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Potential hybrids in *Kharif* sorghum based on specific combining ability for grain yield and its associated components

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Abstract
Four lines and ten testers were crossed in Line x Tester mating design and their resultant 40 hybrids were evaluated coupled with standard checks i.e., CSH-25 (for earliness) and CSH-35 (for grain yield) for grain yield and its associated components to study heterosis and combining ability. The current investigation revealed that total fifteen crosses exhibited positive and significant standard heterosis for grain yield per plant. Out of these fifteen crosses, total eleven hybrids exhibited positive significant SCA effects along with positive significant standard heterosis for grain yield per plant. The hybrid AKMS 14 A x AKR 524 exhibited highest significant positive SCA effects (17.43**) and positive significant standard heterosis (18.53**) for grain yield per plant along with the component traits like panicle weight, panicle breadth, number of grains per panicle, fodder yield per plant, 1000 grain weight and grain hardness. Hence, these eleven crosses need to be tested in multilocation and multisession evaluation trial to find out the stable cross combinations for their further commercial exploitation in *kharif* sorghum.

Keywords: Heterosis, *Kharif* sorghum, SCA, Specific combining ability, Standard heterosis

1. Introduction
Sorghum [*Sorghum bicolor* (L.) Moench] is a plant belonging to the tribe Andropogonae of the *Poaceae* family. It is the fifth major cereal crop in the world after rice, wheat, maize and barley respectively (FAO, 2007) [3].

In India, 75% area and 85% production of sorghum crop is concentrated only in four states *viz.*, Maharashtra, Karnataka, Telangana and Andhra Pradesh. Maharashtra covers about 0.604 million hectares area and 0.575 million tons of production along with productivity of 953 kg/ha under *kharif* sorghum cultivation (Anonymous, 2017) [2].

The commercial exploitation of heterosis and systematic varietal development using hybridization are the quickest and simplest tools to increase the production in *kharif* sorghum. Combining ability useful in identification of the parents and these parents might be used in hybridization programme for producing excellent cross combinations. Ordinarily, the general combining ability (GCA) is the result of additive gene action; while the specific combining ability (SCA) is the result of non-allelic interactions (Jinks, 1954) [11].

The estimates of combining ability are helpful for predicting the relative performance of different lines in various cross combinations. The information on the nature and magnitude of gene action is crucial in understanding the genetic potential and deciding the breeding procedure to be adopted for given population (Prabhakar *et al*., 2013) [19].

The improvement in the past was mainly based on selection in locally adopted types and hybrid population of grain sorghum. However, during recent years, hybrid vigour and selection of parents based on specific combining ability (SCA) have opened up a new approach in the crop improvement (Ghorade *et al*., 2017) [7].

In this background, the present study was undertaken to determine the promising hybrids of *kharif* sorghum exhibiting desirable significant standard heterosis coupled with positive significant SCA effects for grain yield and its associated characters in Line x Tester fashion.

2. Materials and Methods
The experimental material for the existing experiment comprised of four newly developed cytoplasmic genetic male sterile (CGMS) lines i.e., females (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 Line x Tester fashion (Kempthorne, 1957) [15]. The resulting 40 (F_1) hybrids along with their fourteen parents and two standard checks i.e., CSH-25 (for earliness) and CSH-35 (for grain yield) were raised in Randomized Block Design with three replications at the Research Farm of Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The seed material was planted with 45 cm and 15 cm inter and intra spacing respectively.

During the present investigation, total thirteen contrasting traits 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 estimated on percentage basis.

The collected data were subjected to statistical analysis to estimate standard heterosis and combining ability analysis by following Kempthorne (1957) method [15] with an aim for increasing grain yield and yield contributing traits of *kharif* sorghum. The analysis of variance (ANOVA) was performed to test significant differences between the progenies for all the traits under study (Panse and Sukhatme, 1957) [17].

3. Results and Discussion

Analysis of variance (ANOVA) in recent investigation revealed that mean squares due to genotypes were highly significant for all the traits examined except panicle length. This suggested the presence of substantial genetic variability for these characters under the studied material. The parents significantly differed among themselves for all the thirteen characters. Females (lines) noted highly significant differences for the traits such as days to 50% flowering, days to maturity, panicle weight, number of grains per panicle, fodder yield per plant and 1000 grain weight. Also, males (testers) showed high significant variation for all the characters. Females vs males (lines vs testers) showed significant differences in days to 50% flowering, plant height, shoot fly dead heart percentage, panicle weight, panicle breadth, number of grains per panicle and fodder yield per plant. Variance due to hybrids was also highly significant for all the traits except panicle length. Similarly, parents vs hybrids showed high significant differences for all the major component characters except panicle length and threshed grain mold rating (Table 1).

Table 2 illustrated the analysis of variance (ANOVA) for combining ability for various traits under investigation. The total variance due to cross combinations was segregated into various parts referable to the lines (females), testers (males), their interaction (lines x testers) and error sources. The lines exhibited significant differences for various traits 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 and panicle breadth. The variance due to lines x testers noted highly significant differences for almost all the thirteen characters under study.

It is very well known that if SCA variance, which is a measure of non-additive genetic variance, is high for characters and also observed standard heterosis is high; such hybrids can be useful in exploiting the heterosis into the crop commercially.

Considering the resulted 40 (F_1) hybrids from the current investigation, total eleven cross combinations exhibited significant positive SCA effects for grain yield per plant along with positive significant standard heterosis for grain yield per plant and its associated characters (Table 3).

The first hybrid AKMS 14 A x AKR 524 revealed highest significant SCA effects for grain yield per plant (17.43**) along with the component traits like panicle weight, panicle breadth, number of grains per panicle, fodder yield per plant, 1000 grain weight and grain hardness.

The second cross AKMS 30 A x AKR 553 manifested positive and significant SCA effects for grain yield per plant (16.16**) and its associated characters such as plant height, shoot fly dead heart percentage, panicle weight, panicle breadth, number of grains per panicle, fodder yield per plant and 1000 grain weight.

On third position, ICS 733 A x AKR 529 displayed positive significant SCA effects for grain yield per plant (15.03**) along with the other yield contributing traits like days to 50% flowering, days to maturity, panicle weight, fodder yield per plant, 1000 grain weight, grain hardness and threshed grain mold rating.

The cross AKMS 70 A x AKR 560 ranked fourth and noted significant positive SCA effects for grain yield per plant (12.86**) coupled with other component characters like plant height, panicle weight, panicle breadth, number of grains per panicle and 1000 grain weight.

On fifth position, AKMS 70 A x AKR 553 hybrid showed significant positive SCA effects for grain yield per plant (12.67**). This cross also exhibited positive and significant SCA effects for other useful components like panicle weight, number of grains per panicle and grain hardness.

Kalpande *et al*. (2016) [13] reported seventeen promising cross combinations based on positive significant SCA effects for grain yield per plant along with other characters.

Ghorade *et al*. (2018) [5] recorded that hybrid AKMS 90 A x AKR 337 exhibited highest significant SCA effect for grain yield per plant along with other component traits.

Gawande *et al*. (2020) [4] revealed that cross AKRMS-80-1A (39) x PKV-Kranti depicted the highest positive significant specific combining ability (SCA) effects (25.93**) along with positive significant standard heterosis (19.72**) for grain yield per plant among the thirteen hybrids identified for the same purpose.

More *et al*. (2021) [16] observed that total five crosses showed desirable significant SCA effects for grain yield per plant including hybrid MS 104B x PBMR 2 *viz*., identified as the potential cross for grain yield per plant.

Aissata and Ardaly (2022) [1] stated that six hybrids displayed good performance based on positive significant SCA effects and grain yield across the tested environments.

Also, the hybrids ICS 733 A x AKR 545, AKMS 14 A x AKR 558, AKMS 30 A x AKR 560, AKMS 70 A x AKR 73, AKMS 30 A x AKR 545 and AKMS 70 A x AKR 558 recorded higher magnitude of significant positive SCA effects for grain yield per plant and also exhibiting significant SCA effects for most of the contributing characters (Table 3).

It was observed that high heterotic cross combinations exhibited significant specific combining ability (SCA) effects

coupled with higher per se performance (Table 3).
Depending upon SCA, heterosis and mean performance; similar results for promising hybrids were also noticed by Hariprasanna *et al.* (2012) [8], Prabhakar *et al.* (2013) [19], Ghorade *et al.* (2014) [6], Hundekar *et al.* (2014) [9], Kalpande *et al.* (2015) [14], Patil and Kute (2015) [18], Jadhav and Deshmukh (2017) [12], Ingle *et al.* (2018) [10], Tayade *et al.* (2018) [20] and Totre *et al.* (2021) [21].

Table 1: Analysis of variance of parents and hybrids 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/cm²)	Threshed Grain Mold Rating (%)
		1	2	3	4	5	6	7	8	9	10	11	12	13
Replications	2	11.35	11.48	7.47	0.38	41.56	345.33	0.06	18996.8	56.80	130.08	14.76	1.96	14.44
Genotypes	53	56.14**	53.81**	2667.70**	1.77**	635.37**	356.73	1.03**	489879.2**	559.87**	2579.52**	40.99**	5.88**	236.74**
Parents	13	48.47**	41.61**	1413.71**	0.94**	83.97**	1408.17**	0.95**	217207.2**	39.38*	1708.08**	48.19**	3.94**	154.20**
Females	3	45.11**	48.55**	124.42	0.14	76.82**	9.43	0.16	86097.92**	14.80	263.80**	23.55**	0.76	20.60
Males	9	51.29**	41.77**	616.37**	1.11**	84.38**	1946.43**	0.75**	182249**	48.92*	1262.42**	61.56**	5.43**	214.60**
Females vs Males	1	35.15**	19.28	12457.62**	1.75**	101.72*	760.05	5.04**	925159.3**	27.30	10051.89**	1.74	0.00	11.33
Hybrids	39	58.17**	57.95**	2625.58**	2.06**	569.72**	10.59	0.61**	559413.4**	501.66**	2471.92**	34.85**	6.25**	270.22**
Parents vs Hybrids	1	76.82**	50.95**	20612.4**	1.06**	10363.97**	187.56	18.38**	1322781**	9596.08**	18104.83**	187.06**	16.90**	3.98
Error	106	4.72	4.94	46.56	0.14	15.98	359.99	0.13	15549.85	19.34	43.58	2.61	0.66	14.73

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

Table 2: 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/cm²)	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 3: SCA effects, Standard heterosis and Mean yield performance of some promising hybrids

Sr. No.	Crosses	Mean for grain yield per plant (g)	Standard Heterosis (%) over (CSH -35)	SCA effects for grain yield per plant	Significant SCA effects for other characters
1	AKMS 14 A x AKR 524	72.99	18.53**	17.43**	Panicle weight (g), Panicle breadth (cm), Number of grains per panicle, Fodder yield per plant (g), 1000 grain weight (g) and Grain hardness (kg/cm²).
2	AKMS 30 A x AKR 553	75.95	23.33**	16.16**	Plant height (cm), Shoot fly dead heart percentage (at 28 days), Panicle weight (g), Panicle breadth (cm), Number of grains per panicle, Fodder yield per plant (g) and 1000 grain weight (g).
3	ICS 733 A x AKR 529	70.65	14.72**	15.03**	Days to 50% flowering, Days to maturity, Panicle weight (g), Fodder yield per plant (g), 1000 grain weight (g), Grain hardness (kg/cm²) and Threshed grain mold rating (%).
4	AKMS 70 A x AKR 560	79.50	29.10**	12.86**	Plant height (cm), Panicle weight (g), Panicle breadth (cm), Number of grains per panicle and 1000 grain weight (g).
5	AKMS 70 A x AKR 553	77.97	26.61**	12.67**	Panicle weight (g), Number of grains per panicle and Grain hardness (kg/cm²).
6	ICS 733 A x AKR 545	81.23	31.90**	11.63**	Plant height (cm), Shoot fly dead heart percentage (at 28 days), Panicle weight (g), Panicle breadth (cm), Number of grains per panicle, Fodder yield per plant (g) and Threshed grain mold rating (%).
7	AKMS 14 A x AKR 558	87.72	42.45**	8.74**	Plant height (cm), Panicle weight (g), Number of grains per panicle, Grain hardness (kg/cm²) and Threshed grain mold rating (%).
8	AKMS 30 A x AKR 560	69.31	12.55*	8.18**	Shoot fly dead heart percentage (at 28 days), Panicle weight (g), Number of grains per panicle, 1000 grain weight (g), Grain hardness (kg/cm²) and Threshed grain mold rating (%).

9	AKMS 70 A x AKR 73	79.63	29.31**	6.25*	Plant height (cm), Shoot fly dead heart percentage (at 28 days), Panicle weight (g), Number of grains per panicle, Fodder yield per plant (g) and Threshed grain mold rating (%).
10	AKMS 30 A x AKR 545	73.62	19.54**	5.17**	Panicle weight (g).
11	AKMS 70 A x AKR 558	86.53	40.50**	5.16*	Plant height (cm), Shoot fly dead heart percentage (at 28 days), Panicle weight (g), Number of grains per panicle and Fodder yield per plant (g).

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

4. Conclusion

The present investigation clearly indicated the consideration of mean performance and standard heterosis in addition to SCA effects of crosses while selecting the best cross combinations. Out of eleven crosses, the cross AKMS 14 A x AKR 524 exhibited highest positive significant SCA effects (17.43**) and positive significant standard heterosis (18.53**) for grain yield per plant along with the component characters like panicle weight, panicle breadth, number of grains per panicle, fodder yield per plant, 1000 grain weight and grain hardness (Table 3).
Therefore, it can be concluded that these newly developed eleven hybrids need to be assessed in multilocation and multisession trials for finding the most stable genotypes and their commercial exploitation in future breeding programme taking into account the positive significant SCA effects along with positive significant standard heterosis for grain yield per plant in *kharif* sorghum.

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