Website : www.asthafoundation.in
Frontiers in Crop Improvement
Vol 11 (2) : 132-135 (July-2023) Print ISSN : 2393-8234 Online ISSN : 2454-6011
Astha Foundation, Meerut (U.P.) India

Genotype Environment Interaction among Progeny Clones of Wide Crosses in Sugarcane under Waterlogging Stress

Sonali Gaur[1], A.S. Jeena[1], Usha Pant[1], Anjana Chauhan[1], Anil Kumar[1] and Dinesh Pandey[2]
[1]Department of Genetics and Plant Breeding, G.B. Pant University of Agriculture and Technology, Pantnagar-263145
[2]Department of Molecular Biology and Genetic Engineering, College of Basic Sciences and Humanities, GBPUAT, Pantnagar-263145

Abstract

The genotype and environment (G×E) interaction is a crucial area of research in the development of stable cultivars, as it significantly affects crop yield performance. This study focused on assessing the stability of cane yields and CCS (commercial cane sugar) yield in eighteen intergeneric and interspecific clones of sugarcane, along with three check varieties. The research was conducted across four different environments created with the planting seasons and stress conditions. The Eberhart-Russell stability model was employed for the analysis. The combined analysis of variance revealed significant variations among the clones and interactions between the clones and environments for the studied traits. By utilizing the Eberhart and Russell stability model, we identified ISH 584 as the stable variety with consistent yielding ability across diverse conditions. Furthermore, ISH 536 exhibited an above-mean value for CCS %, with a non-significant deviation from regression (S^2_{di}=0) and regression coefficient (b_i=0). Similarly, ISH 548 demonstrated superior CCS (t/ha) values with non-significant deviation from regression and regression coefficient bi > 1, suggesting high sensitivity of genotypes for better environments. The elite clones selected based on different stability analyses could serve as potential sources for hybridization against waterlogging stress. These findings provide valuable insights for the development of stable sugarcane cultivars, which can contribute to enhancing crop productivity and resilience in varying environmental conditions.

Key words : *Sugarcane, interspecific, intergeneric, stability, interaction, yield.*

Introduction

Sugarcane holds a vital position as the main cash crop in India, serving as the primary source of sugar. Given its long growing season, the productivity of sugarcane is significantly influenced by various climatic factors (1). The tropical region accounts for 45% of the area and contributes 55% of the total sugarcane production, while the sub-tropical region accounts for 55% of the area and shares 45% of the total production (2). In India, sugarcane is cultivated under diverse agro-climatic conditions of tropics and sub-tropics; therefore, the crop suffers from various biotic and abiotic stresses that significantly impact yield as well as production. Among the abiotic stresses, waterlogging is a prevailing and serious water stress problem for sugarcane (3), especially for the cane growing areas along the rivers, low-lying and locations receiving high rainfall. In India, where 73.30% of the annual rainfall is received during the southwest monsoon season, sugarcane crops in certain areas (Assam, Bihar, West Bengal, eastern Uttar Pradesh, coastal regions of Andhra Pradesh, Tamil Nadu, Kerala, and Karnataka) can experience stagnant water for 2-3 months, leading to yield losses of 15-25% on average and exceeding 40% in some cases (4). In India, the physical degradation of soil caused by waterlogging has been evaluated to affect approximately 11.60 million hectares of land posing a major constraint on the productivity of sugarcane. Among these areas, sugarcane cultivation occupies a significant portion, ranging from 10% to 30% (5).

While sugarcane is moderately tolerant to flooding and waterlogging, the severity of the issue depends on factors such as the depth and duration of waterlogging, the condition of the water (stagnant or moving), number of aerial roots as well as their presence/absence, the growth phase of crop and genotypes/varieties, the type of variety adopted, soil type, and drainage facilities available (6). Developing stress-resistant sugarcane genotypes is a durable, eco-friendly, and cost-effective solution. Therefore, there is an urgent need to identify and bred sugarcane varieties that are suitable for waterlogging stress conditions to facilitate sustainable sugarcane production. Genotype by environment (G x E) interaction refers to the alterations in varietal performance caused by varying environmental conditions (7). In plant breeding programs, desirable genotypes are selected after evaluation of many potential genotypes under different environments. GxE interaction may affect heritability as a component of phenotypic variance. If this GE is large, it may result in a failure to differentiate the performance of genotypes across environments, and it can reduce the precision of the selection across the environments. Most of the yield component of sugarcane is highly influenced

Received : May-2023; Revised : May-2023; Accepted : July-2023

the environmental factors such as germination, tillering, and stalk elongation rates (8) and Kumar, et al., (2022). Phenotypic stability can be estimated through regression analysis and is useful for evaluating the performance of different genotypes under varying environmental conditions.

Materials and Methods

The present study was conducted with eighteen interspecific and intergeneric hybrid clones alonwith three standard varieties of Sugarcane for two consecutive years (2021-22 and 2022-23) under normal and waterlogging stress conditions at Sugarcane Breeding Block, Norman E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar. The four different environments were created with planting year and growing condition as given in Table-1.

Table-1 : Details of environments for evaluating Sugarcane clones at Pantnagar.

S. No.	Planting Year	Growing Condition	Environment
1.	2021-22	Normal Condition	E1
2.	2021-22	Waterlogged Condition	E2
3.	2022-23	Normal Condition	E3
4.	2022-23	Waterlogged Condition	E4

The interspecific and intergeneric clones viz., ISH 501, ISH 502, ISH 512, ISH 519, ISH 524, ISH 534, ISH 536, ISH 548, ISH 567, ISH 584, ISH 585, ISH 587, ISH 590, ISH 594, IGH 823, IGH 829, IGH 833, and IGH 834 alongwith three check varieties namely Co Pant 90223, Co Pant 97222 and Co Pant 05224 were evaluated in randomized block design with three replications. Each entry was allotted a two-row plot measuring 6.0 m long and the line-to-line spacing was kept at 0.90 m. All the recommended cultural practices were adopted to raise a good crop. Data was recorded for commercial cane sugar (CCS) %, Cane yield (t/ha), and CCS yield (t/ha among the eighteen clones and the three check varieties of sugarcane. Phenotypic stability of genotypes was analysed using Eberhart and Russell's model based on three stability parameters i.e., regression coefficient (S^2_{di}), mean performance ($\bar{x}$), and linear response (b_i) (9).

Results and Discussion

The analysis of the variance of G x E has shown significant variation among genotypes and environments for all the traits under study (Table-2). The genotypes have responded differently across the series of environments (10). Mean squares for G×E interactions were registered significant, hence the G×E interaction was further partitioned into other components such as E (linear), G×E (linear), pooled deviations and pooled error using (9). Significant E+G×E for all the characters suggested the distinct nature of environments and the role of G× E in the expression of the phenotype (11, 12). The significance of E (linear) for all the traits confirmed significant differences among the environments and their role in the expression of traits. G×E (linear) was found significant for all traits which suggest the contribution of linear component and that the behaviour of clones/varieties for these traits can be predicted. MSS for pooled deviation were observed significant for all the traits analysed such as cane yield, CCS %, and CCS yield. This suggests that the prediction of the performance of genotypes over a series of environments solely based on regression analysis of traits cannot be completely true. Also, significant G x E interaction for all traits restricts the identification of stable genotypes based on their mean performance for the trait.

The environmental index (I_j) directly reflects the rich or poor environment. The negative value of I_j indicates a poor environment, while the positive value indicates a rich environment for the performance of a particular trait. Environments E1 and E3 representing normal condition during both years (2021-22 and 2022-23) were found favourable or rich with high mean performance for all three traits (Table 3). Whereas, environment E2 and E4 constituted with waterlogged conditions for both years were found unfavourable or poor for all three traits namely cane yield, CCS %, and CCS yield.

According to the Eberhart and Russel model, three stability parameters, mean, regression coefficient (b), and mean square deviation from regression S^2_{di}, are estimated for all the traits. These stability parameters categorize genotypes into various groups based on stability and suitability over the environment (13). Becker and Leon,1988) However, a higher S2di value signifies the instability of genotypes across diverse environments (14, 15, 16, 17). As per the model, a desirable genotype exhibits a high mean value for the trait, unit regression coefficient (b=1) and mean square deviation non-significant or equal to zero (S^2_{di}=0). The non-significant value of S^2_{di}=0 talks about the stability of the genotype; only genotypes with non-significant S^2_{di} are tested further for regression coefficient. The regression coefficient value is more concerned with genotype responsiveness in an environment. The mean and stability parameters are presented in Table 4 and the stability of clones and varieties studied were elaborated.

The significant deviation from regression (S^2_{di}=0) observed for most of the clones for all the traits indicated instability of the genotypes over the environments. Which is obvious because of the genetic constitution of the clones being progenies of interspecific and intergeneric hybrids of sugarcane. Further, it also indicated that the clones responded differentially to the stress

Table-2 : Analysis of variance of G x E interaction in sugarcane genotypes for different characters.

Source of variation	df	CSS at harvest	Cane yield	CSS t/ha
Variety	20	1.76**	543.08**	8.07**
Environment	3	1.76**	2,132.01**	31.07**
G × E	60	0.71**	82.46**	1.09**
E + G × E	63	0.76**	180.06**	2.52**
E (linear)	1	5.27**	6,396.03**	93.21**
G × E (linear)	20	1.12**	113.54**	1.97**
Pooled deviation	42	0.48**	63.74**	0.62**
Pooled error	160	0.07	28.28	0.33
Total	83			

*, ** : Significant levels at 5% and 1%, respectively.

Table-3 : Estimates of environmental index and Mean performance over the environments.

Character Name	Mean ± S.E.m	Environment Index			
		E1	E2	E3	E4
CSS % at harvest	10.35±0.40	0.09	-0.33	0.35	-0.11
Cane yield	52.11±4.61	4.48	-13.24	10.33	-1.57
CSS t/ha	5.44± 0.45	0.52	-1.55	1.30	-0.26

Table-4 : Mean and stability parameters for twenty-one genotypes of sugarcane.

Variety	CSS at harvest (%)			Cane yield (t/ha)			CSS Yield (t/ha)		
	Mean	b	S^2di	Mean	b	S^2di	Mean	b	S^2di
ISH 501	9.76	5.86	0.15**	53.11	1.71	103.10**	5.41	2.02	1.42**
ISH 502	9.94	-0.86	0.05**	55.95	1.12	12.58	5.54	0.81	0.23**
ISH 512	11.05	0.50	1.84**	53.73	1.32	4.73	5.91	1.26	0.13
ISH 519	10.55	2.62	0.10**	53.22	2.27	52.60**	5.76	2.28	0.91**
ISH 524	10.66	0.29	0.10**	35.96	1.46	32.81**	3.86	1.36	1.01**
ISH 534	10.78	0.74	0.13**	59.10	1.34	150.94**	6.36	1.27	1.15**
ISH 536	10.39	1.03	0.03	52.03	1.38	-0.12	5.49	1.47	0.08
ISH 548	10.03	4.22	0.86**	59.63	0.61	19.20**	6.02	1.15	-0.08
ISH 567	9.27	0.58	0.32**	46.18	0.66	293.22**	4.24	0.56	1.86**
ISH 584	9.20	1.53	0.60**	61.70	1.15	-6.54	5.72	1.10	0.10
ISH 585	9.92	-2.09	0.05**	43.78	0.70	96.45**	4.30	0.36	0.64**
ISH 587	10.54	0.07	0.56**	59.74	-0.18	102.33**	6.27	-0.18	0.64**
ISH 590	10.87	1.00	0.27**	60.64	1.78	26.08**	6.60	1.74	0.04
ISH 594	10.92	-0.70	0.56**	40.64	0.46	86.35**	4.40	0.34	0.74**
IGH 823	9.09	1.68	1.59**	41.51	0.22	53.86**	3.75	0.39	0.15
IGH 829	10.16	-2.67	0.21**	47.78	0.25	-8.52	4.84	-0.07	-0.02
IGH 833	10.27	2.01	0.43**	36.88	1.29	46.86**	3.86	1.24	0.91**
IGH 834	10.41	-1.66	0.13**	29.59	0.42	17.78**	3.06	0.24	0.10
Co Pant 90223	11.38	2.41	0.16**	78.08	0.43	4.92	8.92	0.84	0.42**
Co Pant 97222	11.37	3.36	0.14**	69.89	1.29	61.15**	8.02	1.69	0.44**
Co Pant 05224	10.89	-0.50	0.49**	55.15	1.33	-9.33	5.98	1.15	0.02
Pooled mean	10.35			52.11			5.44		

environments, hence, reflecting instability in the performance over the environment. Only one genotype (ISH 536) had shown non-significant deviation from regression (S^2_{di}=0), an above mean value and regression coefficient (bi =1) for CSS % at harvest, indicating uniform stability and linear response to a series of environments. Non-significant S^2_{di} for the trait cane yield was estimated for the clones ISH 502, ISH 512, ISH 536, ISH 584, IGH 829 and the check Co Pant 90223 and Co Pant 05224 indicating predictable performance based on regression. Among these only clone IGH 829 and Check Co Pant 90223 exhibited bi<1, indicating their specific adaptability to poor environment. It suggested that these to genotypes can tolerate water logging conditions. All other clones and varieties among those showed non-significant S^2_{di} for cane yield exhibited bi>1, suggesting responsiveness of these genotypes towards favourable environments. For CCS yield, ISH 512, ISH 536, ISH 548, ISH 584, ISH 590, IGH 823, IGH 829, IGH 834 and Co Pant 05224 showed non-significant S^2_{di} suggesting predictability of performance for these clones with respect to CCS yield. Among these clones all had bi >1 except IGH clones, revealing their response to better environment. However, the IGH clones showed general adaptability to poor environment (bi<1), hence, tolerance to waterlogging conditions.

The study suggests that the clones ISH 536 was stable and best performing one with respect to CCS %, Cane and CCS yield. However, IGH clones were most suited to stress environment, hence can be utilized in hybridization programme as donor.

Acknowledgement

ICAR-SBI, Coimbatore is sincerely acknowledged for providing the ISH and IGH clones for the study, Project Coordinator, AICRP on Sugarcane for financial support and G B Pant University of Agriculture and Technology, Pantnagar for providing facilities and support for the study.

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