Original Research Article

Decoding Genetic Symphony: Understanding Gene Dynamics and Synergies for Enhanced Sorghum Yield. (*Sorghum bicolor* [L.] Monech)

Abstract

In this investigation usingline × tester analysis, fifteen parents (3 CMS females and 12 males) and 36 hybrids, including the standard check CSH-25, underwent evaluation in a randomized block design with three replications. Notably, significant general combining ability variances for 1000-seed weight and highly significant specific combining ability variances for all traits were observed. The research highlights the prevalence of additive genetic variance in 1000-seed weight and the combined influence of additive and nonadditive gene effects in panicle length ratio. Recognized good general combiners, such as SR (2991 ,2950 2872, 2984) and 691, provide valuable insights for breeding strategies. Subsequent evaluations of promising hybrids, particularly 691 A × SR 2991, 691 A × SR 2872 and 691 A × SR 2950 hold potential for optimizing grain yield, panicle length, and dwarfness. This research offers nuanced insights for future Sorghum breeding programs, enhancing understanding of gene dynamics for improved productivity.

Keywords:Sorghum, General Combining Ability Insights, Additive-Nonadditive Gene effects, Sustainable Crop Productivity.

Introduction

Sorghum (Sorghum bicolor [L.] Moench) is an important cereal crop in India that is used for dual purposes, i.e., feed and fodder.The word sorghum is derived from the Spanish word “*Sorgo*”, which means “rising above”. (Vavilov, 1935). Sorghum belongs to the natural order Poales, tribe Andropogenae, and family Poaceae; it includes annual sorghum with ten pairs of chromosomes (2n = 20). The genome size of sorghum is 730 Mb (Paterson *et al*., 2009). Sorghum is normally a self-pollinated crop, but cross-pollination averages approximately six to ten percent and may reach as high as 30 percent in Sudan grass. Cultivated sorghum is grouped into five races based on panicle morphology,*viz., bicolor, kafir, guinea, caudatum* and *durra*. (Harlan and Dewet, 1972). It originated in the Ethiopian region of East Africa and is now grown in more than 80 countries across the globe. India is the second-largest producer of sorghum in the world (Anonymous, 2019[a]). According to statistical data, the area under which this crop is cultivated in India is approximately 5.65 million hectares, with an annual production of 4.50 million tons and a productivity of 500 kg/ha. (Anonymous, 2019[b]).

Line × tester analysis provides information about the role of the cytoplasm in the effects of GCA on A-lines and on the effects of SCA and heterosis of sorghum hybrids. The concept of combining ability is considered to be a landmark in the development of efficient and effective breeding methodologies for different crop plants. Analysis of combining ability provides guidelines for assessing the relative quality of the parental material. By utilizing this technique, breeders can choose the best combination of parents as well as specific cross combinations for further exploitation. The parental material may be used to develop hybrids or build up populations with desirable and fixable genes depending upon the nature of the gene action.

The assessment of the GCA effects of hybrid parents is important for determining their suitability for developing hybrids, as the mean performance of parental lines need not always be a good indicator of their GCA effects. Hybridization technology results in increased yield, profitability and adaptability to stressful environments. The success of the breeding procedure is determined by useful gene combinations organized in the form of good combining lines and the isolation of valuable germplasms. Accordingly, good knowledge of the gene action involved in the inheritance of quantitative characters of economic importance is required to develop an efficient breeding plan leading to rapid improvement.

Materials and methods

The present investigation was carried out at the College Farm, N.M. College of Agriculture, Navsari Agricultural University, Navsari during the summer and Kharif, 2018. The experimental material for the present investigation comprised three male sterile lines used as female parents and twelve testers used as male parents.All the experimental materials were collected from the Main Sorghum Research Station, Athwa Farm, NavsariAgricultural University, Surat (Gujarat). These females and males were crossed by hand pollination in a line × tester mating system during the summer of 2018.The seeds of individual parental lines and hybrid seeds obtained from female plants were harvested. All the hybrids, along with their 15 parents and one standard check, were grown in accordance with a randomized block design with three replications during *Kharif,*2018. Parents and 36 F1 plants were sown in a single row 3 meters in length. The row-to-row and plant-to-plant distances were 45 cm and 15 cm, respectively. For recording, five competitive plants were randomly selected from each plot forall three replications, and mean observations were taken. For observation on days to 50 percent flowering and days to maturity were recorded on a plot basis.

The replicationwise mean values for all the characteristics were subjected to statistical analysis for computing the mean, variance, general combining ability (GCA) and specific combing ability (SCA).The variation among hybrids was further partitioned into sources attributed to general and specific combining ability components in accordance with the procedure of Kempthorne (1957).

Results and discussion

Analysis of variance

Analysis of variance for combining ability revealed that general combining ability (gca) variance was significant only for 1000 seed weight, indicating that GCA variance significantly contributed to these characteristics. On the other hand,the specific combining ability (sca) variance was highly significant for all the characters studied, revealing the significant contribution of hybrids to the variance in SCA components for almost all the characters (Table1). Similar findings were also reported by Premlatha *et al*. (2006) and Gite *et al.* (2015).

Gene action

A clear picture of the relative importance of additive and nonadditive gene effects in controlling a character can be obtained on the basis of the general predictability ratio (Baker, 1978). In the present study, the general predictability ratio reached 0.50 for all the tested parameters except for panicle length and 1000-seed weight,which indicates that the majority of the genes affected by these traits are nonadditive and emphasize the use of a heterosis breeding approach to exploit available vigour.In the case of the 1000-seed weight, the general predictability ratio closed to unity, revealing the preponderance of the additive genetic system in the inheritance of that characteristic, which emphasized the effectiveness of the selection in future breeding programmes. However, when the ratio was between 0.51 and 0.70 for panicle length, this difference pinpointed the importance of both additive and nonadditive gene effects in the inheritance of this trait. Both additive and nonadditive genetic variances can be utilized at a time through reciprocal recurrent selection for population improvement in the present material.The preponderance of nonadditive types of gene action for grain yield and other traits was previously reported by Bhavsar and Borikar (2002), Wadikar *et al.* (2007), and Thakare *et al.* (2014).The preponderance of the additive type of gene action for determining 1000 seed weight was previously reported by Chikuta *et al.*(2017).

Combined ability analysis

General combining ability

The gca effects of the parents revealed that none of them was found to be superior for all the characters. (Table2). An overall appraisal of the effects of gca revealed that four male parents, namely, SR 2991, SR 2950,SR 2872 and SR 2984, and one female parent, 691,were good general combiners for grain yield. Among these good general combiners for grain yield, the topper male parents SR 2991 and SR 2950 were found to be good general combiners for all the characters studied, except for SR 2950 for plant height. These can be used in future breeding programmes for the development of early-maturing and high-yielding hybrids or varieties that combine all these characteristics. While female 691 A was depicted as a good combiner for days to 50 percent flowering and 1000 seed weight and male SR 2872 was depicted for early flowering, both of these traits can be utilized for the development of genotypes suitable for terminal draught prone areas. By critical examination of the other traits of the parents, SR 2993, SR 2957 and SR 2997 were found to be good general combiners for determining the weight and panicle length of the 1000 seeds. These findings can be utilized in future breeding for the development of promising genotypes with bold grains and long panicle lengths. For days to 50 percent flowering, parents SR 2997 and SR 2993 exhibited good general combining ability. However, the parents of SR 2993 and SR 2997 were observed tobe good general combiners for early maturity and can be utilized for the development of early hybrids or varieties. For plant height, the parents SR 2914,SR 2957,SR 2997 and SR 2999 were reported tobe good combiners for dwarfness and can be utilized for a dwarf breeding programme. These findings are similar to those of Wadikar *et al.* (2006), Prabhakar and Raut (2010), Prabhakar *et al.* (2013), Ghorade *et al.* (2014), Thakare *et al.* (2014), Kalpande *et al.* (2015), More *et al.* (2015), Rani *et al.* (2015) and Chikuta *et al.*(2017).

Specific combining ability

The cross combinations with high SCA effects differed from character to character and displayed differences in their ranking. None of the cross combinations reported consistently high SCA effects for any of the characteristics. (Table 3)

Based on a critical examination of sca effects, nine hybrids,*viz.*, 691 A × SR 2872, 2219 A × SR 2914, 27 A × SR 2997, 27 A × SR 2997, 2219 A × SR 2957, 27 A × SR 2993, 691 A × SR 2926, 2219 A × SR 2984 and2219 A × SR 2999, exhibited positive significant sca effects in desirable directions and emerged as the best specific cross combination for grain yield. Among these, the best specific cross combination for grain yield, 691A × SR 2926, was also found to be a good specific combination for early flowering, early maturity and panicle length; this combination can be utilized in future breeding programmes for the development of high-yielding genotypes or directly exploited as early-maturing and high-yielding hybrids. 691 A × SR 2872 and 27 A × SR 2990 were used for determining the 1000 seed weight, and 2219 A × SR 2914 was used for early flowering. 27A × SR 2990 and 2219A × SR 2957 also exhibited superior dwarfness in addition to grain yield and can be utilized in breeding programs for improvements in these traits in conjunction with grain yield.Critical examination of crosses for other traits revealed that, in the case of earliness,the cross combinations 691A × SR 2991, 27A × SR 2872, 2219A × SR 2990 and 27A × SR 2950 exhibitedsignificant negative sca effects and could be best suited for breeding for earliness. These findings are supported by similar results reported by Gaikwad *et al.* (2002), Premlatha *et al.* (2006), Wadikar *et al.* (2007), and Chaudhari *et al.* (2016).Considering panicle length, the crosses 691 A × SR 2914, 27A × SR 2872 and 27 A × SR 2990 had registered high sca effects in a positive direction. Similar results were observed by Murukar *et al.* (2005) and Ghorade *et al.* (2017).

Among the most important yield-attributing traits for 1000 seed weight, the 27A × SR 2914, 691A × SR 2872 and 27A × SR 2990 crosses exhibited strong positive sca effects. Similar results are reported by Girma *et al.* (2010) and Chikuta *et al.* (2017).From the observations made in the present study, the following relevant points emerged.The inspection of SCA effects and the mean performance of individual crosses indicated that the crosses having high SCA effects did not always possess a high mean.

The crosses identified as having a high SCA effect on grain yield per plant had a high 1000-seed weight.Thus, the 1000 mg/m2 seed weight was the most important yield-related trait. The crosses exhibiting high SCA effects were not always good × good combinations with respect to mean performance. These devices can be further evaluated for their preeminence in terms of performance. A total of 691 A × SR 2872 exhibited greater grain yield and high SCA.

These top performing crosses involved all the types of parental combinations: Good × Good, Average × Good, Poor × Goodand Average × Average. Only two crosses involved good parental combination, and at least one of the parents was either a poor or an average parent in the rest of the crosses. The SCA variance markedly surpassed the GCA variance, thereby resulting in a very low sca/gca ratio, which pinpointed the prominent prevalence of nonadditive gene action ruling the inheritance of grain yield. Notably, the most promising standard heterotic hybrids for grain yield did not exhibit high heterosis for all yield attributing traits, and there was mutual complementation of various yield-attributing characteristics.

Pertaining to the evaluation of combining ability performance, it can be concluded that the hybrids 691A × SR 2991,691A × SR 2872, 691A × SR 2950, 27A × SR 2950 and 2219A× SR 2997 appeared to be more promising for grain yield, panicle length and dwarfness; hence,the stability performance of these crossescouldbe checked and offer a scope for the improvement of grain yield in future breeding programs. The parents 691A, SR 2950, SR 2997,SR 2872 and SR 2991were identified as good general combiners in the material under study, offering scope for further improvement in sorghum. Both additive and nonadditive genetic variants can be exploited simultaneously through population improvement programs, and heterosis breeding may be adopted to exploit nonadditive gene action and the development of hybrids at the commercial scale.

The present study needs to be further tested in observational/multilocation trials to determine the heterotic potential of these materials at the commercial level. Moreover,the cross combinations that show the least importance for SCA effects but originate from parental lines with high GCA effects can be used for recombination breeding with the easy selection of desirable segregants, particularly for developing better performing pure lines.

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Table 1 Analysis of variance in combining ability

Source of variation	d. f	Mean square					
		Days to 50 percent flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Grain yield per plant (g)	1000 seed weight (g)
Replication	2	24.56	20.02	76.576	8.29	10.57	2.82
Hybrids	35	47.95**	186.94**	1160.89**	21.55**	213.97**	49.47**
Line effect	2	90.81	63.58	1929.56	0.09	8.96	81.84**
Tester effect	11	57.54	313.98*	1577.41	32.52	299.76	118.80**
Line x Testers effects	22	39.26**	134.63**	882.75**	18.01**	189.71**	11.86**
Error	70	12.79	13.37	40.00	2.75	12.15	2.21
σ^2_f		1.81	1.65	38.57	0.14	1.53	1.61
σ^2_m		2.80	14.34	74.34	1.53	14.41	5.19*
σ^2_{GCA}		1.55	3.15	34.24	0.32	3.31	1.65*
σ^2_{SCA}		3.77*	12.95**	84.93**	1.733**	18.25**	1.14**
$\frac{2\sigma^2 g}{(2\sigma^2 g+\sigma^2 s)}$		0.27	0.08	0.01	0.58	0.05	0.88

* and ** are significant at the 5 percent and 1 percent levels, respectively.

Table 2 General combining ability effects in parents

Parents	Days to 50 percent flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Grain yield per plant (g)	1000 seed weight (g)
Lines						
691 A	-1.74**	0.88	-0.75	0.01	0.56	1.43**
27 A	0.37	0.63	-6.91**	0.04	-0.20	0.13
2219 A	1.37*	-1.52*	7.66**	-0.05	-0.36	-1.57**
S.E.(g_i)	0.57	0.69	1.01	0.26	0.51	0.24
S.E.(g_i-g_j)	0.80	0.98	1.44	0.37	0.72	0.34
Tester						
SR 2999	1.03	8.58**	-18.76**	-2.21**	-6.63**	-4.29**
SR 2950	-0.29	-7.63**	-0.91	2.14**	8.54**	4.16**
SR 2991	-1.18	-3.63*	15.25**	1.97**	9.93**	2.80**
SR 2993	-3.63**	-4.08**	3.37	-1.83**	-3.98**	2.51**
SR 2872	-3.07**	0.47	-2.13	0.77	5.61**	-3.00**
SR 2896	2.92*	3.58*	-5.22*	-1.73**	-3.65**	1.45**
SR 2914	2.25	8.13**	-18.87**	-3.40**	-3.32**	-8.52**
SR 2957	0.92	-2.75	-9.53**	0.54	-4.84**	2.63**
SR 2997	-1.96	-9.63**	-7.46**	2.56**	0.009	1.66**
SR 2990	-2.51*	0.13	7.16**	0.91	-6.45**	-0.75
SR 2984	4.37**	6.47**	23.82**	0.25	3.45**	1.06*
SR 2926	1.14	0.36	13.31**	0.02	1.34	0.27
S.E.(g_i)	1.14	1.39	2.03	0.52	1.02	0.48

* and ** are significant at 5 percent and 1 percent levels of significance, respectively

Table 3 Specific combining ability (*SCA*) effects of crosses for grain yield and yield traits sorghum

Sr. No.	Crosses	Days to 50 percent flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	1000 seed weight (g)	Grain yield per plant (g)
1	691 A × SR 2999	0.74	2.33	-1.94	-0.70	0.16	1.88
2	691 A × SR 2950	3.40	7.55 **	19.25 **	0.44	0.48	2.92
3	691 A × SR 2991	-4.03 *	7.55 **	-13.20 **	-0.82	-1.35	-1.89
4	691 A × SR 2993	0.07	2.66	5.24	-0.84	-0.24	-2.62
5	691 A × SR 2872	2.51	6.77 **	33.25 **	3.31 **	2.35 **	16.01 **
6	691 A × SR 2896	0.85	-6.66 **	-5.25	-0.27	-0.28	-0.72
7	691 A × SR 2914	5.18 *	-2.22	-6.85	4.77 **	-0.23	-1.75
8	691 A × SR 2957	3.18	-5.33 *	7.724 *	-0.72	-1.45	-5.03 **
9	691 A × SR 2997	-2.92	0.88	-17.29 **	-2.20 *	-0.94	-5.25 **
10	691 A × SR 2990	-2.03	4.11	-18.17 **	-2.73 **	0.24	-3.67 *
11	691 A × SR 2984	-0.93	-1.79	40.65 **	-3.54 **	0.84	-5.28 **
12	691 A × SR 2926	-6.03 **	-11.78 **	4.875	3.31 **	0.44	5.42 **
13	27 A × SR 2999	-2.37	-1.08	5.3	-1.06	0.42	-5.73 **
14	27 A × SR 2950	-3.70	-7.19 **	-7.82 *	-0.10	-2.20 *	3.51
15	27 A × SR 2991	2.51	-1.19	0.96	0.01	-0.32	1.14
16	27 A × SR 2993	2.29	0.58	15.70 **	1.27	-1.40	7.54 **
17	27 A × SR 2872	1.07	-12.31 **	-9.71 **	-2.99 **	1.47	-12.40 **
18	27 A × SR 2876	2.07	2.25	3.04	1.55	1.51	1.16
19	27 A × SR 2914	-0.92	0.02	13.44 **	-1.67	2.64 **	-10.61 **
20	27 A × SR 2957	-0.92	7.25 **	5.75	-0.75	0.13	-3.32
21	27 A × SR 2997	-0.37	1.13	6.66	2.40 *	-0.85	10.38 **
22	27 A × SR 2990	-3.14	3.69	-11.93 **	0.35	2.17 *	9.23 **
23	27 A × SR 2984	1.63	2.02	-6.02	1.88 *	-2.25 **	1.05
24	27 A × SR 2926	1.85	4.80 *	-15.38 **	-0.89	-1.32	-1.95
25	2219 A × SR 2999	1.63	-1.25	-3.35	1.76	-0.58	3.85 *
26	2219 A × SR 2950	0.29	-0.36	-11.43 **	-0.33	1.72 *	-6.43 **
27	2219 A × SR 2991	1.51	-6.36 *	12.24 **	0.81	1.67 *	0.74
28	2219 A × SR 2993	-2.37	-3.25	-20.96 **	-0.42	1.64	-4.91 **
29	2219 A × SR 2872	-3.59	5.52 *	-23.55 **	-0.31	-3.82 **	-3.61 *
30	2219 A × SR 2876	-2.92	4.41	2.21	-1.28	-1.22	-0.44
31	2219 A × SR 2914	-4.25 *	2.19	-6.58	-3.10 **	-2.40 **	12.37 **
32	2219 A × SR 2957	-2.25	-1.91	-13.48 **	1.47	1.32	8.35 **
33	2219 A × SR 2997	3.29	-2.02	10.62 **	-0.19	1.79 *	-5.12 **
34	2219 A × SR 2990	5.18 *	-7.80 **	30.10 **	2.38 *	-2.42 **	-5.56 **
35	2219 A × SR 2984	-0.70	3.86	13.66 **	1.65	1.42	4.22 *
36	2219 A × SR 2926	4.18 *	6.97 **	10.50 **	-2.42 **	0.87	-3.46
	S.E. (S_{ij})	1.98	2.40	3.52	0.91	0.83	1.78

* and ** are significant at the 5 percent and 1 percent levels, respectively.