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Research Article

Evaluation of early maturing sugarcane (*Saccharum spp.* complex) clones for sugar yield and its contributing traits and stability

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Abstract
Sugarcane cultivation is targeted with early varieties having stable higher CCS (commercial cane sugar) yield potential. Therefore, studies were made on 18 traits over three years (2016-19) with seven genotypes at Regional Research Station, PAU, Faridkot. Different multivariate statistical techniques were used for assessing the potential of CCS contributing traits and clonal stability. The observed significant differences due to varieties, years and their interactions were self explaining the role of genotypic differences and weather factors. Cane yield t/ha (CY), CCS t/ha (CCS.T) and their contributing traits were positively loaded on different axes in principal component analyses (PCA). Single cane weight (SCW) was observed to be the primary contributing trait for CY; while brix % and sucrose % for CCS %, and CY for CCS.T were the major contributing traits. CoPb 13181 was observed the most suitable clone for the region. Further, Eberhart & Russell's model was found more appropriate for judging the genotype(s) to environment specificity while "GGE Biplot" was best to evaluate the environments for their discriminating power to genotypes.

Keywords: Sugarcane, GGE biplot, PCA, Eberhart & Russell, stability

INTRODUCTION

Sugarcane (*Saccharum spp.* complex) is an industrial crop, and it is majorly grown for production of sugar and bioenergy. It is grown extensively in tropical and sub-tropical regions of world including India (Singh and Singh, 2021). In India, sugarcane occupies 4.87 million ha area with 377.77 million tones production, of which ~ 65% is concentrated in the sub-tropical states. India is the second largest producer of sugarcane and sugar after Brazil (Anonymous, 2023; Sugar statistics, 2021; Singh *et al.*, 2022a). It is the major source of large number of products like sugar and ethanol (Gowtham *et al.,* 2019). The bagasse residue is now getting popularity in the co-generation of electricity in energy deficient countries including India. During crop growth and development, weather coefficient shifts have been the major factor which affects the sugar content and sugar recovery contributing traits in sugarcane. Hence, the cane and sugar yield are generally fluctuating year to year. Although sugarcane is capable of producing high tonnage of cane and sugar (Kumar *et al.*, 2018), stable and adaptable clones are required for erratic environments. Despite huge efforts in sugarcane breeding and development, comparatively low crop productivity is observed in the Indian sub-continent. It might be due to the genetic potential gap in the cultivars (Singh *et al.*, 2022a). Sugarcane area and sugar recovery in Punjab has been decreasing from 96.00 thousand ha and 9.78 % during 2017- 18 to 89.30 thousand ha and 9.03 % during 2020-21, respectively (Anonymous, 2021). So, the release of stable and adaptable clone(s) as varieties is required for sustaining the productivity of cane yield and sugar recovery. In this context, classical methods *i.e.* sexual hybridization along with selection over environments still has the only role in varietal development programs (Anna Durai *et al.*, 2015).

Environments have profound influence on sugarcane growth and yield due to its year long lifecycle. Inter-seasonal weather variability often significantly affects the sugarcane yield of a region despite the cultivation of potentially high yielding genotypes (Babu *et al.,* 2009; Gowtham *et al*., 2019; Singh *et al*., 2022b). Therefore, development of high cane and sugar yielding clones having stable performance over several environments is one of the important objectives for sugarcane breeders. Multivariate stability analysis of sugarcane yield and related yield contributing traits of multi environmrnt performance is crucial for successful breeding program (Kumar *et al*., 2018). Several statistical models are used to describe Genotype x Environment (G × E) interaction through multi environment trials (METs) that facilitate genotype(s) recommendations for particular environment(s). These models have been classified as univariate and multivariate approaches or parametric and nonparametric methods (Yan *et al*., 2007; Singh and Bhajan, 2016). These statistical techniques, *i.e.,* Eberhart and Russell regression model (Eberhart and Russell, 1966), principal component analysis (PCA) and genotype plus G × E interaction (GGE) biplot (Yan *et al*., 2007; Zoble *et al*., 1988) analysis for deciding genotypic stability, are highly effective in METs.

Therefore, the present study was designed to evaluate the performance and stability of sugarcane clones under multiple growing environments using observable agro-morphological and cane juice quality traits in combination with suitable multivariate statistical techniques. In this study, potential of prospective cane yield and CCS yield contributing traits were studied in order to produce valuable information about the yielding ability and stability of genotypes.

MATERIALS AND METHODS

Experimental site and environments: The field experiments for the present study were conducted at the research farm of Punjab Agricultural University - Regional Research Station (PAU-RRS), Faridkot, Punjab, India. This site is located at South western agro-climatic zone of Punjab (30° 40’ N and 74° 45’ E; altitude: 225m above mean sea level). This zone is climatologically characterized by semi arid dry weather with an average annual rainfall of 400 mm. Most of the rainfall (80% of annual average) in this zone is received during the monsoon period *i.e.,* July to September (Singh *et al*., 2021). The soil texture of the experimental site is broadly classified as loamy with pH varying in between 8.3 to 8.7.

The field trials were conducted for spring season cane during three consecutive years *viz*. 2016-17, 2017-18 and 2018-19. These three growing seasons were considered as three different environments (i.e. E1, E2, E3) to accommodate significant inter-seasonal weather variability in the region. Weather data comprising maximum and minimum temperatures (Tmax, Tmin, °C), relative humidity (RH, %) and rainfall (RF, mm) was collected from the agromet observatory located around 200 m away from the experimental field. The rainy days (Rday, days) were calculated by counting the days with >2.5 mm rainfall. The mean monthly weather summary for the three growing environments is depicted in **Fig. 1**.

Experimental details: A total seven sugarcane clones (**Table 1**) were evaluated for three spring growing season from 2016-17 to 2018-19. Among them, three clones i.e.,Co 13034 (G1), CoPb 13181 (G2), CoS 13231 (G3) were elite advance lines while four clones i.e., CoJ 64 (G4), Co 238 (G5, used as check), Co 05009 (G6) and CoPb 92 (G7) were popular recommended varieties in Northwest Zone of India comprising five states (Uttar Pradesh, Punjab, Haryana, Rajasthan, and Uttarakhand). Randomized complete block design (RCBD) with three replications and plot size of 8 rows x 6.0 meters row length x 0.90 meters row to row spacing was adopted to conduct the experiments for three years. Cane seed rate of 12 buds per running meter with three budded setts of each clone were planted during the month of March (spring) in each of the growing seasons and harvested during next January. All the recommended packages of practices were adopted for raising a good and healthy crop stand during the crop seasons (Anonymous, 2022).

Table 1. Parentage details of sugarcane clones

S. No./ Code	Testing clones	Parentage	Source
G1	Co 13034	Co 0124 GC	ICAR-SBI, Regional centre, Karnal, India
G2	CoPb 13181	ISH 100 × Co 86011	P.A.U., Regional Station, Faridkot, India
G3	CoS 13231	CoS 95255 × CoS 510	UPCSR, Shahjahanpur, India
G4	CoJ 64	Co 976 × Co 617	P.A.U., Ludhiana, India
G5	Co 0238	CoLk 8102 × Co 775	ICAR-SBI, Regional centre, Karnal, India
G6	Co 05009	Co 8353 × Co 62198	ICAR-SBI, Regional centre, Karnal, India
G7	CoPb 92	Co 89003 PC	P.A.U., Regional Station, Kapurthala, India

G:Genotype, Co: Coimbatore, J: Jalandhar, Pb: Punjab, S: Shahjahanpur, ISH: Inter specific hybrid, GC: General collections, PC: Poly crosses

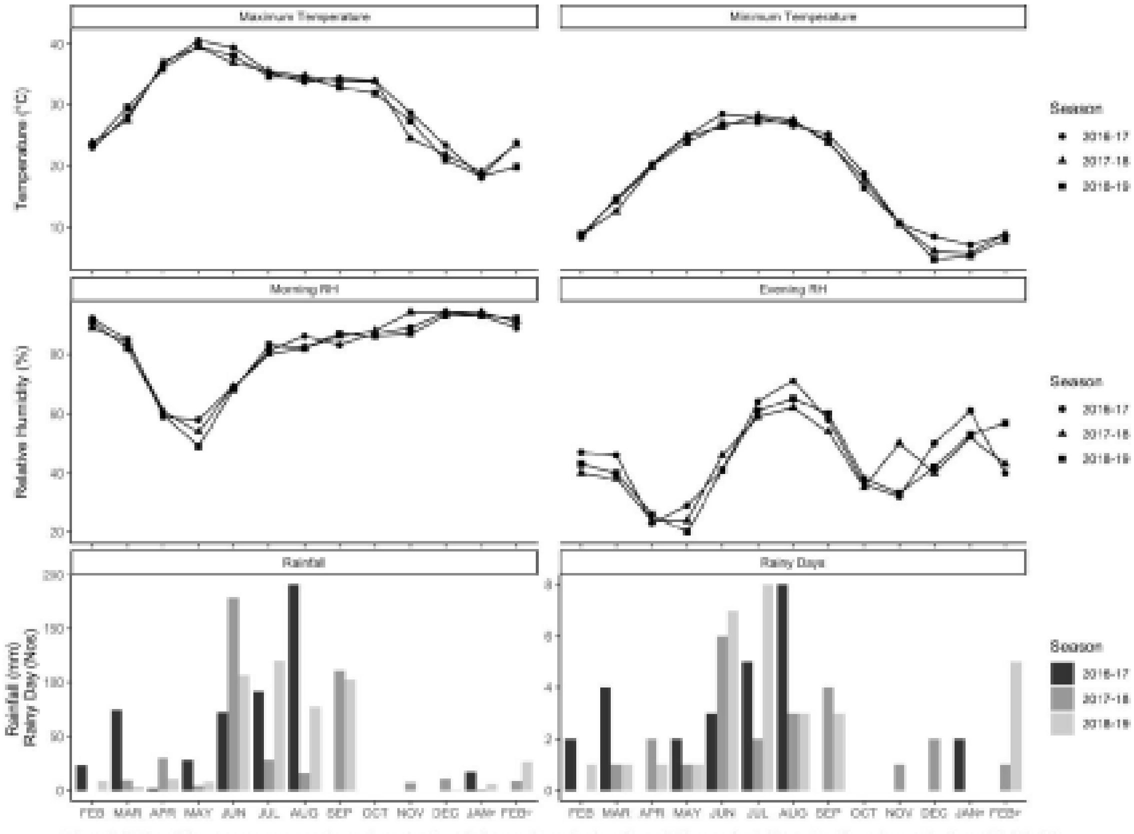

Fig.1. Monthly temperature (maximum & minimum), relative humidity, rainfall and rainy days during 2016-19

Data collections and calculations: The data on cane growth and yield characters were collected during the experimentation period with tagging competitive plants from each plot excluding germination (%) (GM), number of tillers at 120 days after planting (DAP) (TL.120, '000 ha^{-1}), number of shoots at 240 DAP (SH.240, '000 ha^{-1}), Number of Millable Cane at 300 DAP (NMC, '000 ha^{-1}) and cane yield (CY, t ha^{-1}) at maturity to study the performances of early clones. The germination percentage of the clones was manually counted in each plot at 45 DAP, as follows:

$$\text{Germination (\%)} = \frac{\text{Total no. of plants per plot}}{\text{No. of sown buds per plot}} \times 100$$

Tillers, SH.240 and NMC were manually counted from the net plot area. Regarding each growing environment, cane clones were compared by measuring the cane length (CL, m), cane diameter (CD, cm), single cane weight (SCW, kg) and juice extraction (JE, %) of five randomly selected stalks at 300 DAP from tagged plants from each plot. CL was measured using a measuring ruler from the soil surface to the growing point of the cane. Cane diameter was recorded using a Vernier Calliper (Insize Digital Caliper 1112-125). The mean value of the top, middle and bottom diameters was considered as CD of the cane stalk.CY of each whole plot was recorded separately at the time of harvesting. The total weight of clean cane stalks for each plot was taken into account for yield data.

Five randomly selected competitive canes at 240 DAP and 300 DAP was harvested from each plot to judge juice quality of cane clones. For extracting the cane juice, cane crusher was used for quality analysis following standard methods. The per cent brix (BRIX.240, BRIX.300), sucrose content (SU.240, SU.300) and purity (PUR.240, PUR.300) at 240 and 300 DAP, respectively, of the cane juice was measured by Polarimeter and Brix Hydrometer as per standard procedure (Meade and Chen, 1971). Furthermore, for judging the commercial cane sugar (CCS.240, CCS.300, %), the following equation was used:

$$\text{CCS (\%)} = [S - 0.4(B - S)] \times 0.73$$

Where, S = sucrose % in the juice,
B= corrected Brix (%),
0.4 = multiplication factor and
0.73= crusher factor.
From CY and CCS.300, sugar yield tonnage (CCS.T) was calculated as per the following equation:

$$\text{CCS.T (t ha}^{-1}\text{)} = \frac{\text{CY (t ha}^{-1}\text{)} \times \text{CCS.300 (\%)}}{100}$$

Statistical Analysis: Analysis of variance (ANOVA) was performed on pooled data of all 18 observed agro-morphological and cane juice quality traits of sugarcane clones using the mixed effect model with 5% probability threshold. The clones were considered as a fixed effect and the replications nested within year were treated as a random effect for ANOVA. Separation of means was done using least significant difference (LSD) test (p≤ 0.05). Pearson's bivariate correlation coefficient and regression analyses of concerned traits over years of pooled data were done to find out best selection indices for cane yield and sucrose content. Principal Component Analysis (PCA) was performed using pooled trait means from three environments to identify the contribution of traits to the variances of the cane clones. For genotypes × environment interaction analyses, performances over three years (environments) were considered here. Eberhart and Russell's regression coefficient analysis (Eberhart and Russell, 1966) and GGE Biplot analyses (Zoble *et al.,* 1988; Yan *et al.,* 2007) were carried out for the traits namely CY, CCS.240, CCS.300 and CCS.T. All statistical analyses were performed using R statistical software ver. 4.0.2 (R Core Team, 2022).

RESULTS AND DISCUSSION

Variability in growing environments: The variability in air temperature during three growing environments is presented in **Fig. 1**. The monthly mean Tmax and Tmin ranged from 18.1 °C (January, 2017) to 40.6 °C (May, 2016) and 7.1 °C (January, 2017) to 28.4 °C (June, 2016) during year 2016-17, 19.0 °C (January, 2018) to 39.5 °C (May, 2017) and 5.7 °C (January, 2018) to 28.2 °C (July, 2017) during year 2017-18, 18.3 °C (January, 2019) to 39.6 °C (May, 2018) and 4.7 °C (December, 2018) to 27.2 °C (July and August, 2018) during year 2018-19, respectively. So, there were ~ 1 °C fluctuation of both maximum as well as minimum mean monthly temperature over years along with shifting of months from May/ June and January to July/ August and December for extreme weather.

About 80 % of annual rain is generally received during July to September months at the experiment site (Singh *et al*., 2021) but comparatively higher amount of pre-monsoon rains than earlier reported was observed during all three years (**Fig. 1**). A total of 282.6 mm, 155.3 mm and 300.0 mm monsoon (July to September) rainfall was recorded during 2016-17, 2017-18 and 2018-19 growing environments, respectively. However, significant pre-monsoon (February to June) rainfall was also recorded during 2016-17, 2017-18 and 2018-19 growing environments (201.4 mm, 223.3 mm, 136.7 mm, respectively). As a result, the numbers of rainy days was at part during monsoon and pre-monsoon months. About 30 to 100 mm differences with respect to the amount of rain and 3 to 7 days differences of number of rainy days was observed among the three years of experimentation. The monthly mean morning RH was higher in December/ January months (93 – 94%) while it was lower in May month (49 – 58 %) during all three years of study (**Fig. 1**). In case of monthly mean evening RH, higher values (65 – 71 %) were observed in August month while, lower values (20 – 29 %) in April/ May month during all three study environments. The variations in RH were due to combination of both temperature as well as rainfall (number of rainy days and amount of rainfall, both). But the role of temperature was observed more because of month having low temperature exhibited higher RH and vice versa.

The above results showed a significant difference in observed weather parameters among the growing seasons and thus justified the consideration of the three growing seasons (2016-17, 2017-18 and 2018-19) as separate environments. Multivariate analysis was done for yield stability analysis of sugarcane clones and identifying important yield contributing traits.

Variances of CCS, cane yield and their contributing traits: Analysis of variance: Analyses of variance of pooled experimental data of eight agro-morphological, and ten quantitative cane and it's juice quality traits over three environments was carried out to evaluate the major deciding factors of cane growth and yield in South +western zone of Punjab (**Table 2**). The ANOVA showed that the mean sum of squares of the traits like NMC, CL and SCW along with other cane juice quality traits differ significantly (p≤ 0.05) due to random effect of evaluated environments (E). This finding also affirmed the significant contribution of prevailed weather variability among the growing seasons in determining growth and sugar recovery of different cane clones (Singh *et al*., 2022a; Singh *et al*., 2022b).

Similarly, significant difference due to varieties (V) and their interactions with environments (V × E) were observed for all the evaluated traits (**Table 2**).This outcome was self-explanatory for key role of environments *vis-à-vis* weather factors especially temperature and rainfall on genotypic performance differences (Singh and Singh, 2021). Such difference in seven clone's performance may be attributed to differences in RF (30-100 mm) and RDay (3 – 7 days) along with Tmax variability (~ 1°C) within three growing environments (**Fig. 1**).

Principal Component Analysis (PCA): PCA was carried out to identify significant yield attributing traits for cane yield stability using pooled data of three evaluated environments (**Fig. 2**).From Fig. 2A, it is evident that first four components i.e., PC1, PC2, PC3, PC4 accounts for 75 % variability while remaining 25% variability was explained by other PCs. Therefore, first four PCs were considered to examine different variable contribution study. For PC1, the highest positive loading was observed with traits PUR.330 followed by CY, SU.330, SH.240, NMC and TL.120 (Fig. 2B). On the other hand, CL was observed having maximum loading on PC 2 followed by BRIX.300 and CCS.T. The other cane juice quality traits

Table 2. Analyses of variance for various agro-morphological and cane juice quality traits of sugarcane.

Source of variations	df	GM	TL.120	SH.240	NMC	CY	CL	CD	SCW	JE
Variety(V)	6	454.83*	3244.57*	2754.14*	1824.54*	2338.56*	3486.15	0.37*	0.12*	104.94*
Environment (E)	2	94.46	3.45	436.71	571.66*	737.95	8907.95*	0.10	0.17*	139.54*
Replications(R) in E	9	2.61	57.29	28.31	18.40	111.58	84.17	0.01	0.01	2.68*
V X E	12	116.79*	675.06*	347.45*	127.75*	232.01*	1917.03*	0.04*	0.03*	28.15*
Error (e)	54	5.28	48.36	42.50	39.39	107.99	73.83	0.01	0.01	1.09
e + R	63	4.90	49.63	40.47	36.39	108.51	75.31	0.01	0.01	1.32

Table 2. Continued...

Source of variations	df	BRIX.240	SU.240	PUR.240	CCS.240	BRIX.300	SU.300	PUR.300	CCS.300	CCS.T
Variety(V)	6	1.56	1.81*	7.20	1.07	4.24*	4.01*	4.76	2.14**	36.92*
Environment (E)	2	8.66*	7.32*	45.12	4.08*	3.89*	2.73*	2.64	1.27*	8.09
Replications(R) in E	9	0.06	0.11	1.68	0.08	0.21	0.08	2.28*	0.05	1.85
V X E	12	0.71*	0.54*	17.31*	0.43*	0.89*	0.40*	3.92*	0.17**	3.54*
Error (e)	54	0.31	0.16	3.26	0.09	0.18	0.12	0.84	0.06	1.56
e + R	63	0.28	0.15	3.03	0.09	0.19	0.11	1.04	0.06	1.60

*Significant at the 0.05 level

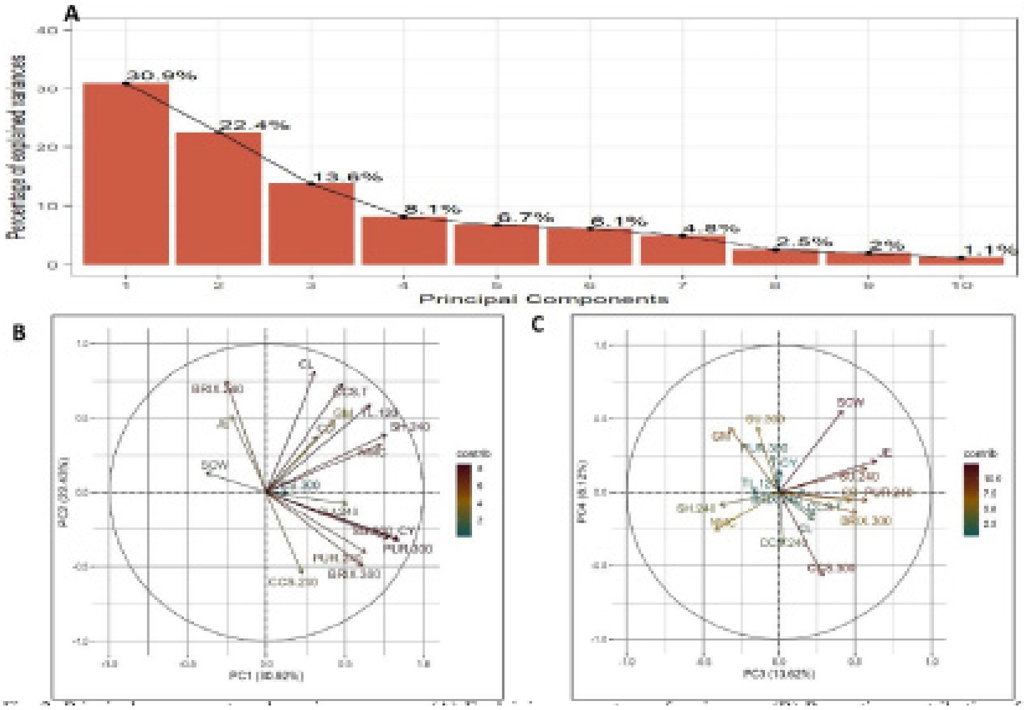

Fig. 2. Principal component analyses in sugarcane: (A) Explaining percentage of variances,(B)Proportion contribution of traits in biplot of PC1 & PC2 and (C) Proportion contribution of traits in biplot of PC3 & PC4.

like JE, SU.300, PUR.300, and BRIX.300 were observed having higher positive loading on PC 3, as in descending order of merit. The traits namely SCW and GM were observed having highest positive loading on PC 4 (Fig. 2B). Therefore, the above traits were established as most significant for sugarcane growth and yield variations. The above findings also manifest from the study of Singh and Singh (2021).

Correlation Analysis: The Pearson's product moment correlation among sugarcane CCS and cane yield attributes is presented by a correlation panel diagram in **Fig. 3**. The upper diagonal panel of **Fig. 3** clearly depicted that CY was significantly and positively correlated with NMC (r = 0.42, p<0.05) and SCW (r = 0.50, p<0.05). However, remaining cane juice quality traits (BRIX.300, SU.300 and CCS.300) except PUR.300 exhibited non-significant but negative association with cane yield. In similar line, CCS.T also expressed significant and positive association with NMC (r = 0.53, p<0.05) and SCW (r = 0.41, p<0.05). In contrast to CY, quality traits viz. BRIX.300, SU.300, PUR.300 and CCS.300 showed positive but non-significant impact on CCS.T (**Fig. 3**). Highly significant negative correlation coefficient between NMC and SCW suggest the cane production strategies by optimising the level of NMC and SCW. The counteracting relationships of SCW and NMC in context to cane yield is being reported in previous studies (Babu *et al.,* 2009; Anna Durai *et al*., 2015; Kumar *et al*., 2018; Singh and Singh, 2021).

Regression Analysis: The linear regression lines between cane yield and related traits, and corresponding coefficient of determination (R^2) is plotted in lower diagonal panel of **Fig. 3**. The relationship expressed among the traits by correlation analysis was reaffirmed by the regression results in the above figure. For CY, the regression line with steep positive slope depicted its significant association with NMC and SCW. The highest R^2 of 0.247 was noticed for SCW as predictor variable of CY. Consequently, CCS.T also expressed higher positive slope and R^2 with NMC and SCW compared to remaining quality traits (BRIX.300, SU.300, PUR.300 and CCS.300). The highest R^2 of 0.283 was obtained when CCS.T was regressed using NMC as predictor variable. It is evident from several studies (Anna Durai *et al*., 2015; Singh and Singh, 2021; Singh *et al*., 2022a, 2022b) that higher sucrose earliness is correlated to lower cane diameter as well as lower SCW; and sucrose value determine the sugar recovery of cane.

Evaluation of genotypes and environments suitability: *Eberhart and Russell stability analysis*: Based on Eberhart and Russell's regression model (Eberhart and Russell, 1966), all the seven sugarcane genotypes were evaluated for CY, CCS.240, CCS.300 and CCS.T (**Table 3**). The significant (p ≤0.05) value of Environment (linear) components and G × E linear component were observed. So, the observed high magnitude of environmental (linear) effect in comparison to G × E (linear) suggested that high magnitude of environmental (linear) effect might be responsible for the high adaptation of these genotypes concerning quality and cane yield (Data not shown) (Singh and Bhajan, 2016). Pooled deviations differed significantly. From the perspective of sugar recovery (CCS %), sugarcane genotypes were observed either non-predictable (linear) or low responsive to weather conditions of crop growing environments;

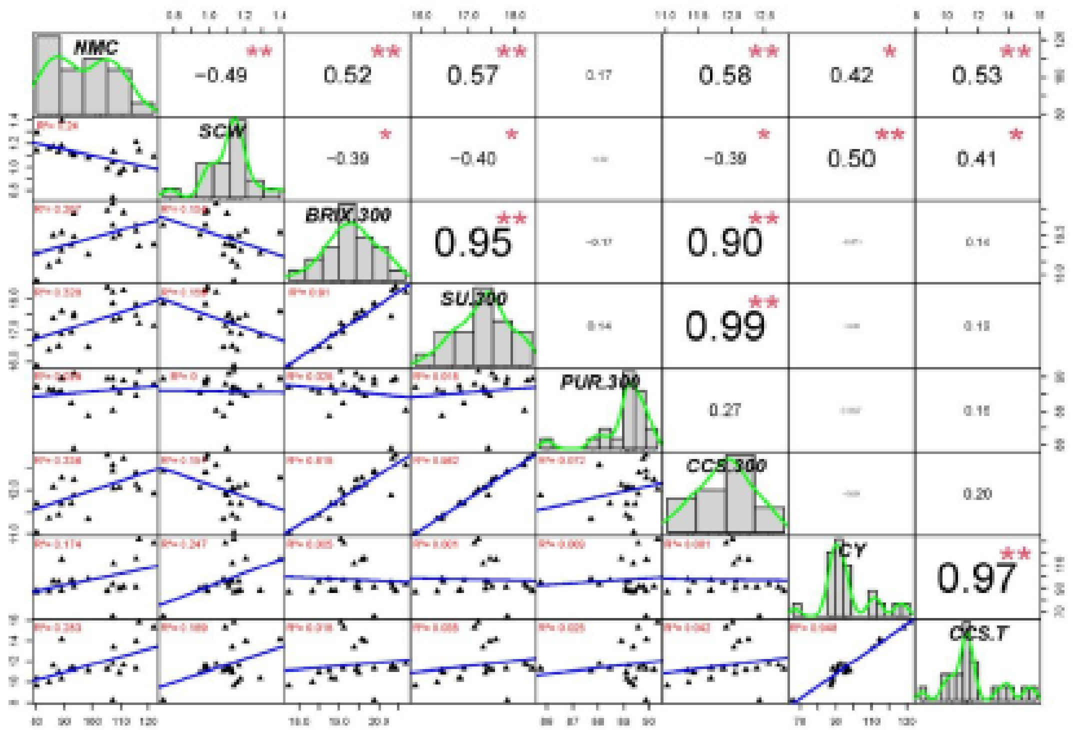

Fig. 3. Regression (Lower diagonal) and correlation (upper diagonal) coefficients among major CCS.T (Commercial Cane Sugar t/ha) traits in sugarcane

Table 3. Regression coefficient, deviation from regression, and mean value of cane and sugar yield over the growing seasons

Genotypes	CY (t ha^{-1})			CCS.240 (%)			CCS.300 (%)			CCS.T (t ha^{-1})		
	m	β_i	S_d^2	m	β_i	S_d^2	m	β_i	S_d^2	m	β_i	S_d^2
G1	92.82	-0.37	-2.47	9.66	0.61	0.08$^+$	11.67	0.98*	-0.01	10.83	-0.85*	-0.36
G2	87.63	0.00	-26.43	9.88	1.09	-0.02	11.36	1.2	0.07$^+$	9.94	0.22	-0.19
G3	104.64$^\#$	2.80*	-23.76	10.01	1.41*	-0.01	12.37	1.52	0.08$^+$	12.93$^\#$	2.75*	-0.36
G4	90.85	-0.06	-26.31	10.31$^\$$	0.68*	0.00	12.34	1.3	0.07$^+$	11.21	-0.50*	-0.27
G5	125.06$^\#$	1.67*	-23.07	9.97	0.63	0.77$^+$	12.02$^\$$	0.43*	-0.01	15.03$^\#$	1.76*	-0.39
G6	96.93	-0.01	-25.17	10.02	1.52*	-0.02	11.7	1.33	0.09$^+$	11.32	0.15	-0.30
G7	83.53	2.96*	-26.53	10.58	1.07*	0.07$^+$	12.46$^\$$	0.23	0.00	10.41	3.48*	0.00
Grand Mean	97.35	-	-	10.06	-	-	11.99	-	-	11.67	-	-

*Significant at 0.05 probability level; $^+$ Significantly deviate from unity; $^{@,\#\text{ and }\$}$Average, High and Low responsive genotypes, respectively, with high mean value for CY, CCS.240, CCS.300 and CCS.T; β_iRegression Coefficient, mGeneral Mean for concerned traits, $S_d^2 S_d^2$ Mean square deviation from linear regression.

while for cane yield as well as CCS t/ha, sugarcane genotypes were observed having linear predictable *per se* performance along with either high response or low response to prevailing crop growth weather (**Table 3**).

Two sugarcane genotypes (G3, G5), out of seven, were observed stable for CY and CCS.T as they deviated significantly from grand mean. These two genotypes also returned significantly higher mean values compared to overall mean of seven clones for CY (>97.35 tha^{-1}) and CCS.T (>11.67 tha^{-1}). G3 and G5 were found to be highly responsive (β_i>1) to growing climatic conditions especially for temperature and rainfall. For CCS.240, comparatively low responsive to environmental variation (β_i<1) genotype, G4 (10.31t ha^{-1}) expressed stable performance compared to grand mean (>10.06 t ha^{-1}) of all genotypes. On the other hand, despite being low responsive in terms of β_i<1, G5 and G7 also expressed significant stable performance for CCS.300 (>11.99 t ha^{-1}) (**Table 3**).

GGE Biplot analysis: GGE biplot is a useful graphical tool for researchers to understand the genotype by environment (G× E) interaction and selection of superior genotypes for different environments (Singh and Bhajan, 2016). In this investigation, three major aspects were studied by GGE (genotype + genotype × environment) biplot analyses of four major traits (CY, CCS.240, CCS.300 and CCS.T) of sugarcane *i.e*., mega environment analyses (**Fig. 4: A–D**), genotype evaluation (**Fig. 5: A–D**) and test environment evaluation (**Fig. 6: A–D**).

Based on the mean value of each genotype in each environment over replications, all three environments i.e., E1, E2 and E3 fell into one sector. However, these were observed to be located far apart from each other. For the trait CY and CCS.T, E2 and E3 were reported on the right upper side of the biplot while E1 was on the right lower side of the biplot. For the sugar recovery trait CCS.240 and CCS.300, E1 was on the right upper side of the biplot while E2 and E3 were on the right lower side of the biplot. So, two mega environments could be explained i.e., E1 in one group while E2 and E3 in another group. Singh and Bhajan (2016) also reported comparable results. It was evident from the trait CCS.240, where they fell into two sectors (two mega environments) i.e., one with E1 (more favourable for sugar recovery) and another with E2 and E3 (more favourable for cane tonnage).

Two genotypes (G3 and G5) for CY, two genotypes (G4 and G7) for CCS.240, four genotypes (G3, G4, G5 and G7) for CCS.300 and two genotypes (G3 and G5) for CCS.T were observed as winning genotypes in the 'which-won-where' view of mega environments analysis (Yan *et al.,* 2000). Specifically, G3 and G5 for CY and CCS.T; G4 and G7 for CCS.240; G3, G4, G5 and G7 for CCS.330 were the higher-yielding stable genotypes than others. Here crossover GE suggested that target environments may be grouped into two mega environments (Yan *et al.,* 2007). The corner genotypes (most responsive to prevailing weather conditions) can be visually determined i.e., G3 and G5 for CY; G7 for CCS.240; G3, G4 and G7 for CCS.300 as most favourable and higher yielding, comparatively (Fig. 4: A – D).

The mean vs stability biplot (Fig.5: A–D) represents the average environment coordination (AEC) view of the GGE biplots with three environments in the niche of clones namely G5 for CY and CCS.T, G7 for CCS. This AEC view facilitated the genotype comparisons based on the mean performance and stability across environments within the mega-environment. Here the word stability means the length of projection of genotypes from the axis. The genotypes having lesser projection length are comparatively more stable and less responsive to

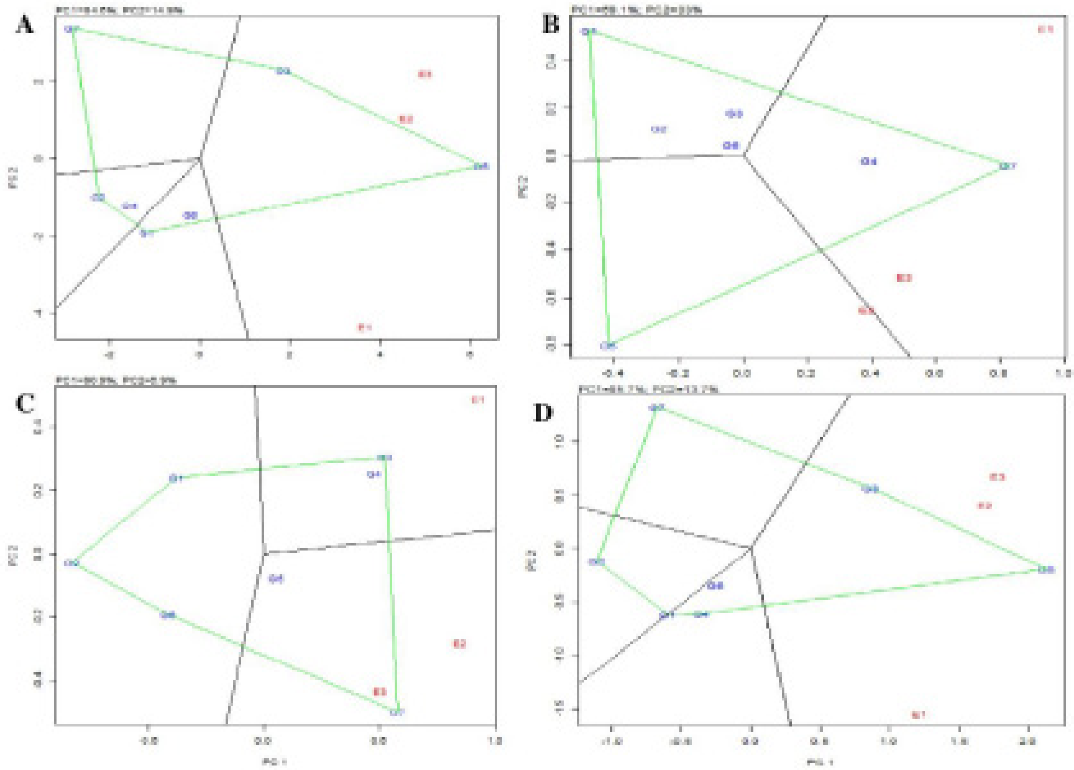

Fig.4. "Which-Won-Where" view of GGE Biplot for CY(A), CCS.240 (B), CCS.300(C) and CCS.T(D).

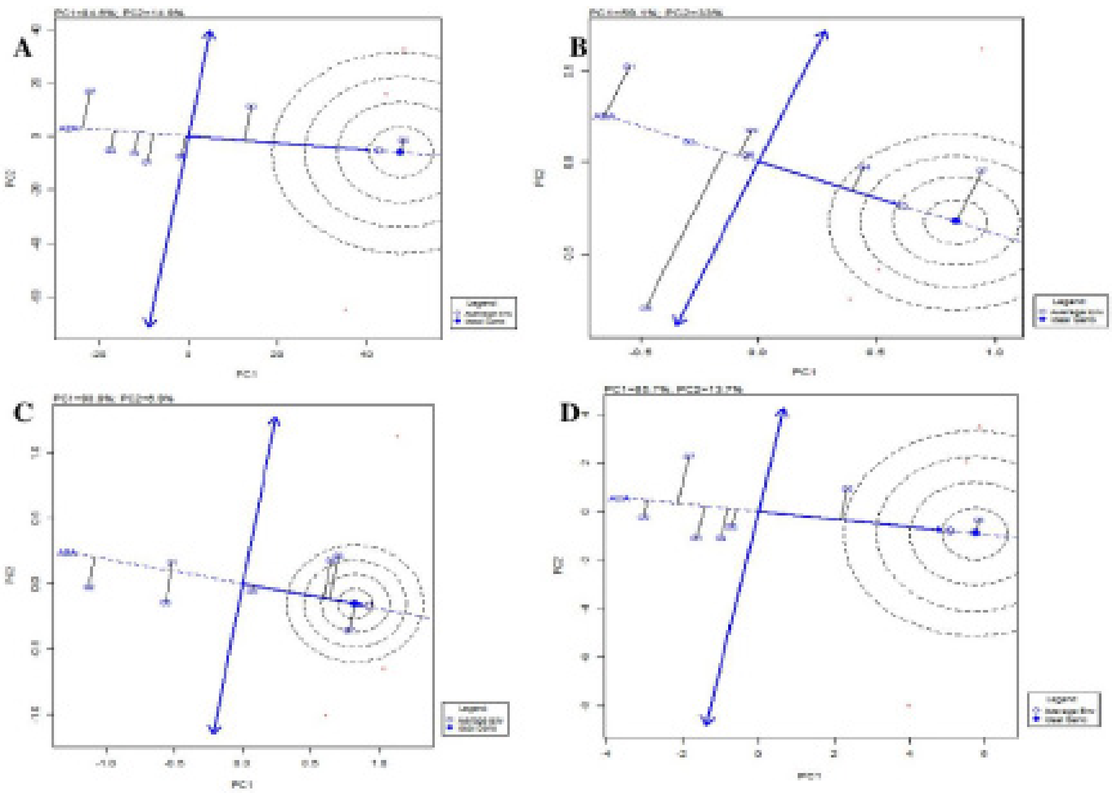

Fig.5. "Mean vs. Stability" view of GGE Biplot for CY (A), CCS.240(B), CCS.300 (C) and CCS.T(D)

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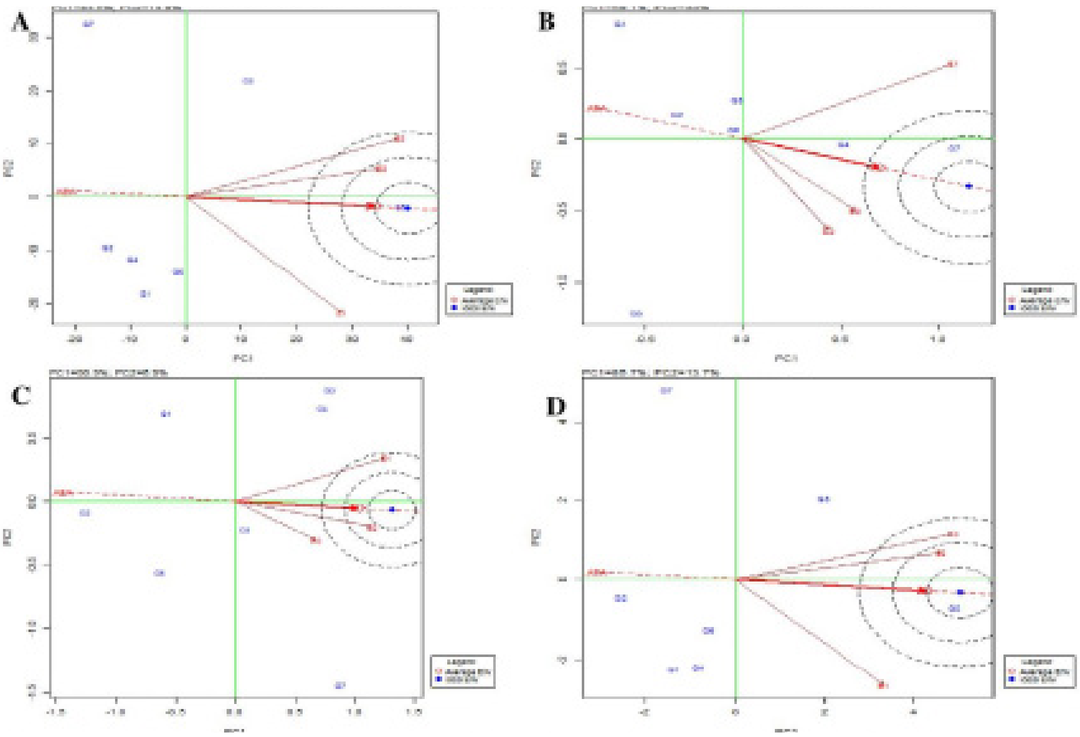

Fig. 6. “Discriminating Power vs. Representativeness” view of GGE Biplot for CY(A), CCS.240 (B), CCS.300(C) and CCS.T(D)

fluctuating environments. The genotypes were ranked according to genotype main effect (G, i.e., proportional to the rank two approximations of the genotype means) as: i.e., for trait CY (Fig. 5 A): G5 > G3 > Mean > G6 > G1 > G4 > G2 > G7; for trait CCS.240 (Fig. 5 B): G7 > G4 > G6 > G3 > G5 > Mean > G2 > G1; for trait CCS.300 (Fig. 5 C): G7 > G3 > G4 > G5 > Mean > G6 > G1 > G2; for trait CCS.T (Fig. 5 D): G5 > G3 > Mean > G6 > G4 > G1 > G7 > G2. GGE represents G+GE while AEC abscissa approximates the genotype’s contributions to GE, which is a measure of their stability and instability. Thus, G5 for CY and CCS.T, G7 for CCS.240 and CCS.300 were identified as ideal cultivars (Yan, 2001), while other genotypes with above-average performances *i.e.*,G3 for CY, G4 for CCS.240,G5 for CCS.300 and G3 for CCS.T were considered more stable as they were located on the AEC abscissa. In contrast, genotypes G3 > G4 only for CCS.300 were the least stable genotypes with above-average performance (**Fig 5: A–D**).

The discriminating power vs representativeness biplot (**Fig. 6**) is based on environment-focused scaling employed to examine the relationships among test environments. In the present study, the environment E2 for CY and CCS.T while environment E1 for CCS.240 and CCS.300 were observed to be more representative of mega environments with high discriminating power of genotypes, because, these environment(s) exhibited long vectors and small angles with the AEC abscissa. These findings were useful for selecting superior genotypes with stable performance with reference to environment instead of going with several environments.

The significant differences in mean squares due to environments for NMC, CY and SCW along with cane juice quality traits revealed the role of weather in determining the plant populations and sugar recovery. Except CY and CCS.T, the other traits viz.TL.120, SH.240, NMC, CL, SCW and JE showed higher positive loading on different PCs of PCA which explain the role of these respective variables contribution in sugarcane yield and related traits. Therefore, NMC, periodic percent brix, sucrose and purity values played key role in deciding the sugar recovery (CCS). From the perspective of sugar recovery, sugarcane genotypes were not in linear relationship with weather conditions of crop growing environments while predictable for CY and CCS.T. Among the seven evaluated clones/genotypes, CoPb 13181 was comparatively performed better and evolved as most suitable clone for the region. Among the growing environments, prevailing weather during 2016-17 was observed more favourable for sugar recovery while the weather of year 2017-19 were more favourable for cane tonnage.

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