



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(7): 673-677
Received: 19-04-2026
Accepted: 23-05-2026

S Sharma
CCS Haryana Agricultural
University, Regional Research
Station, Uchani, Karnal, Haryana,
India

V Gupta
CCS Haryana Agricultural
University, Regional Research
Station, Uchani, Karnal, Haryana,
India

R Kumar
CCS Haryana Agricultural
University, Regional Research
Station, Uchani, Karnal, Haryana,
India

H Singh
CCS Haryana Agricultural
University, Regional Research
Station, Uchani, Karnal, Haryana,
India

Hitesh
ICAR- Indian Institute of Wheat
and Barley Research, Karnal,
Haryana, India

Corresponding Author:
V Gupta
CCS Haryana Agricultural
University, Regional Research
Station, Uchani, Karnal, Haryana,
India

Stability analysis of sugarcane genotypes for cane yield using AMMI in sub-tropical multi-environment trials

S Sharma, V Gupta, R Kumar, H Singh and Hitesh

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7i.5994>

Abstract

Aim: To identify stable, high-yielding sugarcane genotypes across multiple sub-tropical environments by genotype $\times$ environment interaction study using AMMI analysis.

Methodology: In 2021-22 and 2022-23 at three locations in India, the cane yield of nine sugarcane clones and three standard checks was assessed across nine environments. The AMMI model was used to analyze genotype, environment and their interaction effects on cane yield, including principal component analysis to assess stability.

Results: Genotype, environment, and their interaction significantly ($p < 0.001$) affected cane yield, contributing 21.32%, 52.41%, and 26.27% of the total variation, respectively. The first two AMMI principal components explained 71.0% of the genotype $\times$ environment interaction. AMMI1 biplot identified CoS 17236 and Co 05011 as high-yielding and relatively stable genotypes. AMMI2 biplot highlighted CoPb 17215, CoPant 17223, and CoPant 97222 as the most stable across environments.

Interpretation: Yield potential and stability do not always coincide; both must be considered in breeding. CoS 17236 and Co 05011 are recommended for high-yielding targeted environments, while CoPb 17215, CoPant 17223, and CoPant 97222 are suitable for broad adaptation in sub-tropical India.

Keywords: AMMI, Cane yield, Stability, Sugarcane

Introduction

India's tropical and sub-tropical regions are important growing regions for sugarcane (*Saccharum officinarum* L.). With a total production of 405.4 million tons, the crop covers more than 5.64 million hectares in the country (Directorate of Economics & Statistics, 2024) ^[5]. In fact, after Brazil, India is the world's second-largest producer of sugar. A wide range of goods i.e. sugar and ethanol, are made from the crop. Furthermore, in an energy-poor nation like India, the bagasse residue left over after the juice is extracted in the sugar mill has become crucial for producing electricity (Quereshi *et al.* 2022) ^[20]. The high demand of sugarcane products has prompted policy makers to promote the expansion of this crop (Solomon and Swapna 2022) ^[25]. The variation in the environmental condition in sub-tropical India is wide during the sugarcane growth and maturity period with temperature ranging from 0-48 °C, photoperiod from 4-8 hr and relative humidity from 8-100% (Shukla *et al.* 2017) ^[24]. Hence, the sugarcane yield is generally low in sub-tropical part of India (Guo *et al.* 2021) ^[8]. However, sugarcane is primarily a tropical crop capable of producing high cane yield under ideal conditions. But in sub-tropics it is cultivated in erratic environments leading to varied varietal performance over different locations. The search for sugarcane genotypes with high cane and sugar yield which are also adapted in most varied environments is one of the most important objectives of sugarcane breeders.

The development of stable varieties requires a broad genetic base within the populations under investigation. Such genetic diversity enables the identification of genotypes that demonstrate stable performance across a range of environmental conditions. This can be achieved by understanding the interaction between genotype and environment (Appunu *et al.* 2024) ^[2]. Genotype $\times$ Environment Interaction (GEI) refers to the variation in genotypic performance across different environmental conditions and plays a critical role in how genotypes perform under varying environments (Pour-Aboughadareh *et al.* 2022) ^[19]. The efficiency of selection and accuracy of varietal recommendation is reduced by $G \times E$ interaction (Mehareb *et al.* 2022) ^[15].

Due to the interaction between genotype and environment ($G \times E$), it is essential to analyze this interaction prior to the introduction of new high-yielding and stable genotypes across diverse environments. Various statistical methods, categorized into two main groups: parametric and non-parametric approaches have been developed to uncover the $G \times E$ interaction patterns. Parametric methods are further divided into two groups: univariate and multivariate. Univariate methods include stability factor (Shojaei *et al.* 2022) ^[23] and regression-based approaches (Hashim *et al.* 2021) ^[10]. Multivariate methods include the AMMI (Additive Main Effects and Multiplicative Interaction) model (Gupta *et al.* 2022) ^[9] and Genotypic Main Effect plus Genotype by environment (GGE) biplot analysis (Mullualem *et al.* 2024) ^[17]. Additive main effects and multiplicative interaction (AMMI) analysis has been proved as a useful analytic approach for linear and non-linear response of genotypes over the environmental conditions (Achenef 2022) ^[1], which combines ANOVA (with additive parameters) and principal component analysis (with multiplicative parameters) into a single analysis (Gupta *et al.* 2022) ^[9] and interprets multi-environment data structure in breeding programs (Crossa *et al.* 2022) ^[4]. It is also an effective tool to diagnose genotype environment interaction patterns graphically (Mehareb *et al.* 2022) ^[15]. So, for the breeders to develop a variety suitable for different environments, the analysis of the stability of genotypes is the most important tool. In this study, nine sugarcane clones along with 3 checks were evaluated for cane yield across different environments to identify stable genotypes for general and specific adaptation in different sowing conditions and to estimate genotype $\times$ environment interaction and stability parameters.

Materials and Methods

A set of nine advanced genotypes of sugarcane (mid-late group) developed by different research centers of North-West Zone along with three standard checks were evaluated for cane yield under the All India Coordinated Research Project (AICRP) on sugarcane for three crops (First plant crop, second plant crop and ratoon crop) during 2021-22 and 2022-23 at three locations, viz. CCSHAU, RRS, Uchani, Karnal, PAU, Regional Research Station, Gurdaspur and Kapurthala. The experimental material consisted of Co 17018, Colk 17204, CoPb 17215, CoPant 17223, CoS 17234, CoS 17235, CoS 17236, CoH 17261, CoH 17262 along with three cultivars of sugarcane CoS 767, CoPant 97222 and Co 05011 as checks (Table 1). The experiment at three different locations over two crop seasons with three crops constituted nine environments (Table 2). The experiments were laid out in randomized block design (RBD) with three replications at each location. Plots were of eight rows with 6.0m length having 0.90 m spacing between rows. Three budded sets were used for planting with a seed rate of 12 buds/m² at all the three locations. A combined analysis of variance across test environment and an AMMI analysis (Table 3) were carried out using the programme R software.

The AMMI model equation is
$$Y_{ij} = \mu + g_i + e_j + \sum \lambda_n \alpha_{in} \gamma_{jn} + \theta_{ij}$$

Where,
 Y_{ij} = mean yield of i^{th} genotype in the j^{th} environment
 μ = general mean
 g_i = i^{th} genotypic effect
 e_j = j^{th} location effect
 λ_n = eigen value of the Principal Component Axis n
 $\alpha_{in} \gamma_{jn}$ = i^{th} genotype, j^{th} environment Principle component analysis

(PCA) scores for the PCA axis n
 θ_{ij} = residual
n = number of PCA axes retained in the model.

Environment-wise analysis and pooled analysis of variance were conducted as per normal procedure. If genotypes, environments and $G \times E$ interaction are significant, the analysis may proceed further for AMMI analysis.

Table 1: List of 12 sugarcane genotypes used in the present study

G1	G2	G3	G4	G5	G6
Co 17018	Colk 17204	CoPb 17215	CoPant 17223	CoS 17234	CoS 17235
G7	G8	G9	G10	G11	G12
CoS 17236	CoH 17261	CoH 17262	CoS 767	CoPant 97222	Co 05011

Table 2: Codes used for production environments during 2019–2020 and 2020–2021

E1	E2	E3
1 st plant crop, Uchani	1 st plant crop, Gurdaspur	1 st plant crop, Kapurthala
E4	E5	E6
2 nd plant crop, Uchani	2 nd plant crop, Gurdaspur	2 nd plant crop, Kapurthala
E7	E8	E9
Ratoon crop, Uchani	Ratoon crop, Gurdaspur	Ratoon crop, Kapurthala

Table 3: Data collected from separate trials were analyzed as combined over the environments using the following ANOVA outline

Source	Df	MSS	F
Total	(ger-1)		
Treatment	(ge-1)		
Genotypes	(g-1)	MS1	MS1/MS3
Environment	(e-1)	MS2	MS2/MS3
Genotype $\times$ Environment	(g-1)(e-1)	MS3	MS3/Mse
IPCA1	(G+E-1-2n)	MS4	MS4/Mse
IPCA2	(G+E-1-2n)		
Residual			
Blocks	(r-1)		
Error	(r-1)(ge-1)	Mse	

Results and Discussion
AMMI Biplot Analysis

To increase the reliability of multi-environmental trial analysis, AMMI model was used to study the $G \times E$ interaction as AMMI model explains the genotype–environment interaction (Momotaz *et al.* 2021) ^[16], which is used for reliable yield estimates (Yadawad *et al.* 2023) ^[28] and forms a robust base for enhancing the application of other analytical models (Oghan *et al.* 2022) ^[18]. The analysis of variance from the AMMI model revealed that cane yield was significantly ($p < 0.001$) affected by environment, genotype and genotype–environment interaction, which accounted for 53.41%, 26.80% and 19.78% of the total variation, respectively. Furthermore, the analysis showed that two principal components with significant differences collectively captured 71.00% of total genotype–environment (GEI). The first principal component explained 42.95% of the GEI while the second accounted for 28.04% of the genotype–environment interaction (Table 4). The present results clearly demonstrated significant contributions of environment, genotype and their interaction towards cane yield variation, in agreement with earlier findings (Mehareb *et al.* 2022, Sheelamary & Karthigeyan 2021, Durai *et al.* 2025) ^[15, 22, 6]. AMMI revealed that a major part of the variation

in yield is explained by environment, which indicates that the environments were diverse. The results are line with the findings of Vinu *et al.* 2025 [27] and Kumar *et al.* 2023 [12].

Table 4: Pooled analysis of variance for cane yield of 12 sugarcane genotypes across different environments using AMMI model

	DF	SS	MS	(%)	F
ENV	8	54243.6	6780.45	52.40831	274.90
GEN	11	22062.3	2005.66	21.31755	88.93
ENV*GEN	88	27196.3	309.05	26.27413	13.70
PC1	18	11682.2	649.01	42.95475	28.78
PC2	16	7626.1	476.63	28.04227	21.13
PC3	14	4371.7	312.26	16.07398	13.85
Residuals	198	4465.6	22.55		NA
Total	411	135608.2	329.95		

The AMMI 1 Model

The AMMI biplot has the main effect as cane yield per plot in the abscissa and the IPCA1 as the ordinate where the genotypes or environments that lie on the same vertical line have the same yield, and those that lie on the same horizontal line have the same interaction pattern. Genotypes and environments exhibiting IPCA1 scores near zero were associated with minimal interaction effects and are therefore regarded as stable across environments (Elayaraja *et al.* 2022) [7]. In the AMMI 1 biplot, the sugarcane genotypes G7 and G12 are relatively stable and high yielding genotypes indicating their suitability as elite and broadly adapted cultivars. In contrast, G1 and G3 also exhibit stability across environments but are associated with lower yield performance, suggesting they are broadly adapted but less productive lines (Figure 1). Similar to this research, Durai *et al.* 2025 [6] also identified stable and having high cane yield genotypes Co 17001, CoC 13339 and Co 86032, inferring little interaction with the environment. The sugarcane genotypes G2, G4, G5, G6, G8 and G11 are relatively unstable in yield because these lines are far from the origin and can be specifically adapted to particular environment. Especially, genotypes CoPant 17223 and CoS 17235 were likely to perform better in the second plant crop at Uchani, whereas the genotype CoH 17262 was identified as specially adapted in ratoon crop at Gurdaspur. Ratoon crop at Uchani location was the most responsive environment for genotype CoH 17261 (Figure 1). Additionally, Meena *et al.* 2017 [14] identified clones such as Co 98014, Co 07025 and Co 07023 had larger interaction effects because they fall almost on same perpendicular line and away from IPCA-1 axis origin. Especially, the plant crop of Co 07023 and Co 07025 have appeared to have positive interactions with autumn (E1) and spring (E2) seasons and resulted in high cane yield in comparison to their ratoon crop yield in E3 and E4.

The AMMI2 Model

The AMMI2 biplot (Fig. 2), which plots IPCA1 against IPCA2, provided a more refined understanding of G × E interaction patterns. In the present study, genotypes CoPant 17223 (G4), CoPant 97222 (G10) and CoPb 17215 (G3) were located nearest to the origin, indicating the least interaction across both principal components and thus the highest overall stability. In contrast, CoS 17236 (G7) and Co 05011 (G12), though classified as stable in AMMI1, were positioned farther away in AMMI2, reflecting specific adaptation to certain environments. The contrasting outputs of AMMI1 and AMMI2 suggested that CoS 17236 and Co 05011 may be targeted for region-specific release in favourable zones, whereas CoPb 17215, CoPant 17223 and CoPant 97222 can be sown in heterogeneous subtropical regions

due to broader adaptability. These findings align with Momotaz *et al.* (2021) [16], Vinu *et al.* (2025) [27] and Solomon & Swapna (2022) [25] and highlight the importance of using multiple stability measures for reliable selection. According to the AMMI2 biplot, the best-adapted genotype with respect to 1st plant crop in Uchani was CoH 17261, whereas the genotype CoS 17235 was highly adapted to 2nd plant crop in Uchani, genotype CoS 17236 grouped in site E2, Co 05011 grouped into site E2 and E5. Similarly Kumar *et al.* 2018 [11] concluded that the genotypes Co 05018 and CoSe 092423 had shown the positive response for cane yield with E8 and E9, CoSe 05452 with E1 and E3. Similar results were further confirmed by Magalhães *et al.* 2018 [13] while analyzing the stability of 14 RB sugarcane genotypes by AMMI in the in the state of Pernambuco. Therefore, the above-mentioned genotypes were found most stable for cane yield and can be incorporated as breeding stocks in any future breeding programs aiming to produce high yielding cultivars of sugarcane.

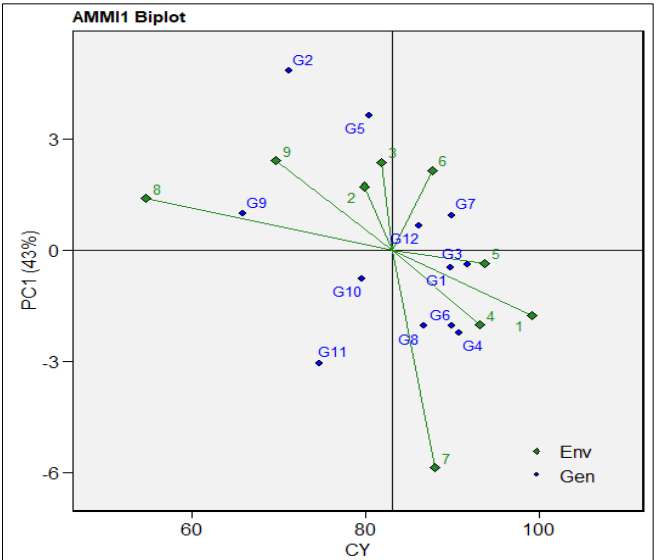


Fig 1: AMMI (Additive Main Effects and Multiplicative Interaction) 1 biplot for cane yield of 12 sugarcane genotypes and 9 environments using genotypic and Environmental scores

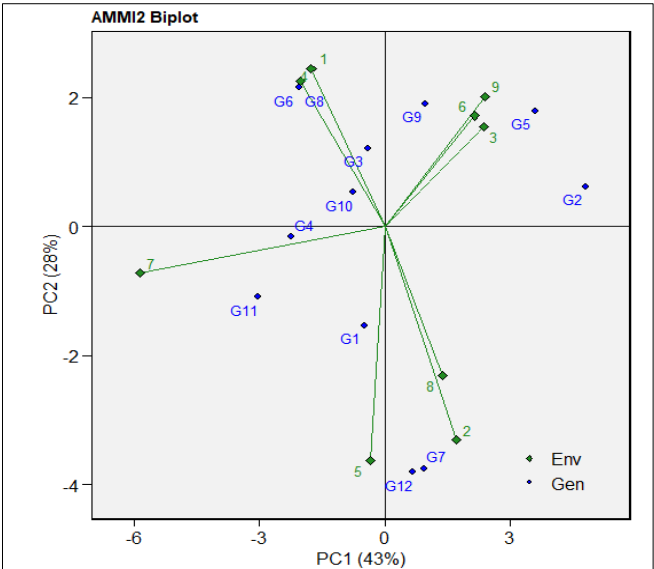
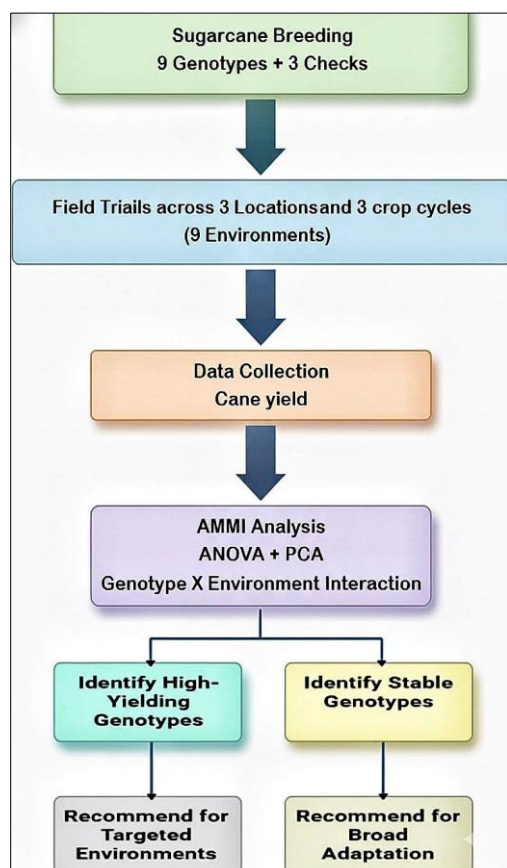


Fig 2: AMMI 2 biplot for cane yield showing interaction of IPCA (Interaction Principal Component Axes) 2 against IPCA 1 scores of 12 sugarcane genotypes in 9 environments.



Acknowledgments: The authors would like to express sincere thanks to CCSHAU, Hisar, Haryana and PAU, Ludhiana for providing the facilities to accomplish this research work.

Author contributions: SS: Conducted the study and collection of data; VG: data analysis and manuscript preparation; RK: Planning and guidance; RB: Helped in preparing manuscript; HS: data curation; NK: Editing of manuscript and Hitesh: Helped in preparing manuscript

Funding: No external funding was received in conducting this research.

Research content: The research content is original and has not been published or submitted elsewhere.

Ethical approval: Ethical approval was not required as the study did not involve human participants and experimental animals.

Conflict of Interest: The authors declare no conflict of interest.

Data from other sources: Not applicable

Consent to publish: All authors have read and approved the manuscript and consent to its publication in the Journal of Environmental Biology

References

1. Achenef G. Advancement of analytical models quantifying $G \times E$ interactions and stability analysis in multi-environment trial. *Int J Res Agric Sci.* 2022;9(4):103-120.
2. Appunu C, Hemaprabha G, Sreenivasa V, Durai AA, Mohanraj K, Elayaraja K, *et al.* Evaluation of sugarcane genotypes (*Saccharum* sp. hybrid) for multi-trait stability analysis across diverse environments. *Ind Crops Prod.* 2024;219:118993.
3. Barati A, Taherian M, Saeidnia F, Nikkhah HR, Arazmjoo E, Mahlooji M, *et al.* Analysis of genotype by environment interaction in barley across various locations in Iran using the AMMI model. *Iran J Genet Plant Breed.* 2024;13(1):11-19.
4. Crossa J, Montesinos-Lopez OA, Pérez-Rodríguez P, Costa-Neto G, Fritsche-Neto R, Ortiz R, *et al.* Genome and environment-based prediction models and methods of complex traits incorporating genotype $\times$ environment interaction. In: Ahmadi N, Bartholomé J, editors. *Genomic prediction of complex traits: Methods and protocols.* New York (NY): Springer; 2022. p. 245-283.
5. Directorate of Economics and Statistics, Department of Agriculture and Cooperation. 3rd advance estimate of production of foodgrains 2023-24. New Delhi: Government of India; 2024.
6. Durai AA, Kumar RA, Hemaprabha G. Elucidating the $G \times E$ interaction using AMMI, AMMI stability parameters and GGE for cane yield and quality in sugarcane. *Trop Plant Biol.* 2025;18(1):3.
7. Elayaraja K, Govindaraj P, Mahadevwamy HK, Appunu C, Hemaprabha G, Rajesh V, *et al.* Stability analysis for identification of stable genotypes of sugarcane (*Saccharum* spp.) through AMMI model. *Indian J Genet Plant Breed.* 2022;82(4):616-622.
8. Guo H, Huang Z, Tan M, Ruan H, Awe GO, Are KS, *et al.* Crop resilience to climate change: A study of spatio-temporal variability of sugarcane yield in a subtropical region, China. *Smart Agric Technol.* 2021;1:100014.
9. Gupta V, Kumar M, Singh V, Chaudhary L, Yashveer S, Sheoran R, *et al.* Genotype by environment interaction analysis for grain yield of wheat (*Triticum aestivum* L.) genotypes. *Agriculture.* 2022;12(7):1002.
10. Hashim N, Rafii MY, Oladosu Y, Ismail MR, Ramli A, Arolu F, *et al.* Integrating multivariate and univariate statistical models to investigate genotype-environment interaction of advanced fragrant rice genotypes under rainfed condition. *Sustainability.* 2021;13(8):4555.
11. Kumar D, Kumar S, Meena LK, Meena LR, Singh SP. Stability analysis of sugarcane (*Saccharum* spp.) genotypes for metric and quality traits by AMMI model. *Indian J Agric Sci.* 2018;88(4):657-664.
12. Kumar R, Dhansu P, Kulshreshtha N, Meena MR, Kumaraswamy MH, Appunu C, *et al.* Identification of salinity-tolerant stable sugarcane cultivars using AMMI, GGE and some other stability parameters under multi-environments of salinity stress. *Sustainability.* 2023;15(2):1119.
13. Magalhães TA, Silva GC, Rocha PR, Silva JD, Mendonça Júnior AD, Oliveira FD. Adaptability and phenotypic stability of the sugarcane RB genotype by the AMMI method. *J Agric Sci.* 2018;10:484-492.
14. Meena MR, Karuppiayan R, Ram B, Kumar R, Kulshreshtha N. Genotype $\times$ environment interactions and stability analysis of sugarcane clones (*Saccharum* spp.) by AMMI model in sub-tropical regions of India. *Indian J Genet Plant Breed.* 2017;77(4):540-546.
15. Mehareb EM, Osman MAM, Attia AE, Bekheet MA, Abo Elenen FF. Stability assessment for selection of elite sugarcane clones across multi-environments based on AMMI and GGE-biplot models. *Euphytica.* 2022;218(7):95.
16. Momotaz A, Davidson RW, Zhao D, McCord PH, Sandhu HS, Baltazar M, *et al.* Genotype-by-environment interaction

- analysis across three crop cycles in sugarcane. *J Crop Improv.* 2021;35(2):276-290.
17. Mullualem D, Tsega A, Mengie T, Fentie D, Kassa Z, Fassil A, *et al.* Genotype-by-environment interaction and stability analysis of grain yield of bread wheat (*Triticum aestivum* L.) genotypes using AMMI and GGE biplot analyses. *Heliyon.* 2024;10(12):e16701.
 18. Oghan HA, Bakhshi B, Rameeh V, Faraji A, Askari A, Fanaei HR. Comparison of AMMI, parametric and non-parametric models in identifying high-yielding and stable oilseed rape genotypes. *Turk J Field Crops.* 2022;27(2):224-234.
 19. Pour-Aboughadareh A, Khalili M, Pocza P, Olivoto T. Stability indices for deciphering the genotype-by-environment interaction (GEI) effect: An applicable review for use in plant breeding programs. *Plants.* 2022;11(3):414.
 20. Quereshe S, Naiya TK, Mandal A, Dutta S. Residual sugarcane bagasse conversion in India: Current status, technologies, and policies. *Biomass Convers Biorefin.* 2022;12(9):3687-3709.
 21. Sanghera GS. Sugarcane disorders associated with temperature extremes and mitigation strategies. *East Afr Sch J Agric Life Sci.* 2020;3:101-114.
 22. Sheelamary S, Karthigeyan S. Evaluation of promising commercial sugarcane genotypes for stability by AMMI analysis. *Electron J Plant Breed.* 2021;12(2):371-378.
 23. Shojaei SH, Mostafavi K, Lak A, Omrani A, Omrani S, Mousavi SMN, *et al.* Evaluation of stability in maize hybrids using univariate parametric methods. *J Crop Sci Biotechnol.* 2021;24:1-8.
 24. Shukla SK, Sharma L, Awasthi SK, Pathak AD. Sugarcane in India. In: Package of practices for different agro-climatic zones. Lucknow: All India Coordinated Research Project on Sugarcane, Indian Institute of Sugarcane Research; 2017. p. 1-64.
 25. Solomon S, Swapna M. Indian sugar industry: Towards self-reliance for sustainability. *Sugar Tech.* 2022;24(3):630-650.
 26. Srivastava AK, Rai MK. Sugarcane production: Impact of climate change and its mitigation. *Biodiversitas J Biol Divers.* 2012;13(4):214-221.
 27. Vinu V, Alarmelu S, Elayaraja K, Appunu C, Hemaprabha G, Parthiban S, *et al.* Multi-environment analysis of yield and quality traits in sugarcane (*Saccharum* sp.) through AMMI and GGE biplot analysis. *Sugar Tech.* 2025;27(2):540-558.
 28. Yadawad A, Patil SB, Kongawad BY, Kadlag AD, Hemaprabha G. Multi-environmental evaluation for selection of stable and high-yielding sugarcane (*Saccharum officinarum* L.) clones based on AMMI and GGE biplot models. *Indian J Genet Plant Breed.* 2023;83(3):389-397.