52	7	67.33	1436.00 **	-5	69.33	497.82 **	12
18.	MS-2003-CR2-129	80.26	14.86	3	9.34	0.51	2	73.11	219.88	9	74.00	93.98	25 +
19.	MS-2003-CR2-131	80.43	40.30 *	0	9.38	2.09	3	94.39	171.64	28 +	65.00	17.80	10
20.	MS-2003-CR2-132	78.49	35.68	-1	9.03	0.96	-1	82.78	534.15	20 +	58.67	251.98	2
21.	MS-2003-CR2-155	79.62	47.82 *	-3	9.17	3.58 *	-4	67.56	280.29	4	66.67	40.64	11
22.	MS-2003-CR5-245	83.94	6.88	21 +	10.29	0.21	20 +	94.17	132.56	27 +	71.78	-5.47	23 +
23.	MS-2003-CR6-295	85.13	49.45 *	20 +	10.31	5.48 **	13 +	80.78	200.53	17 +	63.33	636.69 **	-1
24.	MS-2003-CR7-243	85.46	11.32	26 +	10.06	0.23	14 +	96.83	529.97	29 +	75.00	733.18 **	20 +
25.	MS-2003-CR8-407	81.56	14.14	7	9.92	0.15	11	99.31	134.30	30 +	75.56	564.86 **	22 +
26.	MS-2003-CR9-451	81.79	45.90 *	5	9.85	4.97 **	1	89.21	1175.19 *	20 +	58.00	303.07	1
27.	CP 77/400	85.36	54.14 *	21 +	10.75	2.46	24 +	77.89	337.63	13	72.67	225.44	24 +
28.	Mardan 93	84.86	49.90 *	18 +	10.94	5.29 **	21 +	80.64	444.83	16 +	61.33	36.70	5
	Means	82.82		12.71	10.09		12.36	78.96		13.54	66.83		12.00

***, *= Significant at P=0.1, 0.05 and 0.01, respectively, and also indicate that genotype was judged to be unstable.*

+= Selected genotypes

Mcanes= Number of Millable Canes. Cyield= Cane Yield. negative values for stability variance may be taken as zero.

3.1.2 Cane characters

In stalk length, genotypes S-87-US-2787, CPF-225, S-9883-CSSG-1139, MS-2003-CR1-79, and MS-2003-CR7-243 exhibited lower stability with a range of 18 to 30 for YS_i values which were greater than mean YS_i value (13.39). Their means fell between 171.65 and 191.03. For number of internodes, genotypes MS-2003-CP-209, CPF-225, S-9883-CSSG-1139, MS-2003-CR5-245, and Mardan 93, had non-significant stability variances with a range of YS_i values between 12 and 26 and means ranging from 14.28 to 15.89. For internode length, genotypes MS-2003-CP-275, MS-2003-CP-279, CoJ-76, S-9883-CSSG-1139, and MS-2003-CR2-129 showed lower and non-significant variances with higher YS_i values and means ranging from 13.41 to 15.33.

Stalk diameters of genotypes S-9883-CSSG-1139, MS-2003-CR2-129, MS-2003-CR2-132, MS-2003-CR7-243, and CP 77/400 gave non-significant stability variances with a mean range of 0.93 to 1.02 and YSi values between 12 and 28.

3.1.3 Quality characters

Genotypes MS-2003-CP-300, MS-2003-CP-378, CPF-225, MS-2003-CR8-407, and CP 77/400 manifested lower and non-significant values for stability parameter and high values for yield stability statistic which ranged from 14 to 27. These genotypes showed mean values in the range of 19.42 to 20.03. For Pol, genotypes MS-2003-CP-301, CPF-225, MS-2003-CR1-51, MS-2003-CR5-245, and MS-2003-CR8-407 displayed lower values for stability variances and were non-significant. Their means ranged from 16.13 to 17.07 and YS_i values from 17 to 28.

For purity, genotypes BF-162-166, CPF-225, S-9883-CSSG-1139, MS-2003-CR1-50, and MS-2003-CR5-245 showed non-significant values for stability statistic and higher values for

YS_i than mean YS_i. Means for these genotypes ranged from 82.52 to 85.01. For recovery, genotypes MS-2003-CP-301, CPF-225, MS-2003-CR1-51, MS-2003-CR7-243, and MS-2003-CR8-407 showed non-significant values with higher YS_i values ranging from 14 to 27.

3.1.4 Millable canes and cane yield

Genotypes MS-2003-CP-209, CoJ-76, MS-2003-CR2-131, MS-2003-CR5-245, and MS-2003-CR8-407 manifested lower and non-significant stability variances for millable canes. Their means ranged from 81.72 to 99.31 with YS_i in the range of 19 to 30. For cane yield, MS-2003-CP-209, MS-2003-CP-275, CoJ-76, MS-2003-CR2-131, and MS-2003-CR5-245, showed values for stability parameter which were non-significant. Mean cane yield for these genotypes ranged from 67.22 to 75.44 with YS_i values greater than mean YS_i value (12.00).

The present study showed that the genotypes interacted significantly with the three environments under study. The stability study showed that no single genotype was stable across all the characters. It is natural as different characters respond differently in different genotypes to the varying environments. These results are in conformity with the earlier findings by Tahir et al. [15] wherein a pronounced effect of environments was found and no single genotype stood out stable for all the characters across all environments. Shukla's stability analysis for discerning stable genotypes has been favored by Kang and Martin [1] for sugarcane. It is preferred because it partitions total environmental response into that contributed by each genotype and makes selection of stable genotypes easier. The results of this study revealed that, genotype MS-2003-CR8-407 showed stability for tiller1, tiller2, growth1, brix, Pol, recovery, and millable stalks. Genotypes MS-2003-CP-209, MS-2003-CP-275, CoJ-76, MS-2003-CR2-131, and MS-2003-CR5-245 showed stability for cane yield. MS-2003-CR5-245was relatively stable as it showed good stability for 6 characters including growth2, vigor rate2, number of internodes, Pol, millable canes and cane yield. The genotype MS-2003-CR5-245 could be selected based on stability for growth, quality and yield characters.

Stability across different environments is an important attribute to consider in varietal breeding program. Those genotypes will be of interest, which are stable for most of yield characters. These statistics should be a regular part of the breeding program at Sugar Crops Research Institute, to help find out most stable genotypes.

4. CONCLUSIONS

Analysis of variance for the characters under study showed significant differences among sugarcane genotypes for various sources of variation, including genotype x crop interactions. While no genotypes were stable for all characters studied, two genotypes were stable for most characters. MS-2003-CR8-407 was stable for sugar-related traits, and MS-2003-CR5-245was stable for both a sugar-related trait (Pol) and cane yield. Therefore, although genotype x environment is a significant factor to consider for sugarcane production and cultivar development in Pakistan, it is interesting to note that at least for some traits, we found two of 28 genotypes that were stable across two plant-cane environments and one first-ratoon crop. Since these results show that for the overwhelming percentage of genotypes tested for interaction with crop cycle, we should continue using stability analysis as an essential tool for identifying genotypes that have good performance in both the plant-cane and first-ratoon crops. This also suggests that we should conduct further studies to test the importance of continuing selection to the second-ratoon crop and beyond. Based on the extremely low percentage of genotypes that were stable across all three environments, we strongly discourage against making selections based on plant-cane results only.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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