International Journal of Plant & Soil Science

32(16): 43-49, 2020; Article no.IJPSS.62563
ISSN: 2320-7035

Combining Ability Studies for Identifying High Sugar Yielding Sweet Sorghum [*Sorghum bicolor* (L.) Moench] Genotypes

B. C. Nandeshwar[1*], Beka Biri[1], Alemayehu Dugassa[1] and A. G. Bhoite[2]

[1]Department of Plant Sciences, Faculty of Agriculture, Shambu Campus, Wollega University, Post Box No-38, Ethiopia.
[2]Department of Agricultural Botany, College of Agriculture, Kolhapur, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author BCN designed the study, performed the field experiment, generated data and wrote the whole manuscript. Authors BB and AD performed the statistical analysis, edited, read and approved the final manuscript. Author AGB read and approved the manuscript.

Article Information

DOI: 10.9734/IJPSS/2020/v32i1630379
Editor(s):
(1) Dr. L. S. Ayeni, Adeyemi College of Education, Nigeria.
Reviewers:
(1) Giovani Olegario da Silva, Universidade Federal de Pelotas (UFPel), Brazil.
(2) Derivaldo Pureza da Cruz, State University of Northern Fluminense, Brazil.
Complete Peer review History: http://www.sdiarticle4.com/review-history/62563

Original Research Article

Received 04 September 2020
Accepted 16 November 2020
Published 11 December 2020

ABSTRACT

Combining ability analysis provides information about the gene action involved in the expression of a trait and facilitates breeding of superior cultivars. Hence, 45 hybrids evolved from 10 parent half-diallel were evaluated for combining ability to identify good general combiners and superior cross combinations for high ethanol yield from sweet sorghum. RSSV-21-2 has been identified as the best general combiner. It can be used in pedigree breeding programme for the incorporation of desired traits for enhancing ethanol yield. ARS-SS-35-1 × NSS-218 and ARS-SS-83 × NSS-221-2 have been identified as the best specific combinations. These could be exploited in heterosis breeding programme.

Keywords: Sweet sorghum; half-diallel; general combining ability; specific combining ability; ethanol.

**Corresponding author: E-mail: bhupesh_nandeshwar@rediffmail.com;*

1. INTRODUCTION

Sorghums that have 10-25% sugar in stalk juice at grain maturity are called sweet sorghums [1]. Sweet sorghum is a multipurpose crop which can be used for the production of value-added products like jaggery, syrup and most importantly, fuel alcohol (ethanol) besides food, fiber and fodder. With growing concerns for environmental pollution, energy security, and future oil supplies, the global community is seeking non-petroleum based alternative fuels, along with more advanced energy technologies to increase energy use efficiency [2]. Implementing the Government of India's policy to use 5% ethanol-doped petrol is a step towards reducing air pollution associated with the use of fossil fuels [3]. Ethanol is one of the best tools to fight air pollution because it burns much cleaner than gasoline and reduces most exhaust emissions making it a green fuel.

Sweet sorghum has shown potential as a raw material for fuel-grade ethanol production due to its rapid growth rate, early maturity, high water use efficiency, limited fertilizer requirement and wide adaptability. The feasibility of converting stalk sugars to ethanol prompted researchers to evaluate the potential of sweet sorghum as an alternative crop for ethanol production. Ratnavathi et al. [4] studied genotypic variation for ethanol production from sweet sorghum juice. It is highly imperative to breed new cultivars of sweet sorghum with high sugar content in combination with other desirable agronomic traits. It might become a boon to the farmers in India and may have extensive potential for the ethanol industry [5].

The research related to sweet sorghum in India is in its infancy. Moreover, references on the genetic studies in sweet sorghum are Scanty. Hence, there is an urgent need to characterize the existing material on breeding grounds so as to have an efficient hybridization programme for sweet sorghum improvement. Keeping this in view, an attempt has been made to identify the good general combiners and specific cross combinations along with suggestions for the adoption of breeding methodology for the improvement of sweet sorghum. This in turn may help in breeding superior sweet sorghum varieties or hybrids and in accelerating ethanol production and development of ethanol-based industries in India.

2. MATERIALS AND METHODS

The research was carried out at the College of Agriculture, Kolhapur, Maharashtra, India in year 2016-17. Material comprised of 10 parents *viz.,* Keller, ARI-SS-35-1, ARI-SS-83, NSS-216, NSS-218, NSS-221-2, RSSV-15-2, RSSV-21-2, RSSV-34-2 and RSSV-49 crossed in a half-diallel fashion. Forty-five hybrids thus obtained and the 10 parents were grown in a randomized block design with three replications. Plants were raised at a spacing of 15 × 45 cm. The recommended cultural practices were followed to raise a good crop. Five plants were randomly selected for recording observations on eleven characters, *viz.,* plant height (cm), stem diameter (cm), grain yield (q/ ha), stripped stalk yield (t/ha), juice extraction (%), juice yield (t/ha), reducing sugar (%), total reducing sugar (%), non-reducing sugar (%), total sugars (%) and total sugar index (q/ha). Sugar analysis was done as per Lane and Eynon [6]. Non-reducing sugar was calculated as per Rao et al. [7].

Non-reducing Sugar (%) = [Total Reducing Sugar (%) – Reducing Sugar (%)] × 0.95

Total Sugars (%) = Reducing Sugar (%) + Non-reducing Sugar (%)

Total Sugar Index (q/ ha) =[Juice Yield (t/ ha) × Total Sugars (%)] / 10

Recorded data was subjected to the combining ability analysis according to model 1, method 2 of Griffing [8].

3. RESULTS AND DISCUSSION

Analysis of variance (Table 1) revealed the significance of both GCA and SCA effects except for the non-significance of SCA for stem diameter, total reducing sugar, non-reducing sugar and total sugars thus indicating the importance of both additive and non-additive gene actions. However, GCA/SCA ratio indicated the preponderance of additive and additive × additive gene action for all the traits under study. Hence, selfing followed by progeny selection would be rewarding for these traits. Similar results have also been reported by Ramalingam and Rangasamy [9]. On the contrary, Indhubala et al. [10] and Sandeep et al. [11] have reported the preponderance of non-additive gene action for quality traits in sweet sorghum. The success of any plant breeding programme largely depends on the appropriate choice of parents.

Table 1. Analysis of variance for combining ability

Source	Df	Plant Height (Cm)	Stem Diameter (Cm)	Grain Yield (Q/ Ha)	Stripped Stalk Yield (T/ Ha)	Juice Extraction (%)	Juice Yield (T/ Ha)	Reducing Sugar (%)	Total Reducing Sugar (%)	Non-Reducing Sugar(%)	Total Sugars (%)	Total Sugar Index (Q/ Ha)
GCA	9	2812.429**	0.032**	0.034**	24.297**	91.667**	5.139**	0.260**	5.306**	5.686**	4.864**	96.308**
SCA	45	739.627**	0.013	0.008**	5.752**	13.689**	1.176**	0.130**	1.051	1.106	0.929	16.245**
Error	108	117.249	0.010	0.00024	1.725	5.137	0.277	0.061	0.951	1.062	0.883	5.149
GCA/ SCA		3.80	2.46	4.25	4.22	6.70	4.40	2.00	5.05	5.14	5.23	5.93

***, *: Significant and 1 and 5% level, respectively*

Table 2. Estimates of general combining ability effects and *per se* performance of parents

Sr. No.	Parent	Plant height (cm)	Stem diameter (cm)	Grain yield (q/ ha)	Stripped stalk yield (t/ ha)	Juice extraction (%)	Juice yield (t/ ha)	Reducing sugar (%)	Total reducing sugar (%)	Non-reducing sugar (%)	Total sugars (%)	Total sugar index (q/ ha)
1	Keller	-11.227**	-0.003	0.058**	-1.245**	4.789**	0.019	-0.186**	0.601*	0.859**	0.673*	1.023
2	ARI-SS-35-1	4.087	-0.107**	-0.031**	0.967**	1.614*	0.717**	0.208**	-0.123	-0.383	-0.175	2.258**
3	ARI-SS-83	2.837	0.049	-0.008	-1.092**	-3.944**	-1.002**	-0.143*	-0.100	0.061	-0.078	-3.577**
4	NSS-216	-18.338**	-0.056*	0.053**	-0.371	0.903	-0.041	0.247**	0.255	-0.012	0.233	0.125
5	NSS-218	-2.680	0.023	-0.036**	0.945**	1.060	0.610**	0.066	0.508	0.384	0.450	2.815**
6	NSS-221-2	-0.791	0.003	-0.017**	-0.481	1.032	-0.054	-0.062	-0.303	0.299	-0.363	-0.967
7	RSSV-15-2	11.948**	0.053	-0.026**	0.886*	-0.073	0.351*	-0.008	0.051	0.109	0.099	1.245*
8	RSSV-21-2	29.245**	0.057*	-0.071**	2.239**	-4.929**	0.243	-0.162*	0.874**	0.974**	0.812**	2.092**
9	RSSV-34-2	-23.394**	-0.024	0.101**	-2.624**	-0.581	-1.265**	0.025	-1.537**	-1.458**	-1.433**	-6.107**
10	RSSV-49	8.314**	0.004	-0.023**	0.774*	0.130	0.421**	0.015	-0.225	-0.235	-0.219	1.093

***, *: Significant at 1 and 5% level, respectively*

Table 3. Best specific combinations identified

S. No.	Cross	Plant height (cm)	Stem diameter (cm)	Grain yield (q/ ha)	Stripped stalk yield (t/ ha)	Juice extraction (%)	Juice yield (t/ ha)	Reducing sugar (%)	Total reducing sugar (%)	Non-reducing sugar (%)	Total sugars (%)	Total sugar index (q/ ha)
1	ARI-SS-35-1 × NSS-218	23.839**	0.075	-0.058**	-3.514	1.822**	-0.258	1.541	1.750*	1.490	9.219**	5.347**
2	ARI-SS-83 × NSS-221-2	18.200*	0.202*	0.016	-0.081	0.997*	-0.085	0.154	0.212	0.144	3.803*	2.339*
3	Keller × ARI-SS-83	48.236**	0.055	0.001	-3.621	1.871**	0.046	0.087	-0.195	-0.117	6.249**	5.253**
4	ARI-SS-83 × RSSV-21-2	19.631*	0.118	0.070**	5.633**	0.767	0.475*	0.262	-0.305	0.193	2.784	-0.174
5	NSS-218 × RSSV-15-2	28.378**	0.096	-0.053**	-2.290	1.130*	-0.456*	0.443	0.774	0.320	4.273*	3.225**
6	RSSV-21-2 × RSSV-49	-0.181	0.017	0.059**	0.563	1.197**	-0.153	0.203	0.288	0.134	4.294*	2.897**

***, *: Significant at 1 and 5% level, respectively*

Table 4. Estimates of specific combining ability effects and *per se* performance of crosses

S. No.	Character	No. of F_1s with significant SCA effect in desired direction	Crosses with maximum SCA effects	SCA effect	*Per se* performance	GCA status of the parents involved in cross combination
1	Plant height (cm)	14	Keller × ARI-SS-83	48.236**	355.9	L × L
			Keller × RSSV-21-2	43.695**	377.7	L × H
			Keller × RSSV-49	40.493**	353.6	L × H
2	Stem diameter (cm)	3	ARI-SS-83 × NSS-221-2	0.202*	1.96	L × L
			Keller × RSSV-49	0.186*	1.89	L × L
			NSS-221-2 × RSSV-15-2	0.182*	1.58	L × L
3	Grain yield (q/ ha)	17	Keller × NSS-216	0.260**	12.13	H × H
			Keller × RSSV-34-2	0.232**	12.58	H × H
			ARI-SS-83 × NSS-218	0.100**	5.11	L × L
4	Stripped stalk yield (t/ ha)	8	ARI-SS-35-1 × NSS-218	5.347**	48.85	H × H
			Keller × ARI-SS-83	5.253**	39.20	L × L
			Keller × ARI-SS-35-1	3.654**	40.22	L × H
5	Juice extraction (%)	5	Keller × RSSV-15-2	5.738**	56.00	H × L
			ARI-SS-83 × RSSV-21-2	5.633**	42.31	L × L
			Keller × RSSV-34-2	5.499**	55.25	H × L
6	Juice Yield (t/ ha)	12	Keller × ARI-SS-83	1.871**	16.76	L × L
			ARI-SS-35-1 × NSS-218	1.822**	21.78	H × H
			Keller × ARI-SS-35-1	1.795**	20.41	L × H
7	Reducing sugar (%)	5	NSS-216 × NSS-218	0.759**	2.97	H × L
			ARI-SS-35-1 × RSSV-21-2	0.725**	2.66	H × L
			ARI-SS-83 × RSSV-21-2	0.475*	2.06	L × L
8	Total reducing sugar (%)	2	Keller × NSS-221-2	2.740**	18.86	H × L
			NSS-216 × RSSV-34-2	1.801*	16.34	L × L
9	Non-reducing sugar (%)	4	Keller × NSS-221-2	2.514**	16.37	H × L
			NSS-216 × RSSV-34-2	1.900*	13.73	L × L
			RSSV-15-2 × RSSV-49	1.855*	11.32	L × L
10	Total sugars (%)	2	Keller × NSS-221-2	2.360**	17.86	H × L
			NSS-216 × RSSV-34-2	1.630*	15.62	L × L
11	Total sugar index (q/ ha)	9	ARI-SS-35-1 × NSS-218	9.219**	36.87	H × H
			NSS-216 × RSSV-21-2	6.776**	31.57	L × H
			Keller × ARI-SS-83	6.249**	26.27	L × L

***, *: Significant at 1 and 5% level, respectively*

Hence, parents chosen for the present study were assessed based on combining ability effects. No single parent was a good general combiner for all the characters. The parents showing high GCA status for each character (shown as bold value in table 2) can be used in recombination breeding programme. This is likely to result in superior progenies which in turn may provide the raw material for the selection of superior lines. However, when all the characters were considered together, RSSV-21-2 was the best general combiner followed by Keller and ARI-SS-35-1 (Table 2). These parents appear to transmit genes with additive effects to their progeny for maximum number of traits responsible for enhancing ethanol yield. However, highest per se performance did not point to the best performer on the basis of GCA effects (Table 2), hence indicating no correspondence between the GCA effects and per se performance. On the contrary, Ramalingam and Rangasamy [9] reported correspondence between per se performance and the GCA effects.

The SCA is a useful index to determine usefulness of a particular cross combination for the exploitation of heterosis. Perusal of data revealed that there was correspondence between the per se performance and SCA effects for most of the cross combinations. ARI-SS-35-1 × NSS-218 and ARI-SS-83 × NSS-221-2 were the best cross combinations on the basis of SCA effects, as these cross combinations have excelled for maximum number of traits contributing to high ethanol yield (Table 3). The best specific combinations identified could be exploited in heterosis breeding. Audilakshmi et al. [12] have also recommended the adoption of heterosis breeding for improving the traits associated with high ethanol yield from sweet sorghum stalks. Further, it was observed that cross combinations giving high SCA effects for different traits belong to the parents exhibiting H × H, H × L, L × H and L × L GCA status, with most of them involving at least one parent with high GCA status (Table 4). This study is in accordance with Sandeep et al. [11].

The H × H GCA effects can be attributed to the additive type of interaction between the parents. In view of the considerable importance of the additive effects and possibility of their fixation, single plant selections may be carried out in segregating generations to evolve superior inbreeds. On the other hand, high SCA effects in crosses involving parents with H × L and L × H GCA status may be attributed to their dominant × recessive interactions. In such cases, biparental crossing between two sweet stalk F2 derivatives and advancing to F6 would be more effective rather than following pedigree selection. This may break the undesirable linkages and through recombination can produce transgressive segregants in the subsequent generations thus providing an opportunity for obtaining more desirable selections. These findings are in agreement with the reports of Audilakshmi et al. [12].

4. CONCLUSION

Further, epistatic interactions seem to be responsible for cross combinations which exhibit high SCA effects though parents are of low GCA status.

ACKNOWLEDGEMENT

We thank to Indian Council of Agricultural Research (ICAR), New Delhi, India for funding the research project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/62563