Indian J. Genet. Plant Breed., (2024); 84(2): 266-272
https://doi.org/10.31742/ISGPB.84.2.15
ISSN: 0975-6906
www.isgpb.org

RESEARCH ARTICLE

Drought resilience evaluation of sugarcane (*Saccharum* spp.) hybrids in Indian tropical and sub-tropical climates

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Abstract

Drought is an important limiting factor for cane production globally, imposing significant constraints on cultivation. In this study, we have evaluated eleven sugarcane hybrids with improved germplasm bases of *S. officinarum, and S.robustum* under both drought and normal conditions at tropical and sub-tropical region. Combined analysis of variance revealed highly significant effects ($p < 0.05$) of environments, genotypes and G × E interaction for all studied traits. Severe drought stress was observed in both locations, with a reduction in cane yield and its related traits. GGE analysis under stress conditions indicated that clone 14–90 (G8), a high yielder, performed well in all eight environments. Seven stable clones, namely, 14–161 (G1), 14–111 (G5), 14–90 (G8), 14–58 (G6), 14–34 (G9), 14–124 (G11) and 14–83 (G3) exhibiting adaptive yield-enhancing traits under drought were identified along with displaying resistance to red rot. Selected clones, namely, 14–161, 14–131, 14–90 and 14–144, performed better for yield in sub-tropics, while clones 14-–161, 14–111 and 14–90 performed better in the tropics. Clone 14–90 showcased, the strong performance across all the environments and locations, emerging as the leading genotype and suggested for utilization in pre-breeding programs for both tropical and sub-tropical regions.

Keywords: Sugarcane, clones, drought, yield, genetic stocks

Introduction

Sugarcane (*Saccharum officinarum* L.) serves as a vital source of both food and bioenergy crops and plays a significant role in the global economy. Drought is an important and increasingly impactful stressor, significantly hampering sugarcane production worldwide. Its frequency is expected to rise due to the vagaries of climate change. Drought tolerance in sugarcane is a polygenic trait, presenting challenges in selection due to strong genotype x environment interactions associated. Sugarcane exhibits high sensitivity to water deficit conditions, particularly during the tillering and grand growth stage, thus limiting plant growth, development and yield worldwide (dos Santos et al. 2019; Hoang et al. 2019). Drought results in either reduced or complete loss of yield because of water and accounts for over 50% of yield losses (Hemaprabha et al. 2004), and its impact is expected to escalate as temperatures increase due to climate change.

The primary objective of the plant breeding program is to enhance the stability of crop yield across locations and/or years. Yield performances of genotypes may vary significantly across environments and hence, genotype x environment interaction and stability are essential in breeding programs. Identifying drought-tolerant varieties remains a major challenge. It can be improved by selecting appropriate parameters such as stalk number, height, diameter, and weight, as well as cane yield under water stress regimes. Selecting genotypes with high yield and associated traits under water stress and careful selection of appropriate physiological traits and fast/non-destructive methods for quantifying them will be very important in improving drought tolerance. The current study aims to investigate

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How to cite this article: Meena M.R., Alarmelu S., Vasantha S., Sheelamary S., Anusheela V., Kumar R.A., Kumar R., Chhabra M.L., Mutharasu S. and Karthick M. 2024. Drought resilience evaluation of sugarcane (*Saccharum* spp.) hybrids in Indian tropical and sub-tropical climates. Indian J. Genet. Plant Breed., **84**(2): 266-272.

Source of support: ICAR-SBI, Coimbatore and ICAR-SBI RC, Karnal

Conflict of interest: None.

Received: Dec. 2023 **Revised:** April 2023 **Accepted:** May 2024

the effects of early drought stress on agronomic traits of 11 hybrids under both tropical and sub-tropical conditions and to identify drought-tolerant clones for utilization in breeding programs.

Materials and methods

Plant material and drought treatment

The experiment consists of eleven hybrids (referred as genotypes G1-G11), developed through a base broadening programme at ICAR-Sugarcane Breeding Institute, Coimbatore (tropical region) along with standards (G12-G14) *viz*., Co 85019, Co 10026, CoM 0265 from tropical region and Co 0238, Co 05011 and CoJ 64 from sub-tropical region (SBI Regional Centre, Karnal), were evaluated under drought and normal irrigated conditions during 2021 and 2022 crop seasons (Table 1). Two treatments, normal and drought, represent the main plot, whereas the sub-plot is comprised of 11 clones and six checks. Eight environments were categorized based on location and season, including drought and irrigated conditions as; Irrigated conditions in Karnal location for seasons 1 and 2 (E1, E2), irrigated conditions in Coimbatore location for seasons 1 and 2 (E3, E4), drought condition in Karnal location for seasons 1 and 2 (E5, E6), and drought condition in Coimbatore location for seasons 1 and 2 (E7, E8).

Experiments were raised in a randomized complete block design, replicated twice in each plot of 2 rows x 6 meters x 0.9 cm. Moisture stress was applied at 60 to 150 days crop stage by withholding irrigation in the treatment plot.

Red rot evaluation and observations recorded on cane yield parameters

A comprehensive screening process (plug, nodal) was conducted to evaluate red rot reaction against the prevalent and highly virulent pathotypes of red rot (*Colletotrichum falcatum)*, specifically the CF08 and CF13 at Karnal and CF06 at Coimbatore (Viswanathan et al. 2021). The screening was performed under field conditions at a seven-month stage, with inoculation in September. Cane yield parameters *viz.,* cane height (CHT), cane diameter (CDIA), single cane weight (SCW), number of internodes (CINN) and number of millable canes (NMC) were recorded on three randomly selected canes at 12 months of age. One square meter area from the middle of each plot was harvested for yield (YLD) data.

Table 1. A list of genotypes (Pre-bred clones) used in the study

S. No	Clones	Genotype code	Parentage
1	14-161	G1	(Co 7201 x Pathri) x Co 0209
2	14-131	G2	98-210 x PIR001057
3	14-83	G3	PIO94-345 x PIR96-258
4	14-195A	G4	99-270 x Co 09014
5	14-111	G5	99-270 x Co 09014
6	14-58	G6	99-169 x Co 0209
7	14-144	G7	98-210 x (Co 7201 x Pathri)
8	14-90	G8	PIO94-345 x PIR96-258
9	14-34	G9	(PIR001188 x CoC 671) x CoC671
10	14-109	G10	PIO001057 x PIR0010062
11	14-124	G11	98-210 x PIR001057

G = Genotypes (hybrid clones) PIO = Population improved *S. officinarum*, PIR: Population improved *S.robustum*

Statistical analysis

The study utilizes ANOVA to assess the variation in quantitative traits across the genotypes, locations, and seasons, including genotype-environment interaction. Interaction between genotype and environment (G x E) was analyzed using additive main effects and multiplicative interaction (AMMI) (Gauch and Zobel 1990; Elayaraja et al. 2022) and GGE biplot analysis (Yan et al. 2007) conducted using R studio (http://www. rstudio.com). The analysis focused on multi-environment performance and genotype stability. Percentage reduction and genetic improvement in traits under drought were assessed.

Results and discussion

Analysis of variance and mean performance

The combined ANOVA indicated highly significant effects ($p < 0.05$) of environments, genotypes and G × E interaction (Table 2) for all the traits. Highly significant differences in locations, seasons, and genotypes were observed for all traits under drought stress which indicates the usefulness of these parameters for identifying tolerant types.

ANOVA revealed significant individual and interactive effects of genotypes (G), environments (E), and genotype × environment interaction (G × E) for all the traits under study. Seasons and locations were found to be the most significant causes of yield heterogeneity. For cane height, the genotype explained 21.54%, with the environment's influence accounting for 26.07% (Table 3), and the G × E interaction with 52.40%. A highly significant variation of the environments was recorded for cane yield (49.60%), an interaction main effect of 38.46% and moderate genotype effects of 11.94%. Our finding aligns with the earlier results reported by Meena et al. (2017). Kumar et al. (2023) reported 66.98% variation contributed by environmental effect for cane yield under saline stress conditions in commercial types. In our study, divergence among G × E interaction and genotype effect (prebred clones) indicated the certainty of the presence of varied environments with different genotypes. Since the variance component analysis is not sufficient to clarify the details of the genotype by environment interaction, additional statistical techniques,

Table 2. Combined ANOVA for prebred clones in irrigated and drought environments

Control and drought		Cane height (cm)		Cane diameter (cm)		Internode Numbers		Single Cane Weight (kg)		NMC ('000kg/ha)		Yield ('000kg/ha)	
Source of variation	DF	Sum Sq	F-value	Sum Sq	F-value	Sum Sq	F-value	Sum Sq	F-value	Sum Sq	F-value	Sum Sq	F-value
Environment (E)	7	65769.48	20.90	4.041	15.95	781.92	16.32	3.207	51.36	248615.06	461.51	76140.53	164.29
Replication)	8	1320.58	0.36	0.534	1.84	64.53	1.179	0.069	0.973	1087.334	1.766	633.929	1.196
Genotype (G)	13	54339.61	9.30	6.801	14.46	571.33	6.424	2.893	24.95	48088.402	48.068	18326.48	21.29
G x E	91	132200.45	3.23	10.662	3.23	1521.08	2.443	5.348	6.589	121702.66	17.37	59034.90	9.798
Residuals	104	46736.46		3.7624		711.42		0.927		8003.394		6885.525	
CV (%)		11.40		7.869		15.183		12.51		12.67		16.77	

Table 3. Analysis of variance of main effects and interactions for yield and contributing traits

AMMI		Cane height (cm)		Cane diameter (cm)		NMC (000/ha)		Yield (000/ha)	
Source of variation	df	M.S.	V.E	M.S.	V.E	M.S.	V.E	M.S.	V.E
			(%)		(%)		(%)		(%)
Environment	7	9395.64*	26.07	0.58	18.80	35516.44*	59.42	10877.22*	49.60
Genotype	13	4179.97*	21.54	0.52	31.63	3699.11*	11.49	1409.73*	11.94
Interaction	91	1452.75*	52.40	0.12	49.59	1337.39*	29.09	648.74*	38.46
PC1	19	4296.70*	61.80	0.35	61.50	4703.57*	73.40	2259.59*	72.70
PC2	17	1217.41*	15.70	0.10	15.30	1375.00*	19.20	460.28*	13.30
PC3	15	742.23	8.40	0.06	8.50	294.32*	3.60	334.44*	8.50
PC4	13	788.00	7.70	0.05	6.40	170.81	1.80	146.66	3.20
PC5	11	449.59	3.70	0.04	4.20	131.46	1.20	64.79	1.20
PC6	9	312.59	2.10	0.03	2.90	80.78	0.60	43.48	0.70
PC7	7	104.40	0.60	0.02	1.10	21.63	0.10	35.83	0.40
Residuals	104	449.39		0.04		76.96		66.21	

df = Degree of freedom, M.S = Mean sum of square, VE% = Variability explained (in %)

such as multivariate analysis, can be more useful in understanding the interaction.

Performance of the hybrids in both locations

A base broadening program by utilization of improved clones of *S. officinarum, S. robustum,* and *S.barberi* and commercials attempted through different nobilization stages and several introgressed genotypes with wide diversity were identified as trait-specific genetic stocks with improved cane yield and sucrose content. In order to identify trait-specific, i.e., drought-tolerant types in this multiple-trait gene pool, eleven elite hybrids were assessed for the first time for drought stress in two distinct sugarcane growing zones for two seasons in the current study. Earlier *Erianthus procerus* introgressed hybrids and Coimbatore canes (Hemaprabha et al. 2004) were evaluated under water deficit stress and potential donors for developing drought-resistant clones were identified. Drought stress significantly had an impact on crop growth and yield in both locations. Early stress caused reductions in cane height, single cane weight, NMC and cane yield, consistent with the finding by Venkataramana et al. (1986). Under drought, clones 14–90 was the tall canes with no reduction in cane diameter. It showed reduction for single cane weight with an average value of 0.95 kg followed by 14–161, whereas clones, 14–195 and 14–90 recorded minimum reduction for cane yield (Supplementary Table S2). 14–90 displayed superior performance and stability at Karnal. Clones 14–111, 14–161, 14–161, 14–131, 14–195, 14–58, and 14–144 performed better under stress in Coimbatore and Karnal.

The red rot disease management approach involves host resistance and hence, identifying new sources for red rot resistance is a continuous activity to enrich parental pools with diverse backgrounds for its resistance in sugarcane. Viswanathan et al. (2022) reported that a set of host differentials was identified to establish red rot pathogenic variation into designated pathotypes for different zones across the country, which were recommended for disease screening for the respective zones. Pathotypes CF08 and CF13 at Karnal and CF06 at Coimbatore were used for screening the clones. Our study resulted in the identification of introgressed clones coupled with red rot resistance and drought tolerance. Among the clones tested for red rot at both environments, 14–111 and 14–58 were moderately resistant (MR) to CF08 at Karnal (Narendra 2005) and CF06 at Coimbatore. Similarly, 14–161 was MR at Karnal and resistant at Coimbatore. 14–34 was moderately susceptible (MS) at Karnal and resistant at Coimbatore. 14–90 was MR and MS at Karnal and Coimbatore, respectively. 14–161, 14–195 and 14–90 were MS and 14–124 and 14–59 were MR against CF13 at Karnal 14–34 was highly susceptible against CF13; the most virulence race of red rot pathotypes at Karnal. Viswanathan et al. (2017) also reported that red rot damage differed from trial to trial, possibly due to the different growing conditions experienced. They also reported variations among the germplasm collections and indicated that *S. robustum* and *S. sinense* have more stable resistance. In this context, our study identified R, MR and MS clones that had *S. barberi* and improved *S.robustum* as one of the parents that can be exploited for resistance. Apart from *S. spontaneum*, resistant hybrids involving improved *S. robustum* and *S. barberi* germplasm could also be used as a source for red rot resistance in sugarcane.

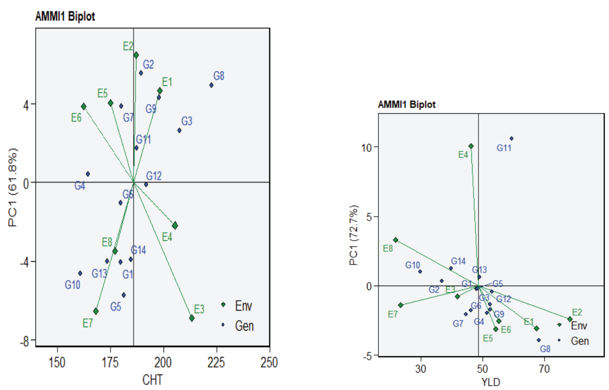
Hybrids performance comparison: sub-tropical vs. tropical

Clone 14-90 (G8) recorded maximum cane height, number of millable canes and cane yield in E1(Subtropics-irrigated). A reduction of 1.19 % to 38.92 % in cane height was observed, indicating adverse effects of drought stress. Yield reduction ranged from 16.70 % to 43.76% under stress conditions. Similarly, Yadav and Prasad (1988) observed more reductions in cane yield in sugarcane clones in response to drought stress under sub-tropical conditions. Clones 14–90 (G8) performed better in both normal and drought environments. Clones *viz.,* 14-161, 14–195A, 14–111, and 14-58 with *S. barberi* complement demonstrated a lead performance under drought conditions in sub-tropics. Under (tropics- irrigated), cane height ranged from 182 cm (G2) to 224.38 cm (G5), with highest yield (103.17 t/ha) in G11 followed by G5. Despite the impressive height, G5 showed 7.80% reduction in yield under drought. The details of traits is given in Supplementary Table S3.

AMMI and GGE biplot analysis

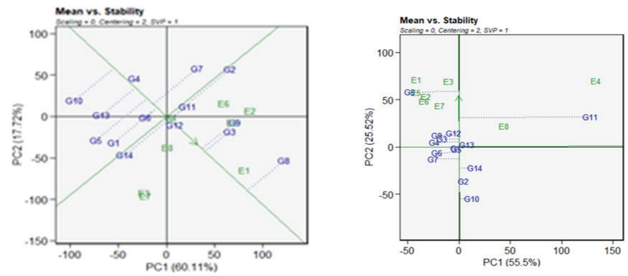
Under drought, genotypic performance was inconsistent in diverse environments and hence, the present study on GEI followed by stability analysis is important in identifying climate-resilient types. The GGE biplots and AMMI are graphical images to exemplify G x E interaction and ranking based on mean and stability. In our study, the AMMI model with only two PCA interactions was the best predictive model, which is in agreement with earlier workers (Kumar et al. 2023).

Biplot analysis (Yan et al. 2000) visualizes GEI, depicting stability *vs* mean performance over environments for genotype evaluation. Genotypes/environments with great PC1 scores (positive or negative) have higher interactions, whereas genotypes/environments with PC1 scores near zero have slight interactions (Crossa et al. 1990). In our study for PC1 vs cane height, E1, E2, E3, and E4 expressed the highest main effects E7 and E8 demonstrated lower average main effects (Fig. 1A) with G4, G6, and G11 as adaptable clones. For PC1 vs cane yield, E1, E2, E4, E5, and E6 were favourable and E3, E7, and E8 were unfavorable environments. G11 expressed higher main effects for cane yield and G4, G7, and G9 exhibited lower main effects (Fig. 1B), indicating their specific adaptation under stress. The



1A.CHT 1B.YLD

Fig. 1. A. AMMI biplot PC1 vs Cane Height (CHT) and B. PC1 vs Cane yield, Where, G = Genotypes (1–14) and E = Environments (1–8) Karnal Irrigated two seasons (E1, E2): Coimbatore Irrigated two seasons (E3, E4), Karnal Drought two seasons (E5, E6) and Coimbatore Drought two seasons (E7, E8)



2A.CHT 2B.YLD

Fig. 2. Mean vs Stability biplot, A. Cane height (CHT) and B. Cane yield (YLD); where G = Genotypes (1–14) and E = Environments (1–8) of two different locations viz., Irrigated condition in Karnal location for Season 1 and Season 2 (E1, E2), Irrigated condition in Coimbatore location for Season 1 and Season 2 (E3, E4), Drought condition in Karnal location for Season 1 and Season 2 (E5, E6), Drought condition in Coimbatore location for Season 1 and Season 2 (E7, E8)

ideal genotype and environment are those that are near the origin (Alarmelu et al. 2015; Kumar et al. 2023), and in our study, G1, G3, and G5, due to their position near the origin, are comparatively stable under the stress environments.

Earlier findings (Crossa et al. 1990; Alarmelu et al.2015) support the notion that the environment's main effect is higher for cane yield and related traits. The study revealed that hybrids with consistent yield under drought showed stability for cane height, cane diameter, single cane weight and NMC.

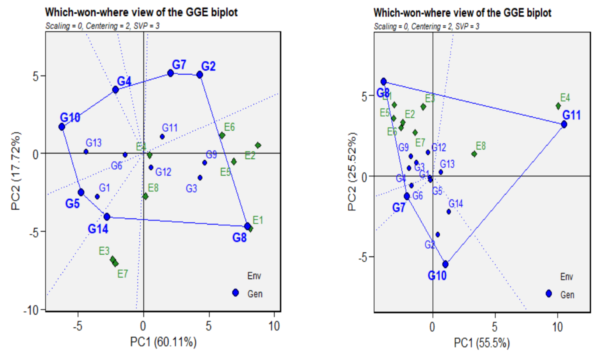
Assessment of genotypic performance and stability across environments is simplified through the mean vs. stability perspective. Our study revealed significant G + G x E variation (Supplementary Fig.2), notably 81.02 % for cane yield per hectare. Earlier studies (Hongyu et al. 2014; Hongyu et al. 2015) indicate that stable genotypes are (AEC abscissa) with zero projection (AEC ordinate), are optimal, and unstable are farther from AEC abscissa. In drought, and irrigated environments (tropics), genotypes G4, G9, G 11 and G8 were stable with high yields (Fig. 2B). G10, despite high mean yield, showed instability due to its farther distance from AEC. Similar results were obtained by Kumar et al. (2023) for salinity-tolerant stable sugarcane varieties and Tena et al. (2019) for high-yielding types. Despite lower yield, G2, G3, G7 and G9 demonstrated stability, indicating their potential as parents in breeding. Khan et al. (2022) indicated that such genotypes might possess a compensatory mechanism, enabling them to withstand diverse environmental changes.

In the GGE biplot, the 'which-won-where' pattern of the GEI data matrix is a crucial feature of the GGE biplot that was extracted by the innermost assets or product of the biplot (Yan et al. 2002) and helps to visualize the mega environments and identification of superior genotypes to the specific drought environment. A separate genotype-environment interaction was noticed for cane height with G2, G7, G4, G10, G5, G14 and G8 as the vertex genotypes (Fig. 3A). G7, G8 and G11 were the vertex genotypes for single cane weight and G7, G8, G10 and G11 for cane yield (Supplementary Fig.3).

Eight environments were divided into two segments each with its own winning genotype for yield (Fig.3B) and G11 was the only distinct genotype of the segment (1), indicating its better yield performance and G8, G7 and G10 in segment (2) (Fig.3B) . Our study aligns with earlier research (Hashim et al. 2021) where all environmental indicators clustered in one section of biplot, indicating performance of unique genotype across environments and mega-environments with stability for yield G4, G7, G2 and G8 were the vertices genotypes in the mega environment (i) indicating their superior performance for cane height. There were also vertexes of genotypes that were located in the regions with no environment at all, like G1, G6 and G13 for cane height, which indicates their poor performance in all the environments. Similar findings by Oladosu et al. (2017) also support that the genotype attached with a vertex of the polygon in a sector performs best in that environment and a genotype that is linked with a polygon vertex where no environment indicator drops was poor in performance across the environment.

Identification of stable drought-tolerant hybrids

The tillering phase of the sugarcane crop is the most sensitive phase to moisture stress, causing a significant reduction in cane yields through the reduction in its component traits. G1 identified as drought tolerant, showed significant genetic enhancement under drought at Coimbatore for yield traits (Supplementary Table S4) in comparison to tropical drought tolerant standard Co 10026. It also exhibited an overall improvement in cane diameter and for number of internodes compared to the sub-tropical variety Co 0238 in Karnal. G5 showcased notable improvement in cane height (13.75%), single cane weight (3.85%), number of millable canes (24.55%)



3A. CHT A 3B. YLD

Fig. 3. 'Which won where' polygon, A. Cane height (CHT); and B. Cane yield (YLD)
where G = Genotypes (1–14) and E = Environments (1–8) of two different locations viz., Irrigated condition in Karnal location for Season 1 and Season 2 (E1, E2), Irrigated condition in Coimbatore location for Season 1 and Season 2 (E3, E4), Drought condition in Karnal location for Season 1 and Season 2 (E5, E6), Drought condition in Coimbatore location for Season 1 and Season 2 (E7, E8).

and cane yield (32.47%) in tropical and subtropical conditions. G8 demonstrated an increase in all cane yield traits under stress in both locations except for cane weight at Coimbatore. As predicted by the GGE and AMMI biplots models, G1, G3, G5, and G4 were categorized as highly stable drought-tolerant clones with high yield and suited to normal and stress environments in both locations. G8 and G11 with low stability were high-yielding, indicating their suitability for drought situations. G2, G7, and G9, despite low yield, demonstrated a high stability, indicating its potential for exploitation. These trait-specific clones are identified for exploitation in both tropical and sub-tropical pre-breeding programs to develop climate-resilient sugarcane genotypes.

Supplementary materials

Supplementary Figs 1 to 3 and Supplementary Tables S1 to S4 are provided, www.isgpb.org

Authors' Contributions

Conceptualization of research (SA, SV, SS, MRM, RK); Designing of the experiments (SA, SS, SV, MRM, RK, MLC); Contribution of experimental materials (SA); Execution of field/lab experiments and data collection (SS, RP, VP, MRM, RK, MLC, SM, SK); Analysis of data and interpretation (SA, VA, MRM); Preparation of the manuscript (SA, MRM, VA, RA, SV, SS, RK, MLC).

Acknowledgments

The authors gratefully acknowledge the funding from ICAR-SBI, Coimbatore and ICAR-SBI RC, Karnal.

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Supplementary Table S1. Performance of pre-bred clones under control (irrigated)

Clone number	Cane height (cm)			Cane diameter (cm)			Number of internodes			Number of millable canes (000/ha)			Yield (000/ha)		
	K	C	Mean	K	C	Mean	K	C	Mean	K	C	Mean	K	C	Mean
G1	172.50	217.08	194.79	2.79	2.69	2.74	13.67	23.00	18.34	76.58	51.62	64.10	69.08	45.81	57.45
G2	210.00	182.00	196.00	1.84	2.34	2.09	16.67	17.50	17.09	94.00	30.27	62.14	57.73	24.91	41.32
G3	231.25	221.88	226.57	2.43	2.55	2.49	16.75	23.00	19.88	107.73	44.00	75.87	83.51	43.30	63.41
G4	172.50	188.13	180.32	2.7	2.64	2.67	16.33	18.00	17.17	100.38	41.25	70.82	80.96	36.41	58.69
G5	231.25	224.38	227.82	2.43	2.54	2.49	16.75	20.50	18.63	107.73	49.75	78.74	83.51	49.10	66.31
G6	180.00	207.50	193.75	1.90	2.50	2.20	16.92	16.00	16.46	203.82	28.27	116.05	81.99	25.52	53.76
G7	195.00	202.50	198.75	1.70	2.60	2.15	15.50	18.25	16.88	184.38	23.10	103.74	82.68	19.04	50.86
G8	262.50	215.00	238.75	2.55	2.68	2.62	22.00	18.50	20.25	92.33	53.72	73.03	104.93	48.01	76.47
G9	255.00	198.75	226.88	2.20	2.60	2.40	21.50	25.50	23.50	101.25	54.50	77.88	78.80	48.05	63.43
G10	135.00	205.00	170.00	2.19	2.68	2.44	18.17	19.25	18.71	81.29	28.37	54.83	44.93	25.36	35.15
G11	205.00	204.69	204.85	2.00	2.66	2.33	15.67	19.75	17.71	97.94	72.81	85.38	57.31	103.17	80.24
Standard 1	193.75	213.13	203.44	2.50	2.57	2.54	15.08	23.75	19.42	85.25	56.75	71.00	77.77	51.45	64.61
Standard 2	156.25	224.38	190.32	2.58	2.73	2.66	13.92	18.75	16.34	105.38	47.25	76.32	76.66	48.30	62.48
Standard 3	176.25	226.88	201.57	2.43	2.78	2.61	15.50	20.25	17.88	81.11	44.25	62.68	59.36	47.27	53.32

Clones, 14-161 (G1), 14-131 (G2), 14-83 (G3), 14-195 (G4), 14-111(G5), 14-58 (G6), 14-144 (G7), 14-90 (G8), 14-34 (G9), 14-109 (G10), 14-124 (G11)
Karnal(K) : Standard 1 : Co 0238, 2 : Co 05011 3.CoJ 64
Coimbatore (C): 1:Co 10026, 2:Co 85019 3. CoM 0265

Supplementary Table S2. Performance of pre-bred clones under drought

Clone no	Cane height (cm)				Cane diameter (cm)				Number of internodes				Number of millable canes (000/ha)				Yield (000/ha)			
	K	C	Mean	% rdn	K	C	Mean	% rdn	K	C	Mean	% rdn	K	C	Mean	% rdn	K	C	Mean	% rdn
G1	140.00	190.00	165.00	15.29	2.73	2.67	2.70	1.46	17.92	18.75	18.34	0.00	68.11	32.74	50.43	21.33	52.00	24.70	38.35	33.24
G2	207.50	158.75	183.13	6.57	2.13	2.36	2.25	-7.42	19.42	13.75	16.59	2.93	85.47	23.84	54.66	12.04	50.05	14.70	32.38	21.65
G3	198.00	179.06	188.53	16.79	2.49	2.37	2.43	2.41	17.33	13.50	15.42	22.44	91.78	38.75	65.27	13.97	53.00	29.32	41.16	35.08
G4	146.25	150.63	148.44	17.68	2.52	2.12	2.32	13.11	16.17	13.50	14.84	13.57	101.42	37.50	69.46	1.91	66.49	26.99	46.74	20.35
G5	141.25	206.88	174.07	23.59	2.35	2.41	2.38	4.23	15.33	16.75	16.04	13.88	73.93	34.25	54.09	31.31	46.97	28.21	37.59	43.31
G6	165.00	167.50	166.25	14.19	1.90	2.46	2.18	0.91	15.17	15.25	15.21	7.59	163.72	20.50	92.11	20.63	65.06	12.49	38.78	27.87
G7	190.00	133.75	161.88	18.55	1.59	2.39	1.99	7.44	16.33	12.25	14.29	15.32	163.75	24.00	93.88	9.51	64.24	11.96	38.10	25.09
G8	227.50	186.25	206.88	13.35	2.75	2.48	2.62	0.00	20.17	17.75	18.96	6.37	79.44	41.74	60.59	17.03	87.41	32.07	59.74	21.88
G9	171.50	166.88	169.19	25.43	2.34	2.74	2.54	-5.83	18.00	15.50	16.75	28.72	86.54	32.50	59.52	23.57	60.26	22.68	41.47	34.62
G10	132.50	171.25	151.88	10.66	2.20	2.49	2.35	3.70	21.46	15.25	18.36	1.90	70.83	21.70	46.27	15.62	32.57	16.27	24.42	30.52
G11	175.00	164.44	169.72	17.15	1.94	2.67	2.31	1.07	15.25	15.50	15.38	13.18	77.17	44.72	60.95	28.61	38.48	38.75	38.62	51.88
Standard 1	178.75	181.88	180.32	11.37	2.70	2.46	2.58	-1.78	17.17	19.25	18.21	6.21	73.63	27.50	50.57	28.78	61.86	21.01	41.44	35.87
Standard 2	138.75	174.38	156.57	17.73	2.63	2.29	2.46	7.34	12.75	15.25	14.00	14.29	101.46	24.50	62.98	17.47	52.82	18.31	35.57	43.08
Standard 3	151.25	184.38	167.82	16.74	2.21	2.56	2.39	8.45	15.75	12.25	14.00	21.68	69.39	22.25	45.82	26.90	34.59	17.93	26.26	50.75

14-161 (G1), 14-131 (G2), (14-83 (G3), 14-195 (G4), 14-111(G5), 14-58 (G6), 14-144 (G7), 14-90 (G8), 14-34 (G9), 14-109 (G10), 14-124 (G11)
Karnal(K) : Standard 1 : Co 0238 2 : Co 05011 3.CoJ 64
Coimbatore (C): 1 :Co 10026, 2 :Co 85019 3. CoM 0265 : % rdn = % Reduction

Supplementary Table S3. Mean performance of prebred clones under drought in sub-tropical and tropical environments

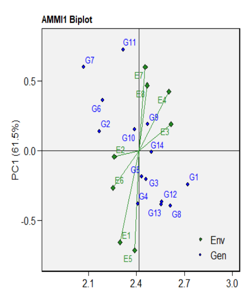
Clone number	CHT (cm)	% rdn	CDIA(cm)	% rdn	NMC(000/ha)	% rdn	YLD(t/ha)	% rdn
Performance at Karnal (Sub -tropical)								
G1	140.00	18.84	2.73	2.09	68.11	11.06	52.00	24.73
G2	207.50	1.19	2.13	-15.84	85.47	9.07	50.05	13.31
G3	198.00	14.38	2.49	-2.75	91.78	14.81	53.00	36.54
G4	146.25	15.22	2.52	6.79	101.42	-1.02	66.49	17.88
G5	141.25	38.92	2.35	3.09	73.93	31.38	46.97	43.76
G6	165.00	8.33	1.90	0.00	163.72	19.67	65.06	20.64
G7	190.00	2.56	1.59	6.37	163.75	11.19	64.24	22.31
G8	227.50	13.33	2.75	-7.84	79.44	13.96	87.41	16.70
G9	171.50	32.75	2.34	-6.44	86.54	14.53	60.26	23.53
G10	132.50	1.85	2.20	-0.38	70.83	12.87	32.57	27.51
G11	175.00	14.63	1.94	2.92	77.17	21.21	38.48	32.86
Co 0238	178.75	7.74	2.70	-8.00	73.63	13.64	61.86	20.46
Co 05011	138.75	11.20	2.63	-1.94	101.46	3.73	52.82	31.10
CoJ 64	151.25	14.18	2.21	9.25	69.39	14.45	34.59	41.73
Performance at Coimbatore (Tropical)								
G1	190.00	12.48	2.67	0.74	32.74	36.57	24.70	46.08
G2	158.75	12.77	2.36	-1.07	23.84	29.90	14.70	41.00
G3	179.06	19.30	2.37	6.96	38.75	11.93	29.32	32.29
G4	150.63	19.93	2.12	19.64	37.50	9.09	26.99	25.87
G5	206.88	7.80	2.41	4.93	34.25	31.16	28.21	42.54
G6	167.50	19.28	2.46	1.80	20.50	28.73	12.49	51.06
G7	133.75	33.95	2.39	8.36	24.00	-3.92	11.96	38.76
G8	186.25	13.37	2.48	7.29	41.74	22.31	32.07	33.21
G9	166.88	16.04	2.74	-5.39	32.50	40.37	22.68	52.79
G10	171.25	16.46	2.49	7.01	21.70	34.24	16.27	35.86
G11	164.44	19.66	2.67	-0.38	44.72	38.57	38.75	62.44
Co 10026	181.88	14.66	2.46	4.09	27.50	51.54	21.01	59.16
Co 85019	174.38	22.28	2.29	16.06	24.50	48.15	18.31	62.09
CoM 0265	184.38	18.73	2.56	8.09	22.25	49.72	17.93	62.07

Clones, 14–161 (G1), 14–131 (G2), 14–83 (G3), 14–195 (G4), 14–111(G5), 14–58 (G6), 14–144 (G7), 14–90 (G8), 14–34 (G9), 14–109 (G10), 14–124 (G11) %rdn = %Reduction

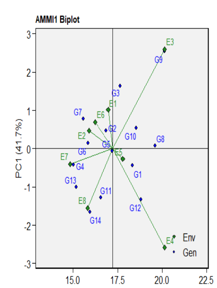
Supplementary Table S4. Genetic improvement for yield traits in hybrids under drought over Standard I in both centre's Karnal(Kar.) and Coimbatore (CBE)

Clones	Cane height (cm)		Cane diameter (cm)		Number of internodes		Single cane weight (kg)		Number of millable canes (000/ha)		Yield (000/ha)	
	Kar	CBE	Kar	CBE	Kar	CBE	Kar	CBE	Kar	CBE	Kar	CBE
G1	-21.68	4.46	1.11	8.54	4.37	-2.60	-9.41	-1.28	-7.50	19.05	-15.94	17.56
G2	16.08	-12.72	-21.11	-4.07	13.10	-28.57	-29.41	-23.08	16.08	-13.31	-19.09	-30.03
G3	10.77	-1.55	-7.78	-3.66	0.93	-29.87	-30.59	-2.56	24.65	40.91	-14.32	39.55
G4	-18.18	-17.18	-6.67	-13.82	-5.82	-29.87	-17.65	-5.13	37.74	36.36	7.48	28.46
G5	-20.98	13.75	-12.96	-2.03	-10.72	-12.99	-22.35	3.85	0.41	24.55	-24.07	34.27
G6	-7.69	-7.91	-29.63	0.00	-11.65	-20.78	-52.94	-16.67	122.36	-25.45	5.17	-40.55
G7	6.29	-26.46	-41.11	-2.85	-4.89	-36.36	-54.12	-37.18	122.40	-12.73	3.85	-43.07
G8	27.27	2.40	1.85	0.81	17.47	-7.79	34.12	-2.56	7.89	51.78	41.30	52.64
G9	-4.06	-8.25	-13.33	11.38	4.83	-19.48	-15.29	-15.38	17.53	18.18	-2.59	7.95
G10	-25.87	-5.84	-18.52	1.22	24.99	-20.78	-45.88	-5.13	-3.80	-21.09	-47.35	-22.56
G11	-2.10	-9.59	-28.15	8.54	-11.18	-19.48	-41.18	8.97	4.81	62.62	-37.80	84.44
Std 1	178.75	181.88	2.7	2.46	17.17	19.25	0.85	0.78	73.63	27.50	61.86	21.01
Std 2	138.75	174.38	2.63	2.29	12.75	15.25	0.54	0.74	101.46	24.50	52.82	18.31
Std 3	151.25	184.38	2.21	2.56	15.75	12.25	0.50	0.80	69.39	22.25	34.59	17.93

Clones, 14-161 (G1), 14-131 (G2), 14-83 (G3), 14-195 (G4), 14-111(G5), 14-58 (G6), 14-144 (G7), 14-90 (G8), 14-34 (G9), 14-109 (G10), 14-124 (G11)
Karnal :Standard 1 : Co 0238 2 : Co 05011 3.CoJ 64 ;
Coimbatore : 1 :Co 10026, 2 :Co 85019 3. CoM 0265



1A



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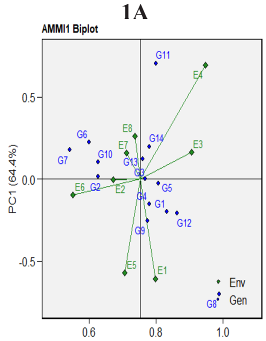

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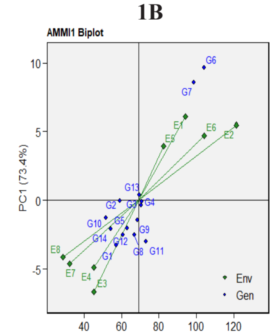
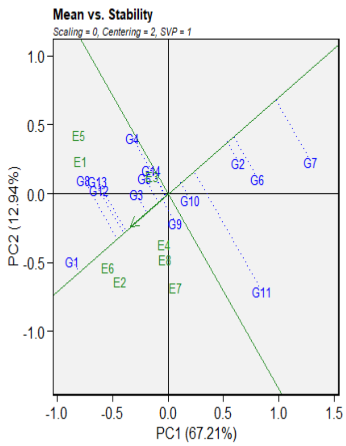
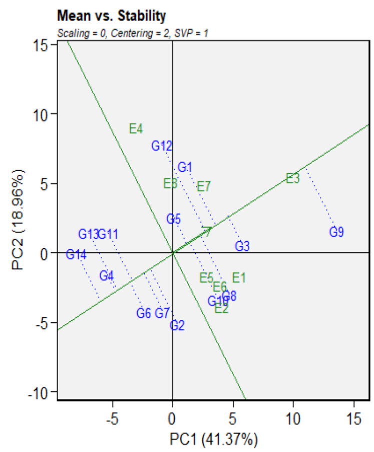


1D

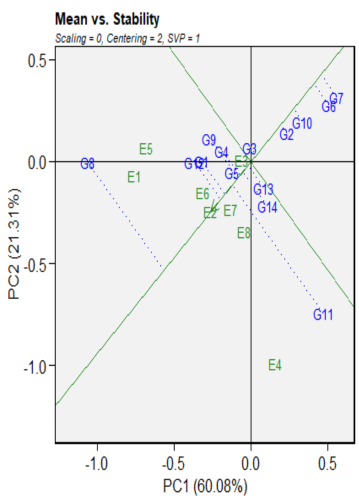
Supplementary Fig. S1. A. AMMI biplot PC1 Vs Cane Diameter (CDIA), B. AMMI biplot PC1 Vs Number of internodes (CINN), C.AMMI biplot PC1 Vs Single Cane Weight (SCW) and D. AMMI biplot PC1 Vs Number of Millable canes. Where G = Genotypes (1–14) and E = Environments (1–8) Karnal Irrigated two seasons (E1,E2): Coimbatore Irrigated two seasons (E3, E4), Karnal Drought two seasons (E5, E6) and Coimbatore Drought two seasons (E7, E8).



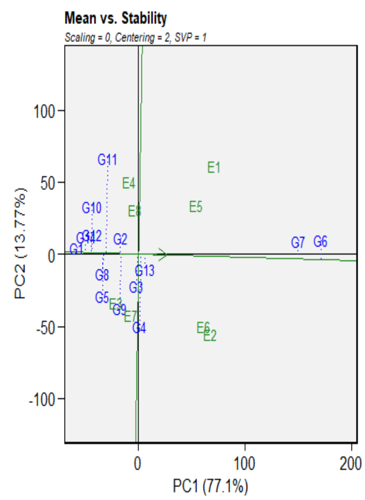
2A. CDIA



2B. CINN

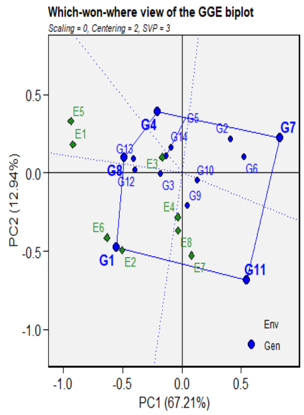


2C. SCW

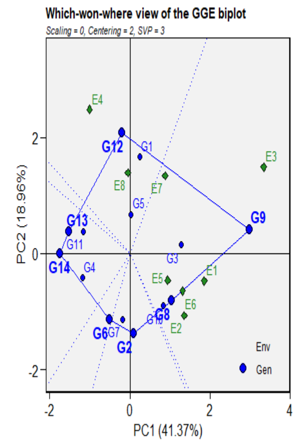


2D. NMC

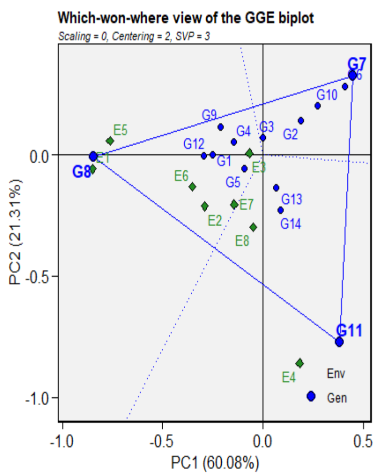
Supplementary Fig. S2. Mean Vs Stability biplot for A. Cane diameter (CDIA), B. Number of internodes (CINN), C. Single cane weight (SCW) and D. Number of Millable canes (NMC). Where G = Genotypes (1–14) and E = Environments (1–8) Karnal Irrigated two seasons (E1,E2): Coimbatore Irrigated two seasons (E3, E4), Karnal Drought two seasons (E5, E6) and Coimbatore Drought two seasons (E7, E8).



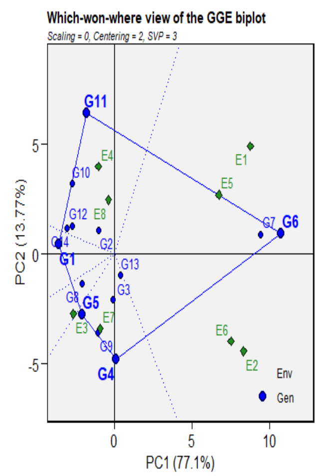
3A. CDIA



3B. CINN



3C. SCW



3D. NMC

Supplementary Fig. S3. 'Which won where' polygon for A. Cane diameter (CDIA), B. Number of internodes (CINN), C. Single cane weight (SCW) and D. Number of Millable canes (NMC). Where G = Genotypes (1–14) and E = Environments (1–8) Karnal Irrigated two seasons (E1, E2): Coimbatore Irrigated two seasons (E3, E4), Karnal Drought two seasons (E5, E6) and Coimbatore Drought two seasons (E7, E8).