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General combining ability analysis of newly developed parental lines in *Kharif* Sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract
The present investigation was undertaken to estimate heterosis and combining ability in parental lines of *kharif* sorghum [*Sorghum bicolor* (L.) Moench] with respect to grain yield and its associated components. Four cytoplasmic male sterile (CGMS) lines and ten testers were crossed in Line x Tester fashion and the resultant 40 hybrids were evaluated coupled with two standard checks i.e., CSH-25 (for earliness) and CSH-35 (for grain yield) at the Research Farm of Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The line AKMS 70 A was found to be the best general combiner in terms of grain yield per plant along with yield contributing traits. Among the testers, tester AKR 73, AKR 545 and AKR 558 were found to be the best general combiner for grain yield per plant along with other component characters. Also, tester AKR 560 showed desirable significant GCA effects for single-cut green fodder yield per plant along with plant height, number of grains per panicle and threshed grain mold rating. Therefore, the line AKMS 70 A and four testers i.e., AKR 73, AKR 545, AKR 558 and AKR 560 need to be extensively used in crossing programme for development of high yielding *kharif* sorghum hybrids.

Keywords: GCA, general combining ability, *Kharif* sorghum, Line x Tester analysis, parents

1. Introduction
Sorghum [*Sorghum bicolor* (L.) Moench] is mainly classified as often cross-pollinated crop possessing chromosome number, 2n = 20 belongs to family 'Poaceae' or 'Gramineae'. Sorghum is a C_4 plant having higher photosynthetic efficiency coupled with higher abiotic stress tolerance (Nagy *et al*., 1995 and Reddy *et al*., 2009) [9, 14].

It is one of the most important staple cereals grown in both rainy (*kharif*) and post rainy (*rabi*) seasons in the semi-arid parts of the world as well as India, especially in marginal areas with least fertile and low water holding capacity soils where, only few other crops can survive. It is grown on 42.00 million-hectares area with production of 63.21 million-metric tons in the world. India acquires area of 5.10 million-hectare and production of 4.57 million-metric tons under cultivation (Anonymous, 2018) [1]. Besides being an important food and fodder crop, sorghum also provides raw material for the production of starch, fiber, dextrose syrup, biofuels, alcohol and other important products.

The estimates of combining ability are useful in predicting relative performance of parental lines in hybrid combinations. Selection of parents for hybridization can be made with the help of combining ability analysis (Sprague and Tatum, 1942) [16].

Besides its use in selecting the parents, it indicates the nature and magnitude of various types of gene actions involved in the expression of quantitative characters. This information is quite convenient in formulating and executing an efficient breeding programme for achieving maximum genetic gain with minimum use of resources and time. Sorghum has good potential for grain yield. The development of the potential hybrids in *kharif* sorghum, making them famous among the present cultivators will therefore, be definitely beneficial for improving and increasing the grain production of crop.

The most important prerequisite for varietal improvement in such an important crop is the selection of suitable parents, which could combine well in a cross and also denotes specific performance of a cross combination against the expectations from the general combining ability of parents. Line x Tester mating design is a precise method for obtaining such statistics when a large number of parents are to be tested. Keeping this in view, an attempt has been made to estimate the general combining ability of newly developed parental lines in *kharif* sorghum by using Line x Tester mating design.

2. Material and Methods

The present investigation comprised of four newly developed females i.e., cytoplasmic genetic male sterile lines (AKMS 30 A, AKMS 70 A, AKMS 14 A and ICS 733 A) and ten testers i.e., males (AKR 73, AKR 524, AKR 529, AKR 532, AKR 545, AKR 553, AKR 557, AKR 558, AKR 559 and AKR 560). These fourteen parents were crossed in a Line x Tester mating design and the resultant 40 hybrids along with these fourteen parents were raised in Randomized Block Design with three replications during *kharif* season on the Research Farm of Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola. Further, two standard checks i.e., CSH-25 (for earliness) and CSH-35 (for grain yield) were also included in the trial. The seed material was planted with inter and intra spacing of 45 cm and 15 cm respectively. Recommended package of cultural management practices and plant protection measures were adopted properly to raise a healthy crop.

During the present investigation, total thirteen characters were studied. The data were recorded on randomly selected five plants per plot per replication for nine characters *viz*., Plant height (cm), Panicle weight (g), Panicle length (cm), Panicle breadth (cm), Number of grains per panicle, Grain yield per plant (g), Fodder yield per plant (g), 1000 grain weight (g) and Grain hardness (Kg/cm^2). However, the obtained field data for Days to 50% flowering and Days to maturity were recorded on plot basis. The data for Shoot fly dead heart percentage (at 28 days) and Threshed Grain Mold Rating (TGMR) were recorded on percentage basis.

The collected data for all above characters were subjected for estimation of combining ability analysis by following Kempthorne (1957) method [5]. The analysis of variance (ANOVA) was performed to test the significant differences between the progenies for all the characters under study (Panse and Sukhatme, 1957) [10].

3. Results and Discussion

Table 1 represented the analysis of variance (ANOVA) for combining ability for various characters under investigation. The total variance due to hybrids was partitioned into portions attributable to lines (females), testers (males), their interaction (lines x testers) and error sources. The variance due to lines x testers exhibited highly significant differences for the grain yield and all the yield associated characters. The lines showed significant differences for various characters like days to 50% flowering, days to maturity, plant height and grain hardness. The testers recorded significant variation for all the traits except shoot fly dead heart percentage (at 28 days) and panicle breadth. The components of variances attributable to lines and testers were used as a measure of general combining ability.

The estimates of general combining ability effects of the lines and the testers for various traits under study are depicted in Table 2. Among the four lines, the line AKMS 70 A has been recognized as the best general combiner for grain yield per plant (3.06**) along with other component characters like plant height (6.07**), shoot fly dead heart percentage (-0.22**), panicle weight (4.01**) and fodder yield per plant (4.53**).

Veldandi *et al*. (2021) [18] evaluated among the lines that line ICSA 427 and line ICSA 433 were found to be the best general combiners for grain yield per plot and other yield contributing traits with consistent performance across locations.

The line AKMS 30 A exhibited significant GCA for number of grains per panicle (78.43**). Also, line AKMS 14 A showed significant GCA effects for days to 50% flowering (-3.23**), days to maturity (-3.19**), plant height (12.91**) and fodder yield per plant (7.03**).

Premalatha *et al*. (2006) [13] suggested that negative significant GCA effects for days to 50% flowering might be advantageous in breeding programme for earliness in sorghum.

Prabhakar *et al*. (2013) [12] identified one line SL-39B with desirable significant GCA for grain yield and days to 50% flowering to develop high yielding early maturing hybrids in *rabi* sorghum.

Besides these lines, ICS 733 A identified as best general combiner for shoot fly dead heart count (-13.59**), number of grains per panicle (47.22*), fodder yield per plant (11.13**), 1000 grain weight (1.26**), grain hardness (0.86**) and threshed grain mold rating (-2.25**) which ultimately imparts the grain mold resistance in the succeeding genotypes.

Among the ten testers, AKR 558 exhibited highly significant and desirable GCA effects for grain yield per plant (16.80**) along with desirable yield contributing characters such as days to 50% flowering (-2.08**), days to maturity (-2.12**), plant height (21.20**), shoot fly dead heart count (-0.37**), panicle weight (17.65**), panicle breadth (0.44**), number of grains per panicle (520.19**), fodder yield per plant (22.13**), 1000 grain weight (3.25**), grain hardness (1.81**) and threshed grain mold rating (-10.08**).

Similarly, tester AKR 545 showed highly significant positive GCA effects for grain yield per plant (9.39**) coupled with essential yield associated characters like days to 50% flowering (-3.58**), days to maturity (-3.54**), plant height (5.54**), shoot fly dead heart percentage (-0.71**), panicle weight (9.29**), panicle breadth (0.30**), number of grains per panicle (390.71**), fodder yield per plant (7.19**), 1000 grain weight (1.95**) and threshed grain mold rating (-4.33**).

Also, tester AKR 73 exhibited significant positive GCA effects for grain yield per plant (8.82**) coupled with other yield components like days to 50% flowering (-4.08**), days to maturity (-3.87**), panicle weight (9.21**), panicle breadth (0.27*), number of grains per panicle (196.01**), 1000 grain weight (3.24**), grain hardness (0.60*) and threshed grain mold rating (-5.00**).

Mangal *et al*. (2017) [7] identified two testers AKR 524 and AKR 528 as good general combiners for high grain yield along with early maturity in *kharif* sorghum.

More *et al*. (2021) [8] suggested that the lines Parbhani Moti and CSV 29 R and testers PBMR 3 and PBMR 5 exhibited desirable significant GCA effects for grain yield per plant and its contributing traits.

The tester AKR 560 displayed significant positive GCA effects for single-cut green fodder yield per plant (25.09**) along with important traits like plant height (26.37**), number of grains per panicle (80.32*) and threshed grain mold rating (-9.25**). Also, testers AKR 559 and AKR 557 recorded highly significant desirable GCA effects for single-cut green fodder yield per plant (33.54*) and (6.31**) along with plant height (36.91**) and (4.17*) respectively (Table 2).

Soujanya *et al*. (2017) [15] revealed that one line, line 185A and three testers RSSV138-1, RSSV466 and RSSV404

exhibited significant general combining ability effects for single-cut green fodder yield in sweet sorghum.

The tester AKR 553 revealed significant and desirable GCA effect for contrasting characters like shoot fly dead heart percentage (-0.40**), 1000 grain weight (1.45**), grain hardness (0.62**) and threshed grain mold rating (-6.17**).

The tester AKR 524 noted highly significant and negative GCA effects for characters like days to 50% flowering (-4.66**) and days to maturity (-4.79**).

The identical results for sorghum were also reported by some researchers like Prabhakar and Raut (2010) [11], Ghorade *et al*. (2014) [2], Kalpande *et al*. (2015) [4], Mangal *et al*. (2017) [6] and Totre *et al*. (2021) [17] from their investigations for promising general combiners for grain yield and its associated components.

The outcomes of this investigation indicated that, the line AKMS 70 A was the best general combiner for grain yield per plant (3.06**) coupled with four component characters. Among the testers, tester AKR 558 had recorded significant GCA effects for twelve different traits including grain yield per plant (16.80**). Similarly, the second preference can be given to tester AKR 545 which exhibited significant GCA effects for total eleven characters including grain yield (9.39**). On the third position, tester AKR 73 had shown significant GCA effects for grain yield per plant (8.82**) along with nine traits. All these three testers hold promise in development of high yielding *kharif* sorghum hybrids (Table 3).

Jain and Patel (2014) [3] reported that parents GJ-39, GFS-5, CSV-15, SSV 84 and SPV 2113 identified as good general combiners for grain yield and other associated traits.

Vinoth *et al*. (2021) [19] revealed that the parents *viz*., CO(S) 28, SPV 759 and IS 9807 exhibited significantly superior GCA value and identified as a good general combiner for grain yield and yield contributing traits.

Tester AKR 560 showed significant GCA effects for single-cut green fodder yield per plant along with three other important traits. Therefore, this tester can be used for development of high fodder yielding hybrids in *kharif* sorghum (Table 3).

Table 1: Analysis of variance for combining ability for various characters under Line x Tester analysis

Source of Variation	d.f.	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Shoot Fly Dead hearts count	Panicle Weight (g)	Panicle Length (cm)	Panicle Breadth (cm)	Number of Grains/ Panicle	Grain Yield/ Plant (g)	Fodder Yield/ Plant (g)	1000 Grain Weight (g)	Grain Hardness (kg/cm^2)	Threshed Grain Mold Rating (%)
		1	2	3	4	5	6	7	8	9	10	11	12	13
Replications	2	9.55	11.10	9.05	0.18	71.29*	0.15	0.05	17944.65	68.20*	154.08*	28.73**	1.64	14.01
Crosses	39	58.17**	57.95**	2625.58**	2.06**	569.72**	10.59**	0.61**	559413.38**	501.66**	2471.92**	34.85**	6.25**	270.22**
Lines	3	171.48**	179.31**	4174.92*	4.57	240.71	16.45	0.02	186630.49	174.71	1941.10	28.66	16.03*	159.60
Testers	9	135.75**	134.76**	6182.64**	1.86	1108.24*	21.55**	1.01	1118366.06*	1013.68*	6376.86**	69.37*	10.05*	749.77**
Line x Testers	27	19.71**	18.86**	1267.74**	1.85**	426.77**	6.29**	0.54**	414516.14**	367.32**	1229.25**	24.03**	3.89**	122.66**
Error	78	4.39	5.26	55.98	0.14	16.10	0.77	0.11	13172.17	18.04	40.54	1.97	0.61	18.17

Note: * - Significant at 5% level of significance

** - Significant at 1% level of significance

Table 2: Estimates of general combining ability effects of parents for various characters under line x tester analysis

Sr. No.	Parents	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Shoot Fly Dead hearts count	Panicle Weight (g)	Panicle Length (cm)	Panicle Breadth (cm)	Number of Grains/ Panicle	Grain Yield/ Plant (g)	Fodder Yield/ Plant (g)	1000 Grain Weight (g)	Grain Hardness (kg/cm^2)	Threshed Grain Mold Rating (%)
		1	2	3	4	5	6	7	8	9	10	11	12	13
Lines (Females)														
1	AKMS 30 A	-0.20	-0.49	-5.39**	0.07	-2.58**	0.03	-0.01	78.43**	-2.44**	-0.43	-0.13	-0.17	0.21
2	AKMS 70 A	1.10**	1.24**	6.07**	-0.22**	4.01**	0.96	0.04	-28.30	3.06**	4.53**	-0.01	0.20	-1.07
3	AKMS 14 A	-3.23**	-3.19**	12.91**	0.52**	-0.34	-0.19	-0.01	-97.36**	0.67	7.03**	-1.11**	-0.89**	3.11**
4	ICS 733 A	2.33**	2.44**	-13.59**	-0.36**	-1.08	-0.81	-0.01	47.22*	-1.28	11.13**	1.26**	0.86**	-2.25**
	SE (gi) +	0.39	0.40	1.24	0.06	0.73	3.46	0.06	22.76	0.80	1.20	0.29	0.14	0.70
	CD at 5%	0.79	0.80	2.48	0.13	1.45	6.89	0.13	45.32	1.59	2.39	0.58	0.29	1.39
	CD at 1%	1.04	1.07	3.28	0.18	1.92	9.14	0.18	60.11	2.12	3.18	0.77	0.39	1.85
Testers (Males)														
1	AKR 73	-4.08**	-3.87**	-10.55**	-0.07	9.21**	1.42	0.27*	196.01**	8.82**	0.90	3.24**	0.60*	-5.00**
2	AKR 524	-4.66**	-4.79**	-15.54**	0.34**	-6.83**	-0.36	-0.43**	-213.45**	-6.60**	-23.94**	-1.29**	-0.97**	4.28**
3	AKR 529	3.91**	3.87**	-22.87**	0.29**	-4.12**	1.00	0.10	-29.26	-4.58**	-19.08**	-0.51	-0.44	4.49**
4	AKR 532	0.75	0.79	-32.12*	0.07	-11.95**	-2.07	-0.39**	-353.66**	-10.14**	-34.69**	-3.00**	-0.64**	9.16**
5	AKR 545	-3.58**	-3.54**	5.54**	-0.71**	9.29**	1.64	0.30**	390.71**	9.39**	7.19**	1.95**	0.06	-4.33**
6	AKR 553	3.83**	3.70**	-13.12**	-0.40**	0.90	-0.23	0.04	15.04	0.74	-17.45**	1.45**	0.62**	-6.17**
7	AKR 557	1.66**	1.79**	4.17*	0.25*	-4.95**	-1.19	-0.06	-390.57**	-7.10**	6.31**	-3.31**	0.19	4.74**
8	AKR 558	-2.08**	-2.12**	21.20**	-0.37**	17.65**	1.60	0.44**	520.19**	16.80**	22.13**	3.25**	1.81**	-10.08**

9	AKR 559	0.75	0.54	36.91**	0.53**	-10.67**	-1.26	-0.10	-215.32**	-9.40**	33.54**	-1.73**	-1.37**	12.16**
10	AKR 560	3.50**	3.62**	26.37**	0.06	1.47	-0.54	-0.17	80.32*	2.08	25.09**	-0.04	0.13	-9.25**
	SE (gi) +	0.62	0.64	1.96	0.10	1.15	5.47	0.10	35.99	1.26	1.90	0.46	0.23	1.10
	CD at 5%	1.24	1.27	3.92	0.21	2.29	10.90	0.21	71.66	2.52	3.79	0.92	0.47	2.20
	CD at 1%	1.65	1.69	5.20	0.28	3.04	14.46	0.28	95.04	3.35	5.03	1.23	0.62	2.92

Note: * - Significant at 5% level of significance
** - Significant at 1% level of significance

Table 3: General Combining Ability effects of promising parents in desirable direction for grain yield and other characters

Parents	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Shoot Fly Dead hearts count	Panicle Weight (g)	Panicle Length (cm)	Panicle Breadth (cm)	Number of Grains/ Panicle	Grain Yield/ Plant (g)	Fodder Yield/ Plant (g)	1000 Grain Weight (g)	Grain Hardness (kg/cm^2)	Threshed Grain Mold Rating (%)
	1	2	3	4	5	6	7	8	9	10	11	12	13
Lines (Females)													
AKMS 70 A	1.10**	1.24**	6.07**	-0.22**	4.01**	0.96	0.04	-28.30	3.06**	4.53**	-0.01	0.20	-1.07
Testers (Males)													
AKR 73	-4.08**	-3.87**	-10.55**	-0.07	9.21**	1.42	0.27*	196.01**	8.82**	0.90	3.24**	0.60*	-5.00**
AKR 545	-3.58**	-3.54**	5.54**	-0.71**	9.29**	1.64	0.30**	390.71**	9.39**	7.19**	1.95**	0.06	-4.33**
AKR 558	-2.08**	-2.12**	21.20**	-0.37**	17.65**	1.60	0.44**	520.19**	16.80**	22.13**	3.25**	1.81**	-10.08**
AKR 560	3.50**	3.62**	26.37**	0.06	1.47	-0.54	-0.17	80.32*	2.08	25.09**	-0.04	0.13	-9.25**

Note: * - Significant at 5% level of significance
** - Significant at 1% level of significance

4. Conclusion

From the present investigation, it may be concluded that the line AKMS 70 A and three testers i.e., AKR 73, AKR 545 and AKR 558 were identified as good general combiners for grain yield per plant and its component characters. Similarly, tester AKR 560 was identified as good general combiner for single-cut green fodder yield per plant and its associated traits. Hence, these above mentioned five parents need to be exploited extensively for developing high yielding *kharif* sorghum hybrids.

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