Plant Archives Vol. 25, No. 2, 2025 pp. 2657-2667 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.384

ASSESSMENT OF STABILITY OF PROMISING SUGARCANE GENOTYPES ACROSS MULTIPLE LOCATIONS BY AMMI STABILITY PARAMETERS AND GGE BIPLOT MODELS FOR BOTH QUANTITATIVE AND QUALITATIVE TRAITS

A.B. Gawhane[1]*, J.M. Repale[1], K.V. Shushir[1], T.L. Pathy[2] and A.D. Kadlag[1]

[1]Vasantdada Sugar Institute, Manjari (Bk.) Tal. Haveli, Dist. Pune - 412 307, Maharashtra, India.

[2]ICAR- Sugarcane Breeding Institute, Coimbatore - 641 007, Tamilnadu, India.

*Corresponding author E-mail : anirudhhagawhane@gmail.com

(Date of Receiving-19-06-2025; Date of Acceptance-05-10-2025)

ABSTRACT

The multi-location trials were conducted during 2021–22 to evaluate the performance and stability of eleven sugarcane genotypes along with five standards across five locations. Combined ANOVA revealed significant genotype, environment and genotype-by-environment interaction effects for most traits related to cane and sugar yield, except for single cane weight (non-significant G×E) and cane diameter (non-significant E and G×E). Stability analyses were performed using AMMI Stability Value (ASV), Average of the Squared Eigenvector Value (EV), Modified AMMI Stability Value (MASV), Sums of the Absolute Value of the IPC Score (SIPC) and Genotypic Stability Index (GSI). Genotypes G4, G5, G6, G7, G8, G12, and G16 were consistently identified as stable and high-performing across traits. Genotypes G2, G5, and G7 were notably stable for cane yield, while G5, G3 and G9 showed stability for sucrose percent. GGE biplot analysis indicated high discriminating power for environments four and five, classifying the five environments into two mega-environments. Vertex genotypes like G5, G11, G15 and G16 emerged as superior for cane yield, whereas G4, G10, and G13 were superior for sucrose content. WAASBY analysis supported the selection of genotypes such as G5, G10, G12, G15, and G16 for their balanced performance and stability. The study underscores the significance of G x E analysis for identifying widely adaptable genotypes suitable for diverse agro-climatic conditions.

Key words : Sugarcane, ASV, GSI, WWW, WAASBY, Mean vs Stability, Discriminativeness vs Representativeness.

Introduction

Sugarcane possesses major role in Indian economy and economical important crop of Maharashtra State, which is grown under varied agro climatic zones of the state. The improvement in productivity and production mainly depends upon proper variety. Varietal impact on boosting sugarcane production has played crucial role for production of sugar and sugarcane productivity. To overcome different constraints *viz*., low recovery, sucrose inversion, instability in sugar and cane yield, susceptible to biotic and abiotic stresses, flowering, low adaptability etc. The selection of suitable parent for hybridization is a pre-requisite. Sugarcane improvement through breeding took a quantum jump in the year 1912, Dr. C. A. Barber crossed the cultivated, sucrose rich *S. officinarum* with wild, grassy sugarless *S. spontaneum* that led the development of the first successful sugarcane hybrid. The landmark achievement, unparalleled in the annals of crop breeding history paved way for a new philosophy of sugarcane breeding all over the world.

The cultivable area and sugarcane production have shown substantial annual growth in key growing regions. The yield has not increased significantly (Upreti and Singh, 2017) because the complex and varied management practices. The effectiveness of sugar improvement programs is evaluated based on the enhancement of juice quality over sugarcane yield itself (Jackson, 2005). The quantitative trait, cane yield predominantly effected due to the interaction between genetic factors and environmental conditions. These varying environmental factors often hinder breeders from effectively selecting or discarding genotypes suited to specific conditions (Van Eeuwijk *et al*., 2016). The genotypes which showed consistency in performance over various locations, yield stability analysis is employed (Doehlert *et al*., 2001). This analysis can be approached in two ways: one focuses on developing highly productive, adaptable and stable genotypes, while, the other involves grouping environments into "mega-environments" that are relatively uniform, with specific genotypes recommended for each (Durai *et al*., 2024). Two commonly used biplot methods for visualizing GEI are the AMMI and GGE biplots. The AMMI model, introduced by Gauch (1992), integrates analysis of variance (ANOVA) with principal component analysis (PCA) to characterize GEI across multiple dimensions. On the other hand, the GGE biplot, proposed by Yan *et al*. (2000) undertaken genotype main effect and genotype environment interaction effect for analysis. AMMI stability parameters help in assessing stability in yield by minimizing the influence of GEI effect (Ajay *et al*., 2020; Anuradha *et al*., 2022). Stability and adaptability are key factors in selecting genotypes for breeders (Wolde *et al*., 2018). A genotype's stability is influenced by environmental conditions (E), genetic factors (G) and their interaction (GEI), which can lead to notable variations for genotypes performance over various environment and different seasons (Muhammad *et al*., 2007). Analyzing GEI in Multi location trials were crucial for the assessment, assortment, and proposal of any variety (Mattos *et al*., 2013 and Regis *et al*., 2018). The AMMI biplot graphical analysis offers a straight forward method for breeding researchers, enabling them to assess genotypic and phenotypic stability, genetic variability among clones and identify location where genotypes perform optimally (Yadawad *et al*., 2023). Thus, the work was undertaken to study stability of the sugarcane genotypes.

Materials and Methods

The experiments were conducted during planting season 2020-21 at five locations viz., Shree T. K. Warana Co-op. Sugar mill Ltd. Kolhapur, Vasantdada Sugar Institute, Pune, K. A. Tope Samarth Co-op. Sugar mill Ltd. Jalna, Bhaurao Chavan Co-op. Sugar mill Ltd. Nanded and Manas Agro Industries and Infrastructure Ltd. (Unit 1), Nagpur located at different agro climatic zones in Maharashtra State (India). The locations represented different climatic conditions (Table 1).

The 11 genotypes along with five standard varieties were planted in RBD during planting season 2020-21 at Nursery farms of various sugar factories in two replications. The seed rate of eight buds per meters used with six meters row length with 137 cm distance between two rows was kept. The recommended crop practices were followed in sugarcane cultivation. The details of sugarcane genotypes under study are as follows in Table 2.

The seven yield contributing characters *viz*., Single cane weight (SCW), Cane Diameter (CD), Number of millable Canes (NMC), Sucrose %, Commercial Cane Suagr yield (CCSY) and Cane Yield (CY) were recorded. The quality parameters i.e. Brix and Sucrose were recorded and compiled C.C.S%.

Statistical analysis

The statistical analysis was carried out in the 'R' version 4.5.0 statistical software. TheAMMI analysis of variance was done by using "metan" package (Olivoto *et al*., 2020).

The AMMI model was applied to estimate the adaptability and phenotypic stability. As per Farshadfar *et al*. (2011), the AMMI model also modified as

$$Y_{ij} = \mu + g_i + e_j + n\sum k = 1\ \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$$

Where, Y_{ij}-ith genotype yield in the jth environment, g_i-ith genotype minus the grand mean as a mean, λ_k-the eigen value of the PCA axis square root, k, α_ik and γ_jk-

Table 1 : Environment Details where Sugarcane Genotypes evaluated.

ENV.	Location	Zone	Latitude	Longitude	Altitude (MSL)
E1	Shree T. K. Warana Co-op. sugar mill Ltd. Kolhapur	Western Ghat	16.73^{0}N	74.23^{0}E	563 meters
E2	Vasantdada Sugar Institute, Pune	Western Plain	18.08^{0}N	73.85^{0}E	625 meters
E3	K. A. Tope Samarth Co-op. sugar mill Ltd. Jalna	Central Plateau	19.50^{0}N	75.53^{0}E	500 meters
E4	BhauraoChavan co-op. sugar mill Ltd. nanded	Central Plateau	19.28^{0}N	77.77^{0}E	568 meters
E5	Manas Agro Industries and Infrastructure Ltd. (Unit 1), Nagpur	Central Vidarbha	21.14^{0}N	79.08^{0}E	312 meters

Table 2 : Sugarcane genotypes undertaken for study.

S. no.	Genotypes	Parentage	Code of genotypes	Remark
1	CoVSI 13020	Co 2000-10 PC	G1	High yielding, high sugar, moderately resistant to red rot
2	CoVSI 11001	Co 8371 PC	G2	High yielding, moderately resistant to red rot and smut
3	VSI 12003	Co 0202 x F 134	G3	High yielding, high sugar, errect
4	CoVSI 12025	Co 94012 x 85 R 186	G4	High yielding, high sugar, thick canes, good ratooner, non-lodging
5	CoVSI 18121	Co 86032 x CoT 8201	G5	Non lodging, high yielding, high sugar, thick canes, good ratooner
6	VSI 14050	ES 9 x Co 89003	G6	High yielding, high sugar, drought tolerent
7	PDN 13002	CoM 0265 x Co 62175	G7	High yielding, high sugar, good ratooner, moderately resistant to smut
8	PDN 13011	CoM 0265 x Co 62175	G8	High yielding, high sugar, good ratooner, moderately resistant to smut
9	CoM 12085	Co 94012 PC	G9	High quality jaggary production, medium thick cane, moderately resistant to wilt disease
10	Co 09004	CoC 671 x CoT 8201	G10	High sugar, moderately resistant to red rot and smut, drought and salinity tolerant
11	Co 12008 Standards	Co 86249 x Co 91004	G11	High yielding, high sugar, moderately smut resistant
12	Co 12009	[{(Co 7201 x (Co 62174 x SES 91)} x(Co 88037)}] x Co 62198	G12	High yielding, high sugar, thick canes, good ratooner
13	MS 10001 (MS 13081)	CoM 0265 x MS 0602	G13	High yielding, high sugar, low fiber, thick canes, good ratooner
14	Co 86032	Co 62198 x CoC 671	G14	High yielding, high sugar, good ratooner, no deterioration in sugar if delayed in harvesting
15	CoM 0265	CoM 87044 GC	G15	High yielding, good ratooner, drought and salinity tolerant
16	VSI 08005 (VSI 12121)	Co 0310 x Co 86011	G16	High yielding, high sugar, good ratooner, fast growing, non flowering, drought tolerent

the ith genotype and jth environment principal component scores for PCA axis k, e_{ij}- residual value. The genotypic and environmental PCA scores as unit vector times the square root of λ_k; i.e., environment PCA score = $\lambda_k Y_{ik}$; genotype PCA score = $\lambda_k \alpha_{ik}$.

The contributions of principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares for each genotype were computed as AMMI stability value (ASV).The response of the genotypes relative to the environments allied with the GEI were represented by IPCA1and the environments that are accountable to GEI as IPCA2.

The AMMI stability value (ASV) was described by Purchase *et al*. (2000) as follows:

$$ASV = \sqrt{\left[\frac{IPCA1\ Sum\ of\ Squares}{IPCA2\ Squares}(IPCA1\ Score)\right]^2 + (IPCA2\ Score)^2}$$

Where, SSIPCA1/SSIPCA2-IPCA1 value weight which computed as dividing the IPCA1sum of squares by IPCA2 sum of squares. As the smaller ASV score, the genotypes are more stable over all locations, while, more adaptable genotypes for particular environment showed larger IPCA score either may be positive or negative values or sign. The Additive main effect and multiplicative interaction (AMMI) (Gauch and Zobel, 1997) and GGE Biplot or Site Regression model (Yan and Kang, 2003) stability models were assessed for the performance of genotypes. In case of AMMI models only GEI is used, but in case of GGE biplot analysis genotypic effect and its interaction with environments both are used. In AMMI firstly genotypes and environments main effects (additive) analyzed by ANOVA and then by using PCA analyzed the residuals (namely the interactions).The GGE biplot based on the site regression linear (SREG) bilinear model (Crossa and Cornelius, 1997; Crossaetal, 2002) shows both genotype and genotype environment variation (Kang, 1993). The multi environment evaluation (which-won-where pattern), genotype evaluation (mean versus stability) and tested environment ranking (discriminative versus representative) based graphs are generated. For ranked genotypes allocate increasing order for each stability parameters. After testing significance of the genotypes by environment interaction the stability for genotypes were determined.

Results and Discussion

Table 3 revealed significant genotype main effects, environment main effects and genotype environment interaction main effects for all characters contributing cane yield and sugar yield except genotype environment interaction main effects for single cane weight while environment main effects and genotype environment interaction main effects for cane diameter was non-significant. The significant effect of environment revealed that there was difference between the genotypes under study over the multi-location environments. The GEI showed significant effects indicated that genotype performs differently in tested environments. The variation was primarily influenced by environmental effects followed by genotypic effects and genotype-by-location interaction effects. The significant differences in soil types and atmospheric conditions over the various environments recognized high environmental variance (Meena *et al*, 2017; Abate, 2020 and Sheelamary and Karthigeyan, 2021). The genotypes under study responded differently over different environment because of GEI (Queme *et al.*, 2005 and Tahir *et al.*, 2013).

Different Stability Parameters

From Table 5, showed various stable sugarcane genotypes over several traits using several stability indices, including the AMMI Stability Value (ASV), the Average

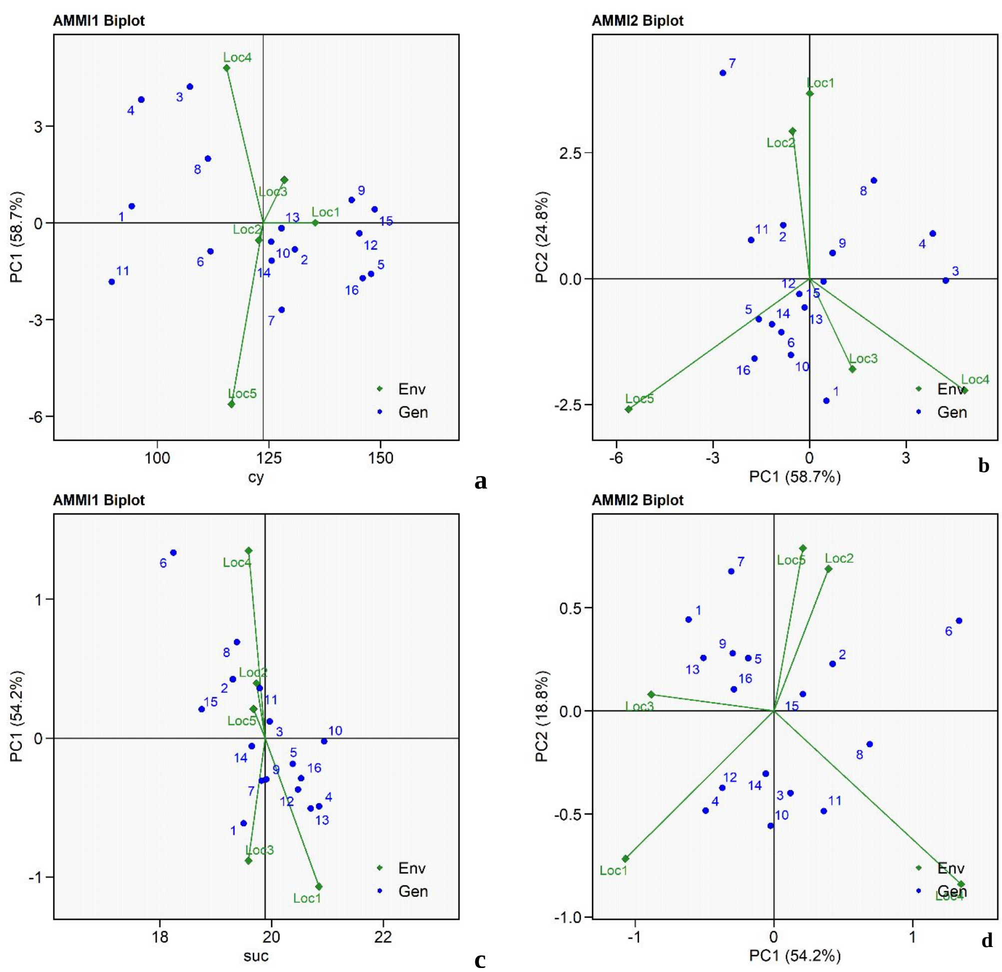

Fig. 1 : AMMI Biplots a. PC1 vs cy (Cane Yield) b. PC1 vs PC2 (Cane Yield) c. PC1 vs suc (Sucrose Percent) d. PC1 vs PC2 (Sucrose percent).

Table 3 : Combined ANOVA of all traits contributing cane yield and sugar yield.

Source	df	CY (tha^{-1})	CCSY (tha^{-1})	NMC (000')	CCS %	Suc. %	SCW (Kg)	Dia. (cm)
GEN	4	2212.07**	97.72**	204.85**	8.35**	9.39**	0.40**	0.36*
ENV	15	3985.33**	89.37**	292.38**	3.56**	5.67**	0.36**	0.20
GxE	60	183.19**	5.55**	70.94**	0.56**	0.96*	0.02	0.05
Error	75	8.35	1.24	5.89	0.35	0.44	0.064	0.12
Total	219							

[CY- Cane Yield(t/ha), CCSY-commercial cane sugar yield (t/ha), NMC-Number of millable canes(000'ha), CCS%- commercial cane sugar yield percent, Suc.- sucrose percent, SCW- single cane weight (kg), Dia.- Cane Diameter (cm)]
(*Significant at P ≤ 0.05 level of significance & **Significant at P ≤ 0.01 level of significance).

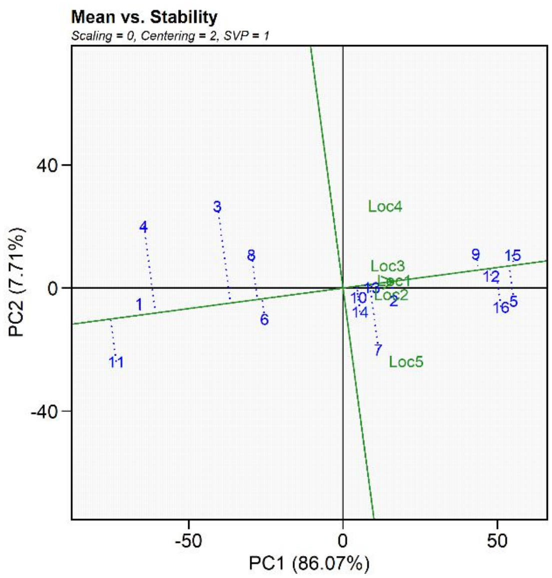

Fig. 2 a : Mean vs Stability for cane yield.

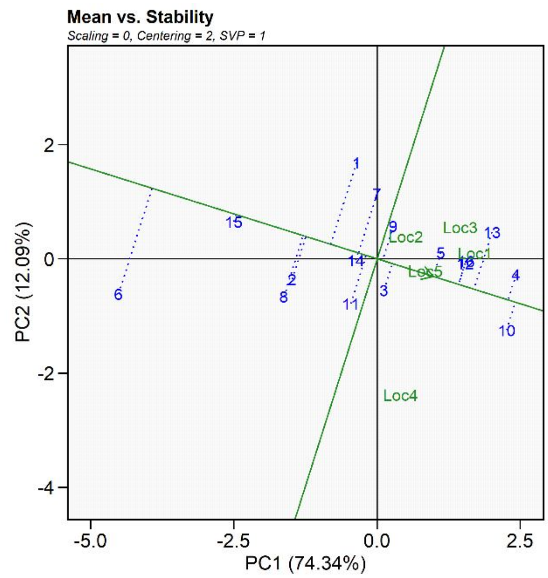

Fig. 2b : Mean vs Stability for Sucrose percent.

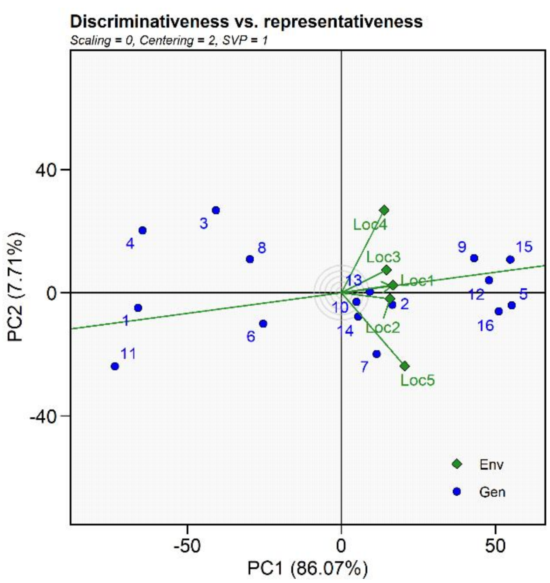

Fig. 2c : Discriminative vs. Representativeness for cane yield.

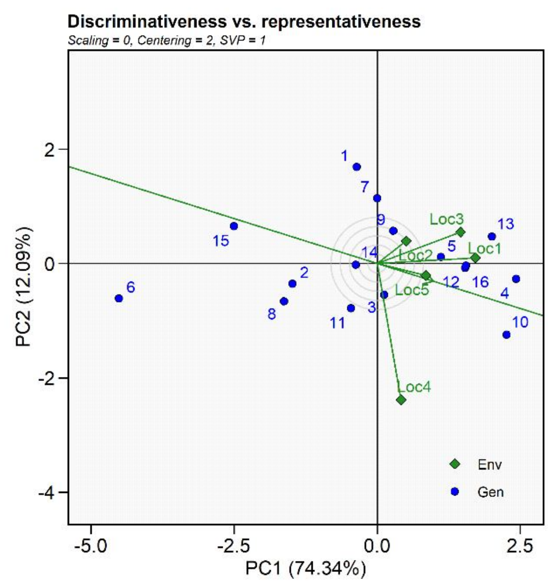

Fig. 2d : Discriminative vs. Representativeness for sucrose percent.

of the Squared Eigenvector Value (EV), the Modified AMMI Stability Value (MASV), the Sums of the Absolute Value of the IPC Score (SIPC) and the Genotypic Stability Index (GSI). The genotypes G4, G5, G7, G8, G12, and G16 were frequently appeared as stable across different traits including cane yield, sugar yield, single cane weight, number of millable canes, sucrose percent, commercial cane sugar percent and cane diameter. While,

Table 4 : AMMI ANOVA of main effects and interaction for cane yield, CCS yield, number of millable canes, CCS percent, sucrose percent, Single cane weight and cane diameter.

Source	df	CY (tha^{-1})		CCSY (tha^{-1})		NMC (000')		CCS%		Suc. %		SCW(Kg)		Dia. (cm)	
		MS	VE %	MS	VE %	MS	VE %	MS	VE %	MS	VE %	MS	VE %	MS	VE %
GEN	4	2212.1**	11.11	97.72**	18.93	204.8**	8.66	8.35**	27.74	9.39**	20.85	0.40**	19.51	0.36*	19.36
ENV	15	3985.3**	75.08	89.37**	64.94	292.4**	46.37	3.56**	44.35	5.67**	47.19	0.36**	65.85	0.20	40.32
GxE	60	183.2**	13.81	5.55**	16.13	70.9**	44.97	0.56**	27.91	0.96*	31.96	0.02	14.64	0.05	40.32
IPCA1	18	358.6	58.7	8.79	47.5	111.6	47.2	1.02	53.0	1.73	54.2	0.03	48.2	0.06	37.1
IPCA2	16	170.5	24.8	5.06	24.3	87.3	32.8	0.41	19.1	0.68	18.8	0.01	21.9	0.05	31.1
IPCA3	14	101.8	13.0	4.82	20.3	44.8	14.7	0.37	15.0	0.64	15.7	0.01	19.4	0.04	21.1
IPCA4	12	32.0	3.5	2.18	7.8	18.5	5.2	0.37	12.8	0.54	11.3	0.01	10.6	0.02	10.8
Residuals	75	69.8	0	1.53	0	30.1	0	0.12	0	0.19	0	0.04	0	0.01	0

[CY- Cane Yield(t/ha), CCSY-commercial cane sugar yield (t/ha), NMC-Number of millable canes(000'ha), CCS%- commercial cane sugar yield percent, Suc.- sucrose percent, SCW- single cane weight (kg), Dia.- Cane Diameter (cm)]. (*Significant at P ≤ 0.05 level of significance & **Significant at P ≤ 0.01 level of significance).

stability rankings varied slightly across indices, genotypes G4, G5, G6, G7, G8, G12 and G16 respectively consistently demonstrated high stability and performance. These genotypes were recommended for more breeding and cultivation because of adaptability and potential for high yield and quality traits under diverse environmental conditions.

Mean vs Stability

The genotypes G2, G5 and G7 were found stable for cane yield as compared to standards G10, G13, G14, G12 and G16, respectively. The genotypes G5, G3 and G9 were found stable for sucrose percent as compared to standards G12, G13 and G14 (Fig. 2a and 2b).

Discriminative vs. Representativeness

The Discriminative vs. Representativeness analysis GGE biplots helps pinpoint the most suitable environments that effectively differentiate between genotypes (Durai *et al*., 2024).

The environment 5 and environment 4 has the longest environmental vectors which bring high discriminating power. The remaining environments having shorter environmental vector for cane yield. For sucrose percent environment 4 having the longest environmental vectors and environment 1, environment 2, environment 3 and environment 5 with shorter environmental vector (Fig.2c and 2d).

Which- Won- Where (WWW)

The GGE biplot polygon indicated vertex genotypes are G11, G7, G16, G5, G15, G3 and G4 respectively for cane yield. The five environments classified into two mega environments, the first mega environment contained environment 1, environment 2 and environment 3 in which G15 and G9 are better performing genotypes. The second mega environment involves environment 2 and environment 5 in which the genotypes G14, G10, G12 and G2 showed good performance (Fig. 2e and 2f).

The genotypes G6, G10, G4, G13, G1 and G15 were vertex genotypes for sucrose percent. The five environments include two mega environments. The first mega environment contain environment 4 and environment 5 in that G3, G12 and G16 genotypes showed greater performance. The genotypes G5 performed better in second mega environment which composed environment 1, environment 2 and environment 3.

Weighted Average of Absolute Scores (WAAS)

Olivoto *et al*. (2019) suggested that evaluating both the average performance and stability of key agronomic traits can enhance varietal selection and

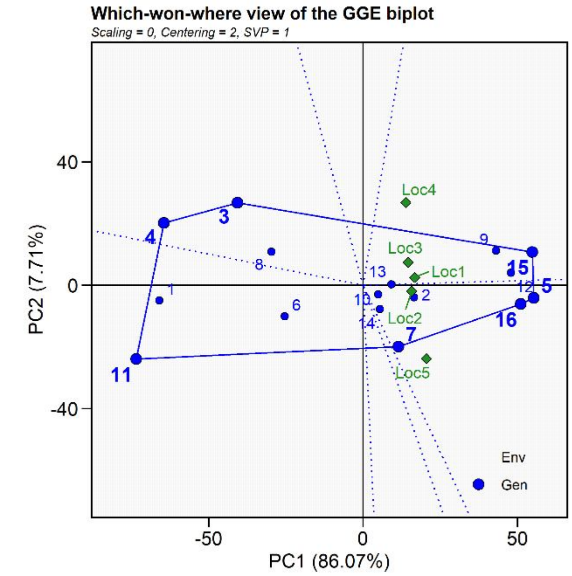

Fig. 2e : Which- Won- Where (WWW) for cane yield.

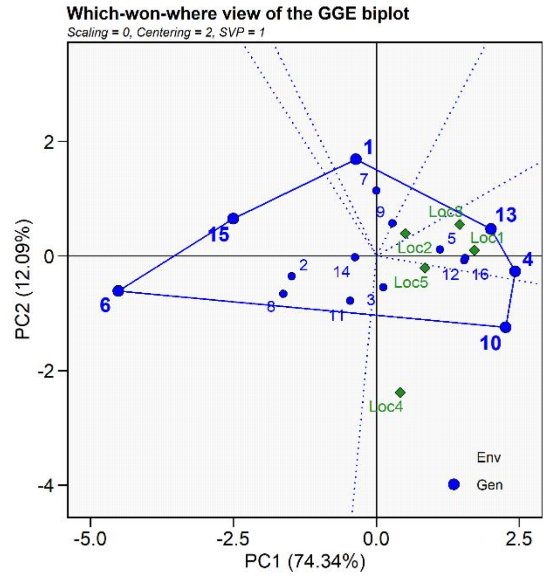

Fig. 2f : Which- Won- Where (WWW) for sucrose percent.

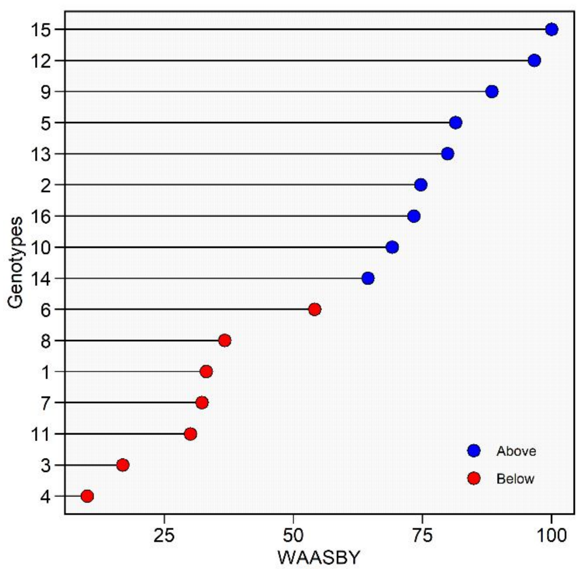

Fig. 2g : Weighted Average of Absolute Scores and Yield based Stability (WAASBY) for cane yield.

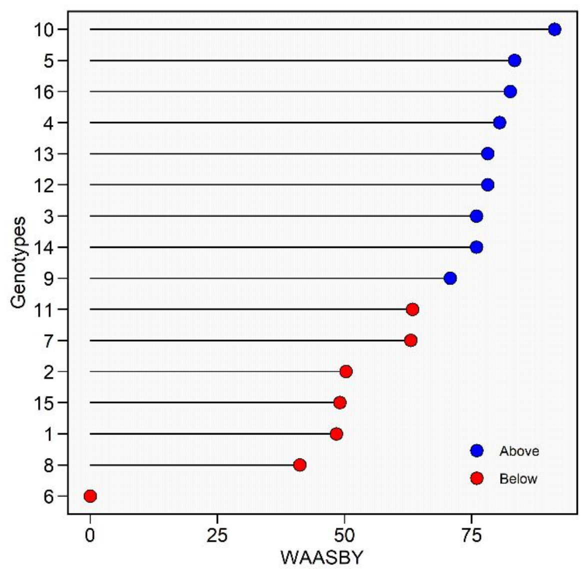

Fig. 2h : Weighted Average of Absolute Scores and Yield based Stability (WAASBY) for sucrose percent.

recommendations. A higher WAASBY score indicate genotypes with better cane yield and stability. Genotypes G15, G12, G9 and G5 were recorded the highest WAASBY values for cane yield. Likewise, genotypes G10, G5, G16 and G4 showed the highest WAASBY scores for sucrose percentage (Fig.2g and 2h and Table 5). These are the similar finding with the Sousa *et al*. (2019), Koundinya *et al*. (2021), Yue *et al*. (2022), Behera *et al*. (2024) and Adilakshmi *et al*. (2025).

AMMI Biplot – PC1 vs CY

The genotypes G 13, G15 and G9 for cane yield and G10 and G3 for sucrose per cent showed low positive interaction with high main effects reflect more preferable for assortment. The genotypes G6 and G11 for cane yield and G1, G7, G9 and G 14 for sucrose per cent had low PC 1 score reflect low negative interaction (Fig. 1a and 1c). The genotypes G10, G2 and G5 for cane yield and G5, G3 and G 14 for sucrose percentage are at the right hand side of the grand mean level and near to PC equal to zero line indicated adopted to all environments. For cane yield G9 and G15 and G3 and G11 showed high mean yield with large PC1 score indicates, these are adapted to the favorable environments. These results resembled with Meena *et al*. (2017), Regis *et al*. (2018), Sheelamary and Karthigeyan (2021).

As near the origin of the biplot genotypes demonstrate better stability across various environments, whereas, those positioned farther, from the origin indicated

Table 5 : AMMI stability value (ASV), genotype selection index (GSI), Eigenvector value (EV), Modified AMMI stability value, Sums of the Absolute Value of the IPC Score (SIPC) and Weighted Average of Absolute Scores (WAAS) for the genotypes for all traits contributing cane yield and sugar yield.

	Cane Yield (t/ha)							Commercial cane sugar yield (t/ha)							Number of millable cane (000'ha)						
Gen	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**
G1	2.73^{8}	23^{15}	0.082	2.73	2.95	1.09	94.2	0.563^{6}	21^{15}	0.101	1.39	1.84	0.449	13.1	1.33^{3}	18^{15}	0.015	1.33	1.26	0.677	67.5
G2	2.04^{5}	15^{10}	0.034	2.04	2.09	0.856	125.0	0.510^{5}	12^{7}	0.100	0.58	0.578	0.190	18.8	2.94^{12}	17^{5}	0.163	2.94	3.06	1.28	79.5
G3	4.37^{12}	26^{16}	0.037	4.37	2.59	1.51	89.8	0.735^{8}	24^{16}	0.007	0.748	0.587	0.244	12.6	0.995^{2}	16^{14}	0.013	1.00	1.19	0.577	67.9
G4	0.817^{2}	6^{4}	0.002	0.817	0.624	0.316	145.0	0.300^{2}	5^{3}	0.019	0.612	0.822	0.203	21.2	1.36^{4}	6^{2}	0.022	1.36	1.58	0.782	84.0
G5	0.684^{1}	9^{8}	0.005	0.684	0.731	0.282	128.0	0.330^{3}	9^{6}	0.002	0.349	0.355	0.129	18.9	1.52^{7}	19^{12}	0.018	1.52	1.27	0.709	73.1
G6	2.91^{9}	18^{9}	0.023	2.91	2.07	1.09	126.0	0.572^{7}	17^{10}	0.016	0.715	0.939	0.292	17.6	2.11^{10}	11^{1}	0.035	2.11	1.68	0.950	84.4
G7	1.02^{3}	4^{1}	0.002	1.02	0.48	0.319	149.0	0.391^{4}	9^{5}	0.009	0.523	0.662	0.207	19.7	1.43^{6}	13^{7}	0.018	1.43	1.37	0.731	77.8
G8	4.35^{11}	14^{3}	0.060	4.35	3.30	1.68	146.0	1.49^{12}	14^{2}	0.066	1.70	2.01	0.675	21.4	1.49^{8}	17^{9}	0.023	1.49	1.63	0.831	76.5
G9	2.21^{6}	12^{6}	0.021	2.21	1.88	0.892	131.0	0.826^{9}	18^{9}	0.013	0.883	0.867	0.321	17.9	2.64^{11}	21^{10}	0.075	2.64	2.95	1.49	75.7
G10	10.0^{16}	29^{13}	0.158	10.0	4.27	2.99	107.0	3.29^{16}	26^{12}	0.125	3.34	2.33	1.01	15.3	4.74^{16}	29^{13}	0.178	4.74	4.01	2.23	71.1
G11	9.10^{15}	29^{14}	0.140	9.10	4.72	2.96	96.4	2.88^{14}	27^{13}	0.096	2.91	2.14	0.924	14.4	3.69^{15}	31^{16}	0.120	3.69	3.62	1.92	67.1
G12	3.81^{10}	12^{12}	0.031	3.81	2.38	1.35	148.0	1.48^{11}	12^{1}	0.022	1.48	0.913	0.429	21.6	1.42^{5}	9^{4}	0.023	1.42	1.64	0.815	79.6
G13	2.33^{7}	18^{11}	0.022	2.33	1.94	0.931	112.0	1.34^{10}	24^{14}	0.163	1.95	2.46	0.605	14.3	2.07^{9}	17^{8}	0.035	2.07	1.85	1.01	77.0
G14	7.57^{14}	21^{7}	0.289	7.57	6.78	3.11	128.0	3.07^{15}	23^{8}	0.206	3.26	3.00	1.13	18.1	2.98^{13}	19^{6}	0.151	2.98	3.57	1.62	78.8
G15	5.11^{13}	25^{12}	0.087	5.11	3.95	1.98	111.0	1.71^{13}	24^{11}	0.132	2.14	2.68	0.858	15.4	3.01^{14}	25^{11}	0.107	3.01	3.49	1.73	75.5
G16	1.77^{4}	9^{5}	0.008	1.77	1.23	0.655	144.0	0.226^{1}	5^{4}	0.013	0.501	0.674	0.169	20.2	0.645^{1}	4^{3}	0.005	0.65	0.74	0.368	80.0

Table 5 continued...

	Commercial cane sugar percent							Sucrose percent							Single cane weight (kg)						
Gen	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**	**ASV**	**GSI**	**EV**	**MASV**	**SIPC**	**WAAS**	**Mean**
G1	1.47^{14}	26^{12}	0.105	1.62	1.72	0.459	13.9	1.72^{14}	26^{12}	0.095	1.95	1.81	0.509	19.5	0.192^{4}	19^{15}	0.027	0.221	0.237	0.056	1.41
G2	0.53^{5}	6^{1}	0.062	0.786	1.14	0.215	15.0	0.56^{3}	4^{1}	0.073	0.886	1.29	0.207	20.9	0.424^{11}	20^{9}	0.34	0.439	0.409	0.130	1.59
G3	0.74^{7}	18^{11}	0.068	0.957	1.23	0.278	14.0	1.14^{10}	20^{10}	0.072	1.30	1.40	0.351	19.8	0.724^{16}	32^{16}	0.67	0.743	0.515	0.187	1.34
G4	0.96^{10}	16^{6}	0.027	1.01	0.877	0.266	14.6	1.13^{9}	14^{5}	0.026	1.17	0.938	0.298	20.5	0.420^{9}	16^{7}	0.69	0.547	0.605	0.162	1.74
G5	1.23^{12}	15^{3}	0.036	1.28	1.02	0.327	14.8	1.48^{12}	15^{3}	0.034	1.52	1.15	0.372	20.7	0.434^{12}	17^{5}	0.023	0.443	0.304	0.114	1.78
G6	0.32^{2}	12^{10}	0.014	0.409	0.418	0.089	14.0	0.35^{1}	12^{11}	0.012	0.419	0.508	0.107	19.6	0.160^{3}	16^{13}	0.048	0.253	0.375	0.072	1.49
G7	0.29^{1}	16^{15}	0.029	0.563	0.674	0.139	13.3	0.61^{5}	20^{15}	0.039	0.963	0.959	0.227	18.7	0.356^{7}	8^{1}	0.128	0.643	0.772	0.178	1.92
G8	0.53^{4}	8^{4}	0.030	0.711	0.795	0.193	14.7	0.84^{6}	10^{4}	0.038	1.10	0.928	0.259	20.5	0.317^{6}	9^{3}	0.018	0.340	0.306	0.096	1.89
G9	1.05^{11}	24^{13}	0.087	1.26	1.50	0.363	13.7	1.24^{11}	25^{13}	0.094	1.61	1.74	0.425	19.3	0.437^{13}	19^{6}	0.047	0.469	0.495	0.145	1.75
G10	0.63^{6}	13^{7}	0.041	0.801	1.03	0.236	14.2	0.53^{2}	9^{7}	0.040	0.737	1.06	0.210	20.0	0.685^{15}	26^{11}	0.102	0.34	0.595	0.205	1.51
G11	1.30^{13}	15^{2}	0.036	1.34	1.01	0.335	14.9	1.49^{13}	15^{2}	0.041	1.53	0.999	0.360	20.8	0.539^{14}	28^{14}	0.154	0.597	0.705	0.184	1.44

Table 5 continued...

Table 5 continued...

G12	0.38^{3}	8^{5}	0.014	0.474	0.598	0.139	14.6	0.59^{4}	10^{6}	0.024	0.695	0.792	0.189	20.4	0.424^{10}	12^{2}	0.031	0.461	0.383	0.124	1.90
G13	3.47^{16}	32^{16}	0.167	3.50	2.07	0.796	12.8	3.87^{16}	32^{16}	0.159	3.92	2.40	0.889	18.2	0.130^{2}	14^{12}	0.061	0.516	0.359	0.087	1.50
G14	0.95^{9}	18^{9}	0.083	1.19	1.46	0.348	14.1	1.11^{8}	17^{9}	0.077	1.32	1.55	0.374	19.8	0.296^{5}	13^{8}	0.057	0.465	0.510	0.127	1.62
G15	1.56^{15}	29^{14}	0.153	1.85	1.96	0.512	13.7	2.00^{15}	28^{13}	0.143	2.37	2.10	0.585	19.4	0.033^{1}	11^{10}	0.099	0.333	0.412	0.057	1.51
G16	0.75^{8}	16^{8}	0.046	0.899	0.995	0.246	14.1	0.90^{7}	14^{7}	0.033	0.990	1.00	0.264	19.9	0.409^{8}	12^{4}	0.036	0.432	0.425	0.128	1.80

Cane diameter (cm)							
Gen	ASV	GSI	EV	MASV	SIPC	WAAS	Mean
G1	0.124^{3}	11^{8}	0.015	0.212	0.236	0.070	3.02
G2	0.213^{8}	21^{13}	0.045	0.350	0.470	0.148	2.88
G3	0.496^{14}	29^{15}	0.112	0.601	0.794	0.280	2.87
G4	0.111^{2}	5^{3}	0.020	0.196	0.265	0.081	3.16
G5	0.632^{16}	22^{6}	0.153	0.736	0.813	0.310	3.10
G6	0.187^{6}	18^{12}	0.025	0.246	0.353	0.117	2.95
G7	0.250^{9}	13^{4}	0.026	0.308	0.332	0.125	3.16
G8	0.253^{11}	13^{2}	0.037	0.347	0.456	0.154	3.22
G9	0.252^{10}	15^{5}	0.032	0.368	0.291	0.102	3.15
G10	0.089^{1}	8^{7}	0.008	0.131	0.192	0.062	3.04
G11	0.210^{7}	21^{14}	0.147	0.525	0.729	0.212	2.87
G12	0.147^{5}	6^{1}	0.008	0.162	0.193	0.073	3.34
G13	0.593^{15}	31^{15}	0.146	0.711	0.878	0.319	2.85
G14	0.348^{12}	22^{10}	0.046	0.395	0.474	0.177	2.99
G15	0.144^{4}	13^{9}	0.108	0.444	0.588	0.164	3.00
G16	0.410^{13}	24^{11}	0.073	0.535	0.552	0.205	2.99

instability and specific adaptability to certain conditions (Kumar *et al*., 2018). The ideal genotypes and environments are represented at the center of the biplot (Al-Naggar *et al*., 2020). To evaluate genotype stability and the extent of GEI effects, the AMMI biplot was created using PC1 and PC2 scores. Genotypes positioned far from the center exhibit large interaction effects, indicating sensitivity to environmental changes, while, those near the origin are less sensitive to such interactions (Sheelamary and Karthigeyan, 2021).

The clones G15, G12 and G13 for cane yield and for sucrose percentage G5, G16 and G16 are close to the origin and therefore, unaffected by environment (Fig. 1b and 1d). The PC1 and PC2 were highly significant, containing 58.7% and 24.8% of the TSS for cane yield, and 54.2% and 18.8% for sucrose percentage, respectively, in the total genotype × environment interaction (GEI) variation. These results suggested that the variability due to GEI was effectively captured, reflecting various environments genotypes responses (Elbasyoni, 2018). Analyzing GEI across different environments helped for selection, evaluation, and recommendation of crop varieties (Yadawad *et al*., 2023).

Conclusion

The eleven genotypes were under study along with five standards during 2021-22 at five locations. The all traits except single cane weight and cane diameter showed genotype, environment and G x E significant interaction. The combined ANOVA revealed significant genotype main effects, environment main effects and GEI main effects for all traits contributing cane yield and sugar yield except GEI main effects for single cane weight and environment main effects and GEI main effects for cane diameter were non-significant. The genotype main effects, environment main effects and GEI main effects were significant for cane yield, commercial cane sugar yield, number of millable canes and commercial cane sugar per cent in AMMI ANOVA. The genotypes G2, G5, G7for cane yield and G5, G3, G9 for sucrose per cent were found stable as compared to standards G10, G13, G14, G12 and G16. The environment 5 and environment 4 has the longest environmental vectors which bring high discriminating power for cane yield and for sucrose percent, environment 4 having the longest environmental vectors. The GGE biplot polygon indicates G11, G7, G16, G5, G15, G3 and G4 were vertex genotypes for cane yield. The genotypes G6, G10, G4, G13, G1 and G15 were vertex genotypes for sucrose percent. Genotypes G15, G12, G9, and G5 recorded the highest WAASBY values for cane yield. Likewise, genotypes G10, G5, G16, and G4 showed the highest WAASBY scores for sucrose percentage. The PC1 and PC2 were highly significant, showing 58.7% and 24.8% of the total sum of squares for cane yield, and 54.2% and 18.8% for sucrose percentage, respectively, in the total genotype × environment interaction (GEI) variation.

Acknowledgement

Authors are thankful to Director General, Vasantdada Sugar Institute, Pune for his constant encouragement.

Author's contributions

Conceptualization of research (JMR, KVS, SDT); Analysis of data (ABG, TLP), Interpretation of data (ABG), Preparation of manuscript (ABG, JMR, ADK)

References

Abate, M. (2020). Genotype by environment interaction and yield stability analysis of open pollinated maize varieties using AMMI model in Afar Regional State, Ethiopia. *J. Plant Breed. Crop Sci.,* **12(1)**, 8-15.

Adilakshmi, D., Padmavathi P.V., Rao D.P. and Rao C.M. (2025). Selection of high-yielding and stable sugarcane (*Saccharum* spp. hybrids) clones across diverse seasons using WAASB and MGIDI methods. *EJPB*, **16(1)**, 79-86.

Ajay, B.C., Bera S.K. and Singh A.L. (2020). Evaluation of genotype × environment interaction and yield stability analysis in peanut under phosphorus stress condition using stability parameters of AMMI model. *Agric Res*., **9**, 477–486.

Al-Naggar, A.M.M., Shafik M.M. and Musa R.Y.M. (2020). AMMI and GGE biplot analyses for yield stability of nineteen maize genotypes under different nitrogen and irrigation levels. *Plant Archives*, **20(2)**, 4431–4443.

Anuradha, N., Patro T.S.S.K. and Singamsetti A.Y. (2022). Comparative study of AMMI and BLUP based simultaneous selection for grain yield and stability of finger millet [*Eleusine coracana* (L.) Gaertn.] genotypes. *Front Plant Sci.,* **12**, 786839.

Behera, P.P., Singode A., Bhat B.V. and Sarma R.N. (2024). Selection of high-yielding stable forage sorghum genotypes using WAASB and MGIDI methods. *Indian J. Genet. Plant Breed*., **84(2)**, 224-231.

Crossa, J., Cornrlius P.L. and Yan W. (2002). Biplots of linear-bilinear models for studying cross over genotype x environment interaction. *Crop Sci*., **42**, 619-633.

Crossa, J. and Cornelius P.L. (1997). Sites regression and shifted multiplicative model clustering of cultivar trial sites under heterogeneity of errors variances. *Crop Science*, **37**, 406-415.

Doehlert, D.C., McMullen M.S. and Hammond J.J. (2001). Genotypic and environmental effects on grain yield and quality of oat grown in North Dakota. *Crop Sci*., **41**, 1066–1072.

Durai, A.A., Amaresh, Arun Kumar R. and Hemaprabha G. (2024). Elucidating the G × E Interaction using AMMI, AMMI Stability Parameters and GGE for Cane Yield and Quality in Sugarcane. *Tropical Plant Biology*, **10**.

Elbasyoni, I.S. (2018). Performance and stability of commercial wheat cultivars under terminal heat stress. *Agronomy*, **8**-37.

Farshadfar, E., Zali H. and Mohammadi R. (2011). Evaluation of phenotypic stability in chickpea genotypes using GGE biplot. *Annals of Biological Research*, **2(6)**, 282-292.

Gauch, H.G. and Zobel R.W. (1997). Identifying mega-environment and targeting genotypes *Crop. Sci.,* **37**, 311-326.

Gauch, H.J. (1992). Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Amsterdam: *Elsevier Science Publishers*.

Jackson, P.A. (2005). Breeding for improved sugar content in sugarcane. *Field Crop Res*., **92**, 277–290.

Kang, M.S. (1993). Simultaneous selection for yield and stability in crop performance trials: consequences for growers. *Agron. J.*, **85**, 754-757.

Koundinya, A.V.V., Ajeesh B.R., Hegde V., Sheela M.N., Mohan C. and Asha K.I. (2021). Genetic parameters stability and selection of cassava genotypes between rainy and water stress conditions using AMMI, WAAS, BLUP and MTSI. *Sci. Hortic.*, **281**(10)1016: 109949

Kumar, S., Hasan S.S., Singh P.K., Pandey D.K. and Singh J. (2018). Interpreting the effects of genotype x environment interaction on cane and sugar yields in sugarcane based on the AMMI model. *Indian J. Genetics*, **3**, 225-231.

Mattos, P.H.C., Oliveira R.A.J., Filho C.B., Daros E. and Veríssimo M.A.A. (2013). Evaluation of sugarcane genotypes and production environments in Parana by GGE biplot and AMMI analysis. *Crop Breed. Appl. Biotechnol*., **13**, 83–90.

Meena, M.R., Karuppiayan R. and Ram B. (2017). Genotypes x environment interactions and stability analysis of sugarcane clones (*Saccharum* spp.) by AMMI model in sub-tropical regions of India. *Indian J. Genetic Plant Breed*., **77(04)**, 540–546.

Olivoto, T., Lucio A.D., da Silva J.A., Sari B.G. and Diel M.I. (2019). Mean performance and stability in multi-environment trials II: selection based on multiple traits. *Agron. J*., **111**, 29-61-2969 (10): 2134

Olivoto, T. and Lucio A.D.C. (2020). Metan : An R package for multi environment trial analysis. *Method Ecol Evol*., **11(6)**, 783–789.

Purchase, J.L., Hatting H. and Vandenventer C.S. (2000). G x E interaction of wheat: stability analysis ofyield performance. *South Africa J. Plant Sci.,* **17**, 101-107.

Queme, J.l., Orozco H., Ovalle W. and Melgar M. (2005). Analysis of genotypes by environment interaction for sugarcane based on the AMMI model. *Sugar Cane Int*., **23**, 21-24.

Regis, J.A.V.B., Andrade J.A.C., Santos A., Moraes A., Trindade R.W.R., Henriques J. and Oliveira L.C. (2018). Adaptability and phenotypic stability of sugarcane clones. *Pesquisa Agropecuária Brasileira*, **53**, 42–52.

Sheelamary, S. and Karthigeyan S. (2021). Evaluation of promising commercial sugarcane genotypes for stability by AMMI analysis. *EJPB*, **12(2)**, 371-378.

Sousa, T.D.J.F.D., Rocha M.D.M., Damasceno-Silva K.J., Bertini C.H.C.D.M., Silva L.M.D., Sousa R.R.D. and Sousa J.L.M. (2019). Simultaneous selection for yield, adaptability and genotypic stability in immature cowpea using REML/BLUP. *Pesqui. Agropecu. Bras*. **54**.

Tahir, M., Rahman H., Amjad A., Anwar S. and Khalid M. (2013). Assessment of genotype x environment interaction and stability of promising sugarcane genotypes for different agronomic characters in Peshawar valley. *Am. J. Exp. Agric.*, **3(1)**, 142-151.

Upreti, P. and Singh A. (2017). An Economic Analysis of Sugarcane Cultivation and its Productivity in Major Sugar Producing States of Uttar Pradesh and Maharashtra. *Eco Affair,* **62(4)**, 711–718.

Van Eeuwijk, F.A., Bustos-Korts D.V. and Malosetti M. (2016). What should students in plant breeding know about the statistical aspects of genotype x Environment interactions. *Crop Sci*., **56**, 2119–2140.

Wolde, L., Keno T., Tadesse B., Bogale G. and Abebe B. (2018). Mega environment targeting of maize varieties using AMMI and GGE biplot analysis in Ethiopia. *Eth. J. Agric. Sci*., **28**, 65-84.

Yadawad, A., Patil S.B., Kogawad B.Y., Kadlag A.D. and Hemaprabha G. (2023). Multi environmental evaluation for selection of stable and high yielding sugarcane clones based on AMMI and GGE biplot models. *Indian J. Genet. Plant Breed*., **83(3)**, 389-397.

Yan, W., Hunt L.A. and Sheng Q. (2000). Cultivar evaluation and mega environment investigation based on the GGE biplot. *Crop Sci*., **40(3)**, 597–605.

Yan, W. and Kang M.S. (2003). GGE Biplot Analysis: a Graphical Tool for Breeders, Geneticists and Agronomists. Boca Raton, FL: CRC Press.

Yue, H., Wei J., Xie J., Chen S., Peng H., Cao H., Bu J. and Jiang X. (2022). A study on genotype by environment interaction analysis for agronomic traits of maize genotypes across Huang-Huai-Hai region in China. *Phyton*, **91(1)**, 57.