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RESEARCH ARTICLE

Genotype × Environment interaction for cane yield of sugarcane varieties (*Saccharum officinarum* L.) in the three agro-climatic zones of Chhattisgarh

O.N. Verma*, N.K. Rastogi, S.K. Sinha[1], J.L. Salam[2] and P.K. Singh[3]

Abstract

An experiment was carried out to ascertain the Gene × Environment interaction (GEI), yield stability and adaptability of 24 sugarcane varieties (*Saccharum officinarum* L.) across three locations in Chhattisgarh India through AMMI and GGE biplot analysis. In the analysis of variance, 75% of the cane yield variation was explained by the differences among varieties, 18.5% by the environment and 6.5% by GE interaction. AMMI analyses revealed significant ($P < 0.01$) genotype and environmental effects as well as G × E with respect to cane yield. GGE-biplot model showed that the three environments belonged to three mega-environments as an obtuse angle was observed between the E1 to E2, E2 to E3 and E3 to E1. According to AMMI and the GGE results, varieties G 19 (CoS 8436 local check), G12 (VSI 8005), the check variety G24 (CoC 0671), and G21 (Co 86032) were the most productive in tons of sugar per hectare and stable and recommended for the test environments. Genotypes, CoS 8436 and Co99006 were considered under specific adaptation to Ambikapur due to high cane yield and large IPCA score whereas, Co 99004 and VSI 8005 had high positive interaction with Kawardha while, CoJN 86-600 was found suitable for Jagdalpur. Among environments, Ambikapur (E_2) and Kawardha (E_1) had highest main effect and were favourable to the performance of most of the genotypes but had high interaction value E_2 (9.35) and E_1 (-5.24), while E3 (-4.11) had low main effect and was very poor. Co 99004 (Damodar) and CoC 0671 could also be used as parents for sugarcane improvement programme.

Keywords: AMMI, GGE biplot, G × E interaction, Sugarcane varieties, Stability.

Introduction

Sugarcane (*Saccharum* spp.) is one of the most important cash crops cultivated in India's peninsular, northern, tropical and sub-tropical states. It plays a significant role in Indian economy, contributing 399.26 m t of sugarcane production with productivity of 82.20 t/ha in the country during 2020-21 from the cropped area of 48.57 lac ha (Anonymous 2021-22). Generally, sugarcane is cultivated widely through vegetative means (stem cutting) with great diversity among cultivated clones. In the northern hill region, sugarcane production is higher than the peninsular zone of India, Chhattisgarh plain and Bastar plateau due to favourable climatic conditions prevailing in the region. The average temperature ranges from 7.07 to 39.5°C, photoperiod range from 4 to 8 h and humidity ranges from 20.19 to 96.14% with rainfall ranging from 723 to 2313 mm indicating wide variations in climate during crop growth to maturity stage. Extreme weather conditions affect sugarcane's active growth, restricting to 2-3 months only and thereby the cane yield varies from region to region. However, the agro-climatic zones (Northern Hill, Central Plain and Bastar Plateau) of Chhattisgarh state

Department. of Genetics and Plant Breeding, College of Agriculture and Research Station, Chhuikhadan, Kairagarh Chhuikhadan Gandai, Chhattisgarh, India

[1]RMD College of Agriculture and Research Station, Ambikapur, Sarguja, Chhattisgarh, India

[2]SG College of Agriculture and Research Station, Jagdalpur, Chhattisgarh, India

[3]Indian Institute of Sugarcane Research, Dilkusha, Lucknow, Uttar Pradesh, India

***Corresponding Author:** O.N. Verma, Department. of Genetics and Plant Breeding, College of Agriculture and Research Station, Chhuikhadan, Kairagarh Chhuikhadan Gandai, Chhattisgarh, India, E-Mail: omnarayanverma1@gmail.com

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provide a large scope for cultivation of this potential cash crop with due consideration to be given to the expression of quantitative traits are dependent on environment (Carvalho et al. 1983). Stability in performance of the cultivars grown in different regions is an important issue. Therefore, identifying widely adaptive and high yielding genotypes requires more time and resources due to the strong presence of genotype x environment interaction. The complexity of GEI makes difficult for breeders to recommend the superior genotypes. Therefore, identifying and selecting location-specific adaptive sugarcane genotypes are expected to maximize the sugarcane production.

The observation and analysis of genotype-by-environment (G x E) interaction in multi environment yield trials (MEYT) are very important for evaluation, selection and recommendation of crop varieties (Verissimo et al. 2012; Mattos et al. 2013; Regis et al. 2018). Considering genotype x environment interaction (GEI), the genotypes should be planted in different environments (locations) in order to identify the best genotypes based on phenotypic performance for cane yield and quality. Interaction of genotype and environment provide a potent evaluation of genotypes towards stability and stable genotype that could be used for wider cultivation. A quantitative character like cane yield is greatly influenced by different environmental conditions hence, superior genotypes may be selected based on yield performance at a multiple location in a year and it may be very effective. Sugarcane usually has high G x E interaction, low fertility and high hetrozygosity due to its polyploid nature and alloploidy. The MEYT experiments involve a series of trials where many genotypes and environments are studied for their main effects and interactions. Such studies are useful to develop sugarcane varieties by determining their average response and ranking the genotypes according to their differential response when exposed to different environmental conditions (GE interaction) for traits such as yield (Gauch 1992; Queme et al. 2005).

These stabilized models quantify the contribution of each genotype and environment to SS G x E and provide an easy graphical representation of results by biplot technique to simultaneously classify genotype and environments (Zobel et al. 1988; Crossa et al. 1990; Gauch and Zobel 1996). The environmental component (E) generally represents the largest component in analyses of variance, but it is not relevant to cultivar selection; only G and GE are relevant to meaningful cultivar evaluation and must be considered simultaneously for making selection decisions (Yan and Kang 2003). In recent past, the quantification of G × E interactions and yield stability investigation involving sugarcane clones have been done through multivariate procedures, principal component analysis (Kumar et al. 2009; Guerra et al. 2009; Rea et al. 2011). Further, GGE- biplot models involving eight environments used for the study belonging to two mega-environments by Tena et al. (2019). They revealed that genotypes and checks were the most productive and stable in terms of sugar per hectare and recommended to grow in the test environments. Therefore, the objective if the present investigation were to find out the high yielding and most stable variety(s) suitable for Chhattisgarh state of India by applying AMMI and GGE biplot techniques and the patterns of GEI in sugarcane varieties.

Materials and methods

A total of 24 varieties of sugarcane, including two local checks *viz*., CoS 8436 (Local Rasgulla) and Co 8014 (Mahalaxmi) and four standard national checks *viz*., Co 86032 (Nira), Co 85004 (Prabha), Co 94008 (Shyama) and CoC 671 (Vasant) were grown at three locations across Chhattisgarh region of India representing three agro-climatic zones *i.e*., Kawardha (E1-Central plain zone) with inceptisols and vertisols soils, Ambikapur (E2-Northern hill zone) having sandy loam soils and Jagdalpur (E3-Bastar plateau zone) having loam soil for crop year 2018-19. The experiment was conducted under randomized block design with two replications. Each test variety was grown in a 6 m long row length containing 6 rows with 120 × 60 cm spacing by transplanting sugarcane plantlets raised in poly bags with 11 polybags in each row and total of 66 plantlets in each plots. Good crop was harvested in each test environment by adopting recommended agronomic practices.

Data recording and statistical analysis

The sugarcane crops were harvested at 12th month after planting and data on cane yield (t/ha), number of millable canes (NMC), single cane weight (SCW) was recorded. Five randomly selected canes from each variety were taken to record observations. The juice was extracted in the crusher and was clarified using lead sub acetate. Juice quality parameters such as brix% in the clarified raw juice, sucrose% in juice, purity% in juice were estimated at 12th month by Bhoramdeo Cooperative Sugar Factory, Ramehpur, Kawardha. The above data were used to determine, commercial cane sugar% (CCS%) and commercial cane sugar yield (CCS yield t/ha) at 12th month were computed as per Chen and Chou (1993). The data of crop were tested at three environments and the effect of sugarcane clones in each environment and their interaction were assessed. Analysis of variance along with combined analysis of variance was performed for different environments. The data on cane yield (t/ha) were used to test adaptability and phenotypic stability of the clones. Adaptability and stability analyses were done using the multivariate AMMI and GGE-biplot methods after the significance of the GxE interaction was determined. The cane yield data were subjected to additive mean effect and multiplicative interaction (AMMI) and GGE biplot analysis. The data was analyzed using the software program PB Tools version 1.4. IRRI, Philippines.

Results and discussion

Analysis of variance for cane yield revealed the highly significant differences at P=0.05 level of significance among genotypes, environment and their interactions across the locations. The significant effect of the G x E interaction showed that genotypes had high variable performance in the tested environment. The change in relative ranking of genotypes resulted from GEI (Genotype Environment Interaction), implying that genotypes responded differently to the environmental conditions justifying the conduction of more refined analysis in multi-environment trial to understand the stability of these genotypes (Queme_et al. 2005 and Tahir et al. 2013).

Out of 24 sugarcane varieties, 13 varieties exhibited higher cane yield than average yield and fell on the right side of the midpoint of the perpendicular line. Variety CoS 8436 exhibited highest yield followed by Co 99004, local Jamun, Co 8014, CoC 671, CoJN 86-600, CoSnk 05103, CoJN 95-05, CoJN 99-17, Co 99006, Co 86032, CoSnk 05104), VSI 8005 and Co 0238 as shown in Table 1. Value closer to the origin of the axis (IPCA1) provides a smaller contribution to the interaction than those are further away from the origin. Out of these 13 clones exhibiting cane yield above the overall mean yield, CoC 0671, CoSnk 05103 and Co 86032 had low positive interaction with environments VSI 8005 had low negative interaction as evident from their low IPCA 1 scores CoC 0671 and CoSnk 05103. So variety VSI 8005 having yield higher than mean was less influenced by environments hence, they may be treated as having high adaptability to different environments or seasons.

The mean cane yield over the locations/environments obtained in Northern Hill Zones, Central Plain Zone and Bastar Plateau Zone is given in Table 1 based on which the interpretation has been made. The AMMI analysis

Table 1. Mean yield, AMMI and biplot scores of the test genotypes and environments

Genotype	Variety	Yield Mean (t/ha)	AMMI Biplot Score		GGE Biplot Score	
			PC1	PC2	PC1	PC2
G1	Co 94008	94.32	-0.89	-0.03	-22.07	-0.77
G 2	Co 0238	106.19	2.7	1.65	16.07	-30.1
G 3	CoN 8177	100.16	0.97	-0.77	-1.02	-8.33
G 4	CoSnk 05103	116.7	0.34	-2.68	20.36	17.91
G 5	CoSnk 05104	107.09	1.26	2.72	6.86	-22.72
G 6	Co 8201	99.26	-1.37	-0.44	-17.76	8.76
G 7	MS 10001	104.43	-5.5	-0.82	-38.29	47.61
G 8	VSI 434	76.56	-4.37	1.07	-70.92	10.08
G 9	VSI 3102	93.1	-0.76	-0.53	-22.45	-0.24
G 10	VSI 9805	61.31	-1.89	3.91	-79.56	-35.05
G 11	Local Jamun	131.22	2.61	1.06	51.56	-8.68
G 12	VSI 8005	106.97	-0.92	-0.87	-3.48	12.62
G 13	Co 09004	101.63	2.05	1.51	5.57	-27.28
G 14	Co 99006	108.76	3.45	1.93	24.25	-35.85
G 15	CoJN 86-141	61.47	-4.1	-0.02	-89.33	2.35
G 16	CoJN 86-600	117.65	-1.2	3.04	5.57	3.57
G 17	CoJN 95-05	109.43	1.08	0.63	11.31	-9.45
G 18	CoJN 99-17	109.42	-1.29	-0.85	-2.4	17.27
G 19	CoS 8436	142.24	3.99	-0.85	78.16	-3.04
G 20	Co 8014	130.29	1.75	-2.68	48.73	15.9
G 21	Co 86032	108.54	0.78	-1.49	10.38	2.7
G 22	Co 85004	100.63	0.17	-1.4	-4.81	1.6
G 23	Co 99004	133.18	1	-1.26	46.44	17.29
G24	CoC 671	121.98	0.16	-2.82	26.83	23.84
E1	Kawardha	116.36	-5.24	-5.88	0.3	0.94
E2	Ambikapur	138.84	9.35	-0.49	0.94	-0.32
E3	Jagdalpur	62.61	-4.11	6.37	0.18	0.09
	Over All Mean	105.94				

showed that the variation in cane yield could almost be equally attributed by the genotypes effects (75.3%) and environmental effects (24.7%) on cane yield (Table 2, Fig. 1). This response to environmental and genotypic effects coincides with those also found by Rea et al. (2011). Momotaza et al. (2021) by using AMMI analysis also reported significant variations in mean stalk weight and cane yield attributable to genotypes, environments, and GEI.

Graphical analysis of IPCA I with average cane yield revealed that genotype (or environment) that appear near or on almost perpendicular line have similar mean that is G2 (Co 0238), G5 (CoSnk 05104), G12 (VSI 8005) and G21 (Co86032) *viz* 106.19 t/ha, 107.09 t/ha, 106.97 t/ha and 108.54 t/ha with mean yield (105.94 t/ha) (Fig. 2). Horizontal line fall clones/ varieties had similar interaction pattern revealed in G4'CoSnk 05103 and G24' CoC0671 with PC1 value 0.17 and 0.16 had mean cane yield 116.70 t/ha and 121.98 t/ha, respectively. The high IPCA 1 score (either positive or negative) have high interaction with genotype G8 (-4.37), G7 (-5.5), G14 (3.45) and G19 (3.99) (Table 1). In the AMMI model, genotypes with high value for trait and greater than grand mean and near to zero IPCA score are considered under general adaptability across environments. Thus, G24 and G4 were having general adaptability.

Genotypes, G19 and G14 were considered under specific adaptation (9.35) in E2 due to high cane yield and large IPCA score. Among environments, E3 (-4.11) had low main effect and was very poor while E$_2$ and E$_1$ had highest main effect and were favourable to the performance of most of the genotypes. The difference in mean yields of cane more than double as revealed in Table 1, indicating that the environments E1 and E2 were found favourable due to prolonged winter during growth period and environment E3 was unfavourable for the varietal expression as also reflected in terms of mean yield of the clones at three locations. Nagesh Kumar et. al. (2021) studied 10 rainfed environments with 28 pigeon pea genotypes for stability and adaptability using AMME and GGE biplot method. They reported that E2, E3 and E6 were the most discriminating environments. These environments were classified into two mega environments which were identified for several winning genotypes across the wide range of environments in pigeon pea.

CoS 8436 (G19), Local Jammun (G11) and Co 8014 (G20) had highest average main effect and highest IPCA I value (3.99), (2.61) and (1.75) so highly unstable while, G24 (CoC 0671) and G4 (CoSnk 05103) had higher main effect with lowest IPCA I value (0.16) and (0.34), respectively (Table 1). Therefore, AMMI stability parameters for environments have been used to analyze GEI and found stable and compatible genotypes to such environments as reported earlier (Yan 1999; Yan et al. 2000; Yan and Rajcan 2002; Mohammadi et al. 2008).

All the three environments showed different mean for yield and because of that AMMI 2 biplot does not show the additive main effects, interaction as suggested by AMMI1 biplot, but interaction component GxE is very informative (Figs. 1 and 2). This graph is useful when IPCA2 is sizeable and significant. In AMMI 2 biplot, if a genotype is located near the biplot centre, it will be considered more stable than those far from the centre. Genotype G17 (CoJN 95-05), followed by G12 (VSI 8005) and G23 (Co99004) were found as stable genotypes. Most stable environment was E$_2$ followed by E$_1$ and E$_3$ as observed in AMMI 2 score. Genotypes G19 and G17 were having positive interaction with E$_2$, whereas G23 and G12 had high positive interaction with E$_1$. Pénél and Béhou (2020) also reported that GxE interactions were highly significant for five traits: cane and sugar yields, stalk borer infestation rate, fibre content and the average stalk height.

According to the IPCA I vs IPCA II scores of genotypes and environments, when a genotype is near to an environment, it indicates that the genotype is specifically adapted to that environment (Shafii et al. 1992; Kumar et al. 2016). Thus, in present study genotypes G19 and G17 were recognized as superior and stable genotypes for environment E2. In order to select appropriate environment with high ability for distinguishing genotypes, environments should have a high IPCA I and low IPCA II (Mohammadi et al. 2008). According to IPCA I and IPCA II, E2 and E1 environments had the most stability and the least contribution of interaction, whereas, E3 with the least IPCA I and high IPCA II had the

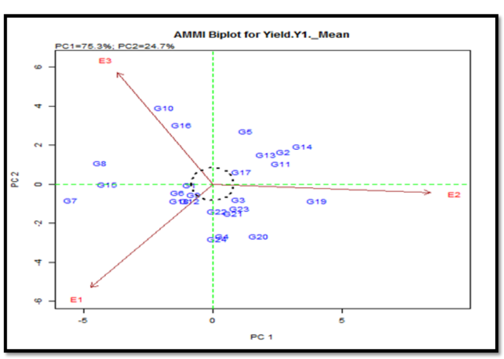

Fig. 1. AMMI II biplot of IPCA1 with IPCA 2 depicting the genotype x environment interaction and stability of 24 sugarcane varieties evaluate in 3 environment of chhattisgarh state.

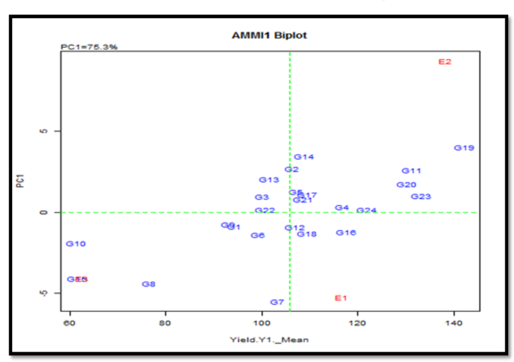

Fig. 2. A biplot of sugar yield environmental mean (ton ha^{-1}) Vs IPCA 1 for 24 sugarcane varieties in the 3 environments

most contribution to produce GEI. Most ideal environment was E2 based on the high IPCA I and the low IPCA II (Fig. 1). The AMMI method combines the traditional ANOVA and PCA into a single analysis with both additive and multiplicative parameters (Gauch 1992). The first part of AMMI uses the normal ANOVA procedures to estimate the genotype and environment main effects. The second part involves the PCA of the interaction residuals (residuals after the main effects are removed). AMMI analysis for cane yield showed high significant differences among genotypes, environments and Genotype and Environment interactions. The Genotype × Environment components were further divided and explained by two IPCA (interaction principal components axes): IPCA I and IPCA II. First two IPCA axes explained about 100% (PC 1 = 75.3 %; PC 2 = 24.7%) of total variation and thus, this model was effective in explaining Genotype × Environment components and interaction in the present study (Fig. 1). Rea et al. (2017) also found that in sugarcane the genetic variation for cane yield is largely attributed by genotypic and environmental effects. Aamer et al. (2018) revealed that first four PCs contribute more than 85% of the total variation. Further, he found that the suitable selection of clones can be carried out by considering the best

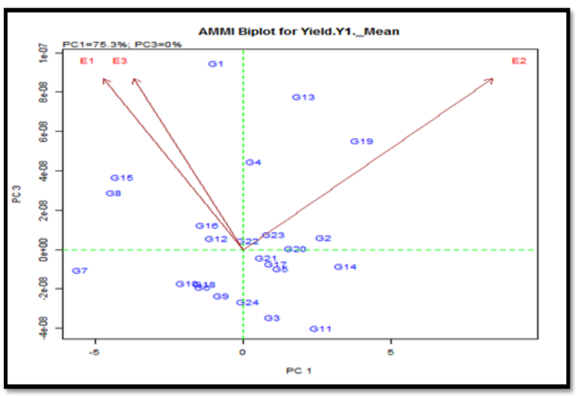

Fig. 3. AMMI 2 biplot of IPCA I with IPCA III.

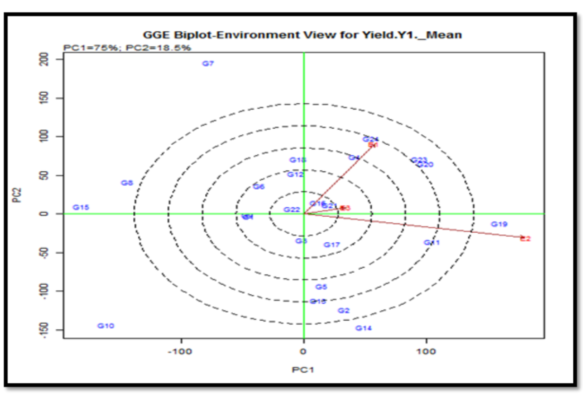

Fig. 4. GGE biplot showing average cane yield (t/ha) and stability of sugarcane varieties over environments. GGE-biplot based on genotype focused scaling for comparison of the genotypes with the ideal genotype. Blue and red numbers stands for genotypes and environments respectively

commercial merits for cultivation in different environments through principal component analysis.

In the AMMI II biplot, the angle between the vectors of two environments or between genotypes and environment also throw light on the relationship between the two (Yan and Kang 2003, Gauch 2006). The lines that connect to test environments to the biplot origin are called environmental vectors and the vector length which indicates the discriminating ability of testing environments. Hence, Environments E2 (Northern Hills) and E1 (Chhattisgarh plains) were positively correlated and had the power to discriminate genotypes efficiently as evident from the longest vector distance of these environments from the IPCA axes origin point. The distance between two environments (locations) measured by the cosine of the angle between the vectors indicate their similarity or dissimilarity in discriminating the genotypes (Yan and Tinker 2006), whereas, E3 was negatively correlated with their short vector distance. Only the environments E2 (Northern Hill Zone) recorded the highest and positive IPCA 1 and 2 scores, indicating that this region had more favorable environments for obtaining higher cane yield. It may be due to crop getting more duration for active growth period compared to other environments, as reported by Meena et al. 2017 in different planting season of sugarcane. The angle between E1 and E2 (Central Plain Zone and Northern Hill Zones), E2 and E3 (Northern Hill Zones and Bastar Plateau Zone), E3 and E1 (Bastar Plateau Zone and Central Plain Zone) were wide or obtuse which implies a strong crossover of GE. Hence, the responses of these three sets of environments were in opposite directions and have different requirements for genotypes. The mean cane yield of Northern Hill Zones, Central Plain Zone and Bastar Plateau Zone as shown in Table 1 also justify the interpretation made as above.

The specific adaptability of a variety to a particular environment may be judged by analyzing the position of the clones with reference to environment vectors in AMMI II biplot graph (Fig. 2). The clone G12 (VSI 8005) was aligned

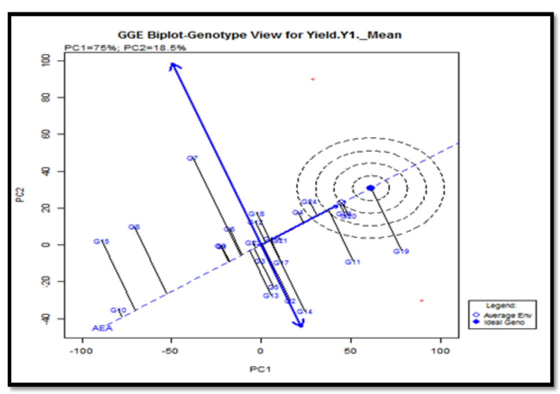

Fig. 5. Average environment coordination (AEC) view of the GGE biplot based on environment-focused scaling for the means performance and stability of test varieties

Table 2. Means squares of combined analysis of variance for 24 varieties in 3 environments

Source	DF	Sum of Square	Mean Square	F Value Calculated	F Value Tabulated
Environment	2	147706.0783	73853.0392	170.00**	19.496
Rep. with in Env	3	1303.2553	434.4184	2.10	8.526
Genotype	23	54621.4750	2374.8467	11.47**	1.767
Env. X Genotype	46	43540.6301	946.5354	4.57**	1.0893
Pooled Error	69	14287.9410	207.0716	%Explained	%Accumulated
IPCA 1	24	34671.21	11363.06	444.6337	75.3%
IPCA II	22	75.3%	516.5029	24.7%	100%
Total	143	261459.3798			

**significant at 0.05 level of significance.

in proximity to E1 vector. So it can be treated as having greater adaptability for Central Plain Zone planting. The clone G19 (CoS 8436) was aligned in proximity to E2 vector. Thus, it can be treated as having greater adaptability for Northern Hill Zones planting. Similarly, clone G16 (CoJN 86-600) was aligned in proximity to E3 vector and exhibited better adaptability in Bastar Plateau Zone. The different genotypes identified for Central Plain Zone (E1), Northern Hill Zones (E2), and Bastar Plateau Zone (E3) also justify the interpretation made as above that they have different genotype requirements for different zones. AMMI 2 biplot of IPCA I with IPCA III indicated that the interaction PC1 value 75.3% and PC3 0% show negligible contribution of PC3 with PC1 so it should be ignored (Fig. 3).

GGE biplot analysis

Graphical virtualization for identification and evaluation of genotypes, environments and their interactions is facilitates by GGE biplot (Yan et al. 2000). Genotype + Genotype x Environment (GGE) biplot analysis revealed that the first two principal components PC1 and PC2 explained 93.5% of the total variation comprising PC1 = 75% and PC2 = 18.5% (Fig. 4). Genotypes having high PC1 scores and low PC2 scores were considered as ideal. Environments should be considered as ideal which have high PC1 scores and low PC2 scores (Yan and Rajcan 2002; Yan et al. 2000). Accordingly, the genotypes G19, G20, G23 and G24 were high yielder and

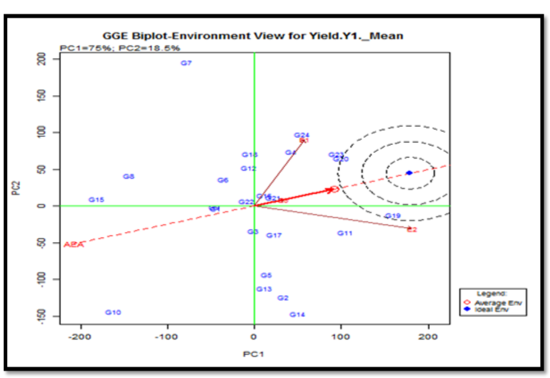

Fig. 6. GGE biplot showing stable Sugarcane Varieties over environments

G15, G10 and G8 with large negative PC1 scores were comes under low yielder genotypes. Genotypes with low PC2 scores such as G11 can be considered as stable. Large PC1 scores are those environments that better differentiate the genotypes and PC2 scores near zero represent an average suitable environment (Yan 2001; Yan et al. 2000). Projection to the *y*-axis (AEA line) produces measure for the stability of the genotypes. This signifies that, greater the absolute length of the projection of a genotype, the less stable it is and *vice-versa* (Yan 2001).

The AEA line partitioned genotypes which yield below and above the mean yield. The genotypes to the right of this line are high yielders, while left side is low yielders. Therefore, the genotype ranking according to this interpretation is in the order of G19, G11, G20, G23 and G24 (Fig. 5). G10 is the poorest genotype for cane yield. In contrast, genotype G19 was identified as the ideal variety which has high PC1 scores (78.16) and low PC2 scores (-3.04) is considered as shown by the concentric circles around it (Fig. 6). Further, genotype G19 (CoS 8436) had a projection near to the y-axis that is -3.04 and therefore, it has absolute stability i.e., wider adaptation to all the test environments. It would be recommended uniformly for cultivation in all three agro-climatic zones of Chhattisgarh state, India. The varieties' G11' (Local Jamun) is also among the high yielding which has high PC1 scores (51.56) and PC2 scores (-8.68) and 'G23' (Co 99004) is also among the high yielding which has high PC1 scores (46.44) and PC2 scores (17.29) and relatively stable variety. E2 as an ideal environment, having large PC1 scores (0.94) and lower PC2 scores that is less than zero (-0.32) is represent an ideal suitable environment also in closer concentric circles e.g., E1 and E2 were considered as ideal environments while E3 is poor environments having lower PC1 scores (0.18) and lower PC2 scores near to zero (0.09) (Fig. 7). Assessment of genotypes under different environments is essential to evaluate quantitative characters, to measures stability and adoptability. A complex trait like yield is highly influenced by environments. Further, to evaluate multi-environment data in effective use of both models is recommended (Gauch and Zobel 1988). Although, GGE biplot procedure has been used in stability studies of several annual crops

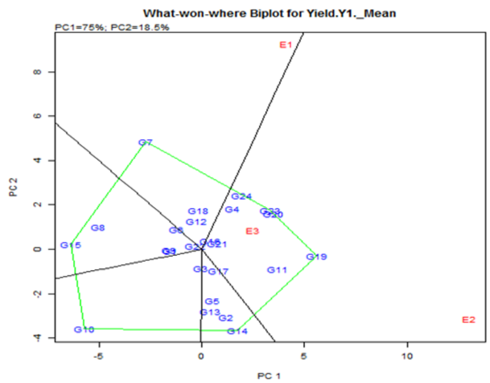

Fig. 7. Genotype main effect +genotype x environment interaction (GGE) biplot, representing tons of sugar yield per hectare of 24 sugarcane varieties (G) evaluated in 3 environments (E) in 2018-19

including peanut (Lal et al. 2021) and pearl millet (Reddy et al. 2022), it has been used in limited occasions for perennials like sugarcane. The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness of the test environments has been studied in perennial crop like tea (Kottawa-Arachchi et al. 2022).

An AMMI and GGE biplot method facilitates visual comparison and conclusive information to detect stable genotypes over environments. Momotaza et al. (2021) also reported the application of GGE biplot in the sugarcane testing programme will be helpful in the identification of the clones best adapted to specific locations. Beside this, AMMI and GGE biplot analysis were also found helpful in other crops as reported by Sanwal et al. (2021) for selecting alkaline tolerant okra parent for further breeding programme and recommending the suitable genotypes for alkalinity prone areas. In the present study, these two methods were well employed and sugarcane variety G19 *i.e.* CoS 8436 Local Rasgulla would be recommended for commercial cultivation in all the three prevailing agro-climatic zones of the Chhattisgarh state, India and also next high yielding and stable variety i.e. CoSnk 05103 and VSI 8005 while, variety Co 99004 (Damodar), Co 86032 (Nira) and CoC 0671 (Vasant) could also be used as parents for sugarcane improvement programme and further yield and quality performance of PII and ratoon should be evaluated for further confirmation.

Authors' contribution

Conceptualization of research (ONV, NKR); Designing of the experiments (ONV, NKR, PKS); Contribution of experimental materials (ONV); Execution of field/lab experiments and data collection (ONV, SKS, JLS); Analysis of data and interpretation (ONV, NKR, PKS); Preparation of the manuscript (ONV, NKR, PKS).

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