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Performance stability of juice yields in sweet stalk sorghum genotypes across different seasons

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Abstract
An experiment was conducted to study green cane yield stability and adaptability involving twenty-three sweet sorghum genotypes and one hybrid in four contrasting sowing dates. The objective of the research is to analyze genotype-environment interaction (GxE) on multi-seasonal data for the juice yield (l/ha) parameter of sweet sorghum. Therefore, stability analysis was carried out by Eberhart and Russell 1966 model to identify stable genotypes for juice yield which is great in demand by distilleries. From the comparative ranking of the environment, it was clear that the *kharif* sowing showed positive environmental indicators for juice yield (l/ha). Whereas, *rabi* and *summer* seasons showed negative environmental indicators, suggesting that the environment is unfavorable for this trait. Based on the stability analysis, the genetic standard the genotype RSSV-594, RSSV-512, RSSV-585, RSSV-466, RSSV-509, and RSSV-589 showed average stability, while CSH-47 performed below average. The genotypes such as RSSV-552 and RSSV-313 exhibited unstable performance across different environments.

Keywords: Sweet sorghum, sowing season, juice yield, genotype x environment interaction

Introduction
Sorghum [*Sorghum bicolor* (L.) Moench] is a hardy and adaptable crop from the Poaceae family, with a rich history of cultivation dating back to 8000-6000 BCE in Africa, particularly in the Nile Valley of Egypt and Sudan (Venkateswaran *et al.*, 2019) [9]. India, considered a secondary center of origin, has evidence of sorghum cultivation as early as 4500 BCE, particularly during the Harappan civilization (Winchell *et al.*, 2017) [10].

In 2022, global sorghum production reached approximately 60.06 million tonnes, harvested from an area of about 44.7 million hectares. India, with a production of 3.8 million tonnes in 2022-2023, ranks seventh globally, with major contributions from states such as Maharashtra, Karnataka, and Rajasthan (ipad.fas.usda.gov).

Sweet sorghum, known as the "sugarcane of the desert," thrives in arid climates and was initially introduced in the U.S. for sugar production. Over time, its use shifted to syrup and forage, and it is now seen as a promising biofuel crop for bioethanol production, offering a sustainable solution to reduce dependence on fossil fuels (Dar *et al*., 2018 [1]; Gutjahr *et al*., 2013) [2].

Sweet sorghum thrives under low water conditions and can grow in a variety of climates, including tropical, subtropical, and arid regions. It requires only one-third of the water needed by sugarcane and exhibits drought tolerance, even remaining dormant during dry periods (Reddy *et al*., 2005) [7]. Moreover, sweet sorghum's C_4 photosynthetic system allows it to accumulate biomass quickly, making it an ideal candidate for biofuel production (Ratnavathi *et al.*, 2004) [5]. Its ability to generate ethanol, a renewable fuel that can be blended with gasoline, further highlights its potential in reducing fossil fuel consumption (Wu *et al.*, 2010) [11].

In short, sweet sorghum is considered to be one of the best alternative source for biofuel production, to achieve targeted bioethanol production there is a continuous demand of feedstock to distilleries all year round in India. Sweet sorghum is usually planted during the rainy season to get good juice and bio-yield, but it's habituated poorly to *rabi* and *summer* season. This means that the genes that work best during the *kharif* season are not necessary the best performers in the *rabi* or *summer* season. However, the environment specific genotypes need to be study through the genetic testing under a variety of climatic conditions which would helpful to recommend well balanced genotypes over the seasons.

Material and Methods
A field experiment was conducted during 2022-23. The twenty-three sweet sorghum genotypes and one hybrid were grown at PGI, Research Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar Maharashtra (India). Total three sowing seasons were used to mark mean calculations: i) *kharif*- 1st july 2022 ii) *rabi*- 1st October 2022 iii) *summer*- 1st February 2023. The experiment was carried out in Randomized Block Design with two replications. The gross and net plot size were 4.20 x 2.40 m^2 and 3.90 x 2.40 m^2, respectively, with spacing 60 x 15 cm and the recommended dose of fertilizer was 100:50:50 NPK kg/ha applied to the soil. The half dose of nitrogen and full dose of phosphorous and potash was given at the time of sowing. The remaining half dose of nitrogen was applied at 35 days after sowing. The three plants in each plot were randomly selected in a net plot area and tagged for recording of green cane yield parameter. The experimental data were analyzed using Eberhart and Russell (1966) model based on these stability parameters, regression coefficient (S^2di), mean performance ($\bar{x}$) and linear response (bi).

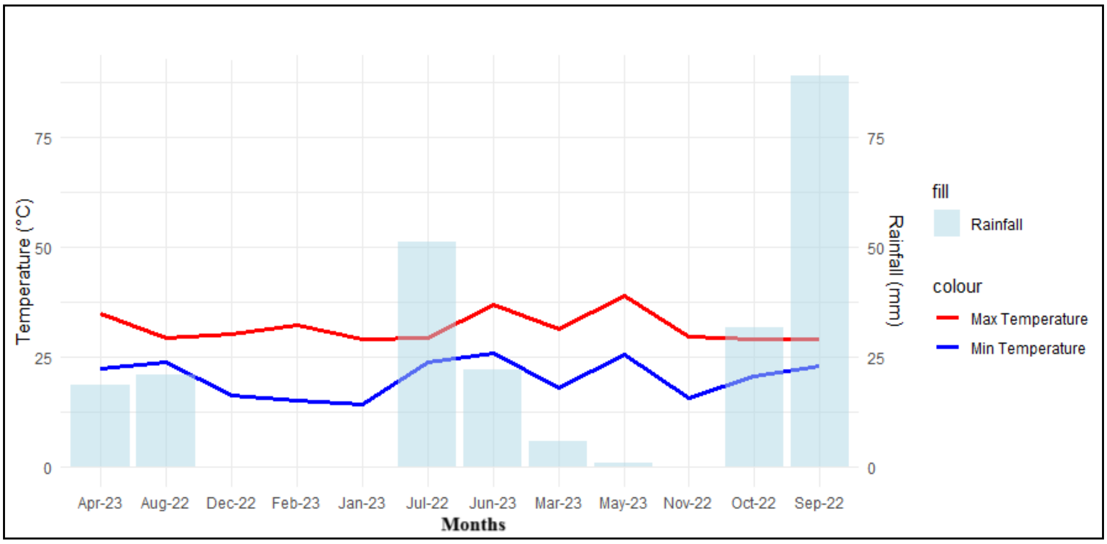

Fig 1: Weather data during the experimental period from July 2022 to June 2023

Results and Discussion

Effect of different seasons on juice yield (l/ha):

The juice yield is an associated trait of biomass component in sweet sorghum. From the results, the grand mean of juice yield (l/ha) was recorded highest in the *kharif* season (9018 l/ha) due to optimal rainfall, temperatures, and photoperiods. Sweet sorghum's photoperiod sensitivity results in better growth and productivity in the *kharif* season, with taller plants and higher juice extractability. Ratnavathi *et al.* (2012) [6] highlighted juice extractability as a key factor influencing yield, particularly in June plantings. While *rabi* season

recorded lower yield (5475 l/ha). The combination of lower temperature, reduced solar radiation, moisture stress, suboptimal conditions, including limited water availability and reduced biomass production makes the *rabi* season less conductive to high juice yield in sweet sorghum compared to *kharif* season. Pagire, (2020) [3] have noted that *kharif* season's higher temperature and optimum moisture level during the growth period result in better biomass production, and thus higher juice content than rest of sowings, and least yield was recorded in *summer* season (4565 l/ha), likely due to high temperatures and water stress, which hinder biomass accumulation and sugar translocation. Similar result was reported was Pagire (2020) [3]. The decrease in juice yield post-maturity supports findings that sugars are rapidly converted as the plant matures, reducing extractable juice volume. Rains *et al.* (1989) [4] whom indicated that juice yield is dependent on length of growing season and the amount of radiation intercepted.

Table 1: Effect of sowing season on juice yield (l/ha) at physiological maturity

Sr No	Genotypes	Juice yield (l/ha)		
		Kharif	***Rabi***	***Summer***
1	RSSV-522	8839	4482	3450
2	RSSV-542	9551	4797	4046
3	RSSV-552	8562	7052	4907
4	RSSV-594	9802	7563	6516
5	RSSV-595	9330	6223	3381
6	RSSV-512	10108	7782	6755
7	RSSV-585	9191	5945	4751
8	RSSV-313	11617	6682	6303
9	RSSV-355	6947	3671	3387
10	RSSV-466	10269	8125	6885
11	RSSV-509	10034	6492	5883
12	RSSV-558	8502	4056	3644
13	RSSV-575	8951	5699	3718
14	RSSV-589	9654	5830	5522
15	RSSV-635	9302	4777	4073
16	RSSV-638	6983	3463	3070
17	RSSV-639	9149	4832	4046
18	RSSV-640	8747	4356	4201
19	RSSV-642	7826	4278	3959
20	RSSV-643	6437	4019	2607
21	RSSV-644	6686	3352	2612
22	CSV19SS	9232	5019	4448
23	CSH-47	12041	8234	7226
24	SSV-84	8682	4667	4181
	Mean	9018	5475	4565
	SEm	330	229	194
	C.D. 5%	965	671	568

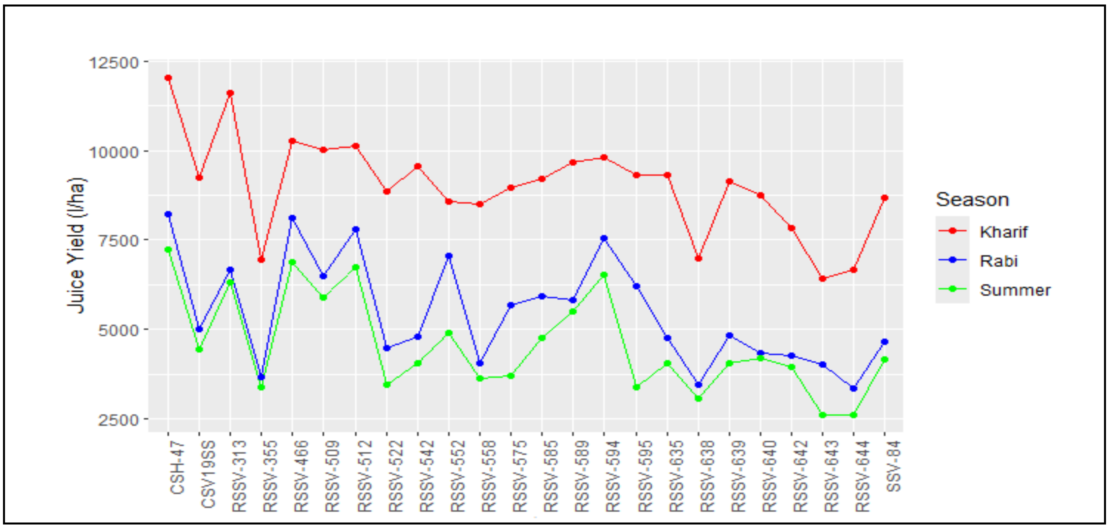

Fig 2: Genotype x Environment interaction in juice yield (1/ha)

Table 2: Estimate of environmental index for juice yield character under different environment

Sr. No.	**Character**	**Environmental index**		
		Kharif	**Rabi**	**Summer**
1	Juice yield (l/ha)	2665.507	-878.014	-1787.493

Table 3: Pooled analysis of variance for juice yield of sweet sorghum genotypes

Source	**Df**	**Juice yield (l/ha)**
Genotype (G)	23	5464057.61$^{\#\#++**}$
E+(G × E) (E)	48	5829876.59$^{\#\#++**}$
Environment	2	132851592.22$^{\#\#++**}$
(G × E)	46	307193.30**
Environment (L)	1	265703184.44^{++**}
(G × E) (L)	23	366865.30**
P.D.	24	237207.91**
P.E.	69	66325.45
Total		5711371.85

$^{\#,\#,\#}$ Significance at 0.05 and 0.01 respectively when tested against G×E
$^{+,++}$ Significance at 0.05 and 0.01 respectively when tested against P.D (Pooled deviation)
*,** Significance at 0.05 and 0.01 respectively when tested against P.E (Pooled error)

Analysis of variance for stability: The pooled analysis of variance for juice yield parameter showed highly significant differences among the genotypes and environments.

Table 4: Estimate of stability of sweet sorghum genotypes for juice yield (l/ha) for different environment

Sr. No.	**Genotypes**	**Juice yield (l/ha)**		
		$\bar{X}$	**Bi**	**S^2di**
1.	RSSV-522	5590.50	1.216*	-64147.80
2.	RSSV-542	6131.00	1.27	16023.60
3.	RSSV-552	6840.20	0.71	1100886.3***
4.	RSSV-594	7960.80	0.71	17377.20
5.	RSSV-595	6311.50	1.21	1513214.3***
6.	RSSV-512	8215.00	0.73	2936.80
7.	RSSV-585	6629.00	0.97	-17732.40
8.	RSSV-313	8200.70	1.25	230891.9*
9.	RSSV-355	4668.20	0.84	50354.10
10	RSSV-466	8426.50	0.72	112619.60
11.	RSSV-509	7469.80	0.95	-33066.30
12.	RSSV-558	5400.70	1.14	134008.00
13.	RSSV-575	6122.30	1.10	429408.9**
14.	RSSV-589	7002.20	0.97	104568.60
15.	RSSV-635	6051.00	1.20	11948.70
16.	RSSV-638	4505.30	0.91	31242.40
17.	RSSV-639	6008.80	1.17	-27801.90
18.	RSSV-640	5768.00	1.08	290485.2*

19.	RSSV-642	5354.50	0.91	65079.90
20.	RSSV-643	4354.30	0.81	169813.10
21.	RSSV-644	4216.80	0.92	-61964.00
22.	CSV19SS	6233.30	1.11	31290.10
23.	CSH-47	9166.80	1.080*	-66614.00
24.	SSV-84	5843.50	1.05	44855.00
	Population Mean	6353	1.00	
	S.E. m±	344.40	0.10	

Conclusion

As per (Eberhart and Russell 1966) model the selection of ideal genotypes is based on high mean performance, regression coefficient (bi) nearer to unity and deviation from regression (S^2di) as small as possible or zero. From the relative ranking of the environment (table 2) as evident from additive environment it is observed that *kharif* sowing shown positive environmental indices for juice yield (l/ha) and *rabi* and *summer* seasons showed negative environmental indices suggesting that environment was unfavorable for this trait. The findings supports to several researchers like Shinde *et al*. (2019) [8]. Based on stability parameters, among the 23 sweet sorghum genotypes and one hybrid the genotype RSSV-594, RSSV-512, RSSV-585, RSSV-466, RSSV-509, and RSSV-589 showed average stability, while CSH-47 performed below average. Genotypes such as RSSV-552 and RSSV-313 exhibited unstable performance across different environments, as assessed using regression coefficient (S^2di), mean performance ($\bar{X}$), and linear response (bi). The recommendation derived from this study is, the *kharif* is the most appropriate and suitable sowing time for sweet sorghum cultivation to get maximum juice yield which result in maximum bioethanol production as compared to *rabi* and *summer* season.

Therefore, this research would helpful to reduce high fluctuations of bioethanol production in semi-arid India.

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