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PROMISING HETEROTIC COMBINATIONS FOR GRAIN YIELD AND YIELD CONTRIBUTING TRAITS IN *KHARIF* SORGHUM (*SORGHUM BICOLOR* L. MOENCH)

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ABSTRACT

The present investigation was performed to estimate magnitude of heterosis, heterobeltiosis and standard heterosis of *kharif* sorghum [*Sorghum bicolor* (L.) Moench] in 40 crosses (F_1's) by crossing four newly developed (CGMS) lines and ten testers coupled with two standard checks (CSH 25 - for earliness and CSH 35 - for grain yield) in Line × Tester fashion. The present study was carried out at the Research Farm of Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth (P.D.K.V.), Akola. Observations were recorded on thirteen different characters. Total 36 hybrids recorded significant positive average heterosis and 27 hybrids showed significant positive heterobeltiosis for grain yield per plant. In order to identify the high yielding *kharif* sorghum hybrids, promising hybrids were sorted out based on higher mean performance and positive significant standard heterosis over the check CSH-35 for grain yield per plant along with important yield associated traits. Total fifteen hybrids were emerged as promising hybrids. Among the total 40 hybrids, the cross combination AKMS 14 A × AKR 558 recorded maximum grain yield per plant with 97.23%, 83.87% and 42.45% heterosis over the mid parent, better parent and standard check respectively along with minimum days to 50% flowering, days to maturity and maximum panicle weight, panicle breadth. Therefore, these newly developed fifteen promising hybrids need to be tested to find out the most stable genotypes in multilocation and multi season trials on large scale for assessing the grain yield and yield contributing characters and their further commercial exploitation in *kharif* sorghum.

***Key words*: Average heterosis, Grain yield, Heterobeltiosis, Hybrids, *Kharif* sorghum, Standard heterosis.

Introduction

Sorghum is botanically known as *Sorghum bicolor* (L.) Moench. It is one of the most indispensable staple cereal crops among the field crops grown in both rainy (*kharif*) as well as post rainy (*rabi*) seasons in the semi-arid parts of the world and India, especially in marginal areas with least fertile and low water holding capacity soils where, only few other crops can survive. It is mainly grown in India not only as a food crop but also as a forage crop. Sorghum belongs to natural family 'Poaceae' or 'Gramineae', plants of which are usually grass having chromosome number, 2n = 20.

It is often cross-pollinated crop. It is a C_4 plant possessing higher photosynthetic efficiency and higher abiotic stress tolerance (Reddy *et al.*, 2009).

Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Gujarat and Uttar Pradesh are the major sorghum growing states of India. Hybrid vigour coupled with its commercial exploitation have rendered rich remittance in *kharif* sorghum leading to radical change in sorghum production (Rana *et al*., 1997). However, the broad exploitation of heterosis on commercial scale and the systematic varietal development through hybridization are the quickest and simplest tools to increase the *kharif* sorghum production.

Stephens and Holland (1954) reported the use of cytoplasmic genetic male sterility for developing hybrids of sorghum for the first time. The commercial exploitation of heterosis through the use of cytoplasmic genetic male sterility (CGMS) emerged as one of the major plant breeding triumphs in sorghum crop. As a result, a series of hybrids from CSH-1 to CSH-35 and varieties from CSV-1 to CSV-29 have been released at national level under All India Coordinated Sorghum Improvement Project (AICSIP) in India.

The present investigation was made to evaluate performance of high grain yielding potential hybrids produced by crossing newly developed parental lines of *kharif* sorghum in Line × Tester mating design. The promising hybrids were sorted out on the basis of average heterosis, heterobeltiosis and positive significant standard heterosis for grain yield and yield associated traits in *kharif* sorghum.

Material and Methods

The experimental material of the present study 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 by using Line × Tester mating design (Kempthorne, 1957). The resultant 40 (F_1) hybrids along with their fourteen parents were raised in Randomized Block Design with three replications at Research Farm of Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Further, two standard checks 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 to raise a healthy crop. During the present investigation, total thirteen contrasting 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 were subjected to statistical analysis for estimation of the average heterosis, heterobeltiosis and standard heterosis with an aim to increase the grain yield and yield contributing characters of the *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).

Results and Discussion

In recent investigation, analysis of variance (ANOVA) represented in Table 1 revealed that mean squares due to genotypes were highly significant for all the traits studied except panicle length. This indicated the presence of substantial genetic variability for these characters under the studied material. The parents differed among themselves significantly for all the characters under study. Similarly, females (lines) also exhibited highly significant differences for the characters except plant height, shoot fly dead heart percentage, panicle length, panicle breadth, grain yield per plant, grain hardness and threshed grain mold rating. Further, males (testers) showed highly significant differences for all the traits. Also, females vs males (lines vs testers) exhibited non-significant variation in case of days to maturity, panicle length, grain yield per plant, 1000 grain weight, grain hardness and threshed grain mold rating. Variance due to hybrids was also highly significant for all the characters except panicle length. Also, parents vs hybrids showed highly significant differences for all the characters except panicle length and threshed grain mold rating.

The range of mean performance and heterosis percentage (%) over mid parent, better parent and standard check along with best significant heterotic cross over standard check was depicted in Table 2. The range of mean performance for grain yield per plant was found to be greater in crosses (45.79 g to 87.72 g) as compared to their parents (38.37 g to 49.40 g). Similarly, fodder yield per plant exhibited the larger range of mean performance from 105.83 g to 231.30 g in crosses than its parents (107.47 g to 184.47 g). Moreover, the wider range in panicle weight was recorded in hybrids (67.03 g to 112.23 g) than its parental lines (55.90 g to 73.37 g). Also, 1000 grain weight from 29.65 g to 39.84 g for hybrids was depicted higher than its parental lines (25.39 g to 39.01 g) regarding mean performance. In case of days to 50% flowering, crosses obtained slightly early flowering

Table 1: Analysis of variance of parents and hybrids for various characters under Line × 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	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

range (60.33 days to 75.33 days) with respect to their parents (62.33 days to 75.33 days).

Kalpande *et al*., (2016[a]) examined that the crosses exhibited wider range of variation (mean performance) for most of the yield contributing characters as compared to their parents in their sorghum studies.

In response to grain yield per plant, the range of average heterosis, heterobeltiosis and standard heterosis was observed from 6.68% to 97.23%, -0.91% to 83.87% and -25.64% to 42.45% respectively. Likewise, heterosis (%) for fodder yield per plant varies from -11.10% to 56.18%, -19.81% to 49.02% and -35.97% to 39.93% for mid parent heterosis, better parent heterosis and economic heterosis. Heterosis for panicle weight was recorded broadly from -0.76% to 69.49%, -3.61% to 59.65% and -16.83% to 39.25% for average heterosis, heterobeltiosis and standard heterosis respectively. The wider range of heterosis for 1000 grain weight noted from -5.44% to 31.66%, -14.86% to 20.93% and -18.85% to 9.04% for mid parent heterosis, better parent heterosis and useful heterosis respectively.

In sorghum breeding scheme, the negative heterosis for days to 50% flowering and days to physiological maturity is desirable as earliness is always preferred in rainfed crop. Likewise, broad range of mid parent heterosis (-11.71% to 8.65%), better parent heterosis (-18.83% to 7.11%) and standard heterosis (-7.18% to 15.90%) was obtained for days to 50% flowering.

Mangal *et al*., (2017) revealed that nine crosses showed superior heterotic potential over its parents for grain yield and yield associated characters in *kharif* sorghum.

Cross AKMS 14 A × AKR 558 exhibited highest magnitude of significant standard heterosis *i.e*., 42.45% for grain yield per plant over the standard check CSH-35 and identified as promising hybrid. However, two crosses AKMS 14 A × AKR 557 and AKMS 14 A × AKR 558 were identified as promising cross combinations for days to 50% flowering with -7.18% standard heterosis over the standard check CSH-25 and recorded superior performance for earliness as represented in Table 2.

Similar outcomes for grain yield per plant were reported by Boratkar *et al*., (2014), Gite *et al.,* (2015), Kalpande *et al*., (2016[b]), More *et al*., (2017) and Ingle *et al*., (2018).

The estimation of average heterosis (over mid parent), heterobeltiosis (over better parent) and standard heterosis (over standard check) was performed to identify the heterotic potential of the hybrids (F_1's), for all the traits

Table 2: Range of mean performance and heterosis percentage (%) for various grain yield and its associated traits.

S No.	Characters	Range of mean		Range of heterosis percentage (%) over			Best significant heterotic cross over check
		Parents	Crosses	Mid parent	Better parent	Standard check	
1	**Days to 50 % flowering**	62.33 to 75.33	60.33 to 75.33	-11.71 to 8.65	-18.83 to 7.11	-7.18 to 15.90	AKMS 14 A × AKR 557 and AKMS 14 A × AKR 558
2	**Days to maturity (days)**	102.33 to 115.00	101.00 to 115.33	-6.15 to 5.33	-10.59 to 4.22	-3.81 to 9.84	AKMS 14 A × AKR 73 and AKMS 14 A × AKR 558
3	**Plant height (cm)**	140.33 to 205.00	154.33 to 281.00	-7.86 to 60.52	-14.10 to 37.24	-16.80 to 51.66	AKMS 14 A × AKR 559
4	**Shoot fly dead heart percentage (at 28 days)**	12.96 to 27.51	6.32 to 29.32	-46.60 to 22.11	-50.85 to 8.34	-47.00 to 14.77	ICS 733 A × AKR 558
5	**Panicle weight (g)**	55.90 to 73.37	67.03 to 112.23	-0.76 to 69.49	-3.61 to 59.65	-16.83 to 39.25	AKMS 14 A × AKR 558
6	**Panicle length (cm)**	23.47 to 30.13	26.93 to 33.67	-59.19 to 24.28	-74.89 to 24.03	-6.59 to 16.76	Nil
7	**Panicle breadth (cm)**	4.67 to 6.37	5.34 to 6.98	5.27 to 35.02	-4.92 to 30.56	-11.69 to 15.44	AKMS 14 A × AKR 558
8	**Number of grains per panicle**	1036.97 to 1885.20	985.03 to 2564.77	-22.81 to 90.57	-32.57 to 80.26	-49.61 to 31.21	ICS 733 A × AKR 545
9	**Grain yield per plant (g)**	38.37 to 49.40	45.79 to 87.72	6.68 to 97.23	-0.91 to 83.87	-25.64 to 42.45	AKMS 14 A × AKR 558
10	**Fodder yield per plant (g)**	107.47 to 184.47	105.83 to 231.30	-11.10 to 56.18	-19.81 to 49.02	-35.97 to 39.93	AKMS 14 A × AKR 559
11	**1000 grain weight (g)**	25.39 to 39.01	29.65 to 39.84	-5.44 to 31.66	-14.86 to 20.93	-18.85 to 9.04	AKMS 70 A × AKR 73
12	**Grain hardness (kg/cm^2)**	6.77 to 11.23	6.67 to 12.33	-26.71 to 53.50	-33.23 to 41.67	-29.82 to 29.82	AKMS 70 A × AKR 553 and ICS 733 A × AKR 558
13	**Threshed grain mold rating (%)**	7.67 to 31.67	5.00 to 35.67	-73.09 to 89.56	-79.45 to 41.39	-78.57 to 52.86	AKMS 30 A × AKR 560 and ICS 733 A × AKR 558

under current investigation (Table 2). It was observed that among 40 hybrids, total fifteen crosses exhibited positive significant standard heterosis over the standard check CSH-35 for grain yield and CSH-25 for earliness along with other important yield contributing parameters and appeared best promising combinations for development of high yielding *kharif* sorghum hybrids (Table 3).

Out of the total 40 crosses, the cross combination AKMS 14 A × AKR 558 was identified as the most excellent hybrid with highest positive significant standard heterosis of 42.45% for grain yield per plant. Similarly, this cross combination recorded average heterosis of 97.23% and heterobeltiosis of 83.87% for grain yield per plant. Also, it showed significant positive standard heterosis for other traits like fodder yield per plant, days to maturity, panicle weight, number of grains per panicle, grain hardness and threshed grain mold rating (Table 3).

On second position, the cross combination AKMS 70 A × AKR 558 exhibited significant useful heterosis (40.50%) over the check CSH-35 for grain yield; it also revealed significant average heterosis and heterobeltiosis (89.60% and 81.36%). Similarly, this hybrid also characterized with significant standard heterosis for traits like plant height, panicle weight, number of grains per panicle, fodder yield per plant and threshed grain mold rating.

Another hybrid ICS 733 A × AKR 545 ranked third for the standard heterosis and possessed significant positive standard heterosis 31.90% over the check CSH-35 for grain yield per plant. Likewise, the cross combination exhibited significant positive average heterosis (80.77%) and heterobeltiosis (64.44%). Also, this cross exhibited significant standard heterosis for other characters like plant height, shoot fly dead heart percentage, panicle weight, number of grains per panicle, fodder yield per plant, 1000 grain weight, grain hardness and threshed grain mold rating.

The cross AKMS 70 A × AKR 73 ranked fourth and exhibited significant standard heterosis for grain yield

Table 3: Desirable and significant Average heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis over CSH-35 (H_3) for yield and other important components.

Sr. No.	Crosses	Mean performance for given yield per plant (g)	Average heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) for grain yield	Significant Average heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) for other characters
1	AKMS 14 A × AKR 558	87.72	H_1=97.23**	1,3,5,7,8,10,11,12,13
			H_2=83.87**	1,2,3,4,5,7,8,10,12,13
			H_3=42.45**	1,2,3,5,7,8,10,12,13
2	AKMS 70 A × AKR 558	86.53	H_1=89.60**	3,5,7,8,10,12,13
			H_2=81.36**	2,3,5,7,8,10,12,13
			H_3=40.50**	3,5,7,8,10,13
3	ICS 733 A × AKR 545	81.23	H_1=80.77**	3,4,5,7,8,10,11,12,13
			H_2=64.44**	1,2,3,4,5,7,8,10,11,13
			H_3=31.90**	3,4,5,7,8,10,11,12,13
4	AKMS 70 A × AKR 73	79.63	H_1=74.42**	3,4,5,7,8,10,12,13
			H_2=66.77**	1,2,3,4,5,7,8,10,13
			H_3=29.31**	3,4,5,10,11,13
5	AKMS 70 A × AKR 560	79.50	H_1=71.44**	3,5,7,8,10,11,12,13
			H_2=61.64**	1,3,5,7,8,10,13
			H_3=29.10**	3,5,7,10,13
6	AKMS 70 A × AKR 553	77.97	H_1=78.78**	3,5,7,8,10,12,13
			H_2=78.57**	3,5,8,10,12,13
			H_3=26.61**	5,12,13
7	AKMS 30 A × AKR 553	75.95	H_1=70.67**	3,4,5,7,8,10,11,12,13
			H_2=67.51**	3,4,5,7,8,10,11,12,13
			H_3=23.33**	3,4,5,7,8,10,11,13
8	AKMS 14 A × AKR 73	74.88	H_1=68.27**	1,2,3,5,7,8,10,11,12,13
			H_2=56.81**	1,2,5,7,10
			H_3=21.59**	1,2,5,11
9	ICS 733 A × AKR 558	73.99	H_1=67.81**	3,4,5,7,8,10,11,12,13
			H_2=55.08**	4,5,8,12,13
			H_3=20.15**	3,4,5,8,10,12,13
10	AKMS 30 A × AKR 545	73.62	H_1=55.41**	1,2,3,4,5,7,8,10
			H_2=49.03**	1,2,5,8,10,12
			H_3=19.54**	5,8
11	AKMS 70 A × AKR 545	73.39	H_1=57.90**	3,4,5,7,8,10
			H_2=48.58**	1,2,3,4,5,10,13
			H_3=19.18**	3,4,5,13
12	AKMS 14 A × AKR 524	72.99	H_1=78.95**	3,4,5,7,8,10,11,13
			H_2=76.98**	3,4,5,7,8,10,11
			H_3=18.53**	3,5
13	ICS 733 A × AKR 73	71.51	H_1=62.11**	5,7,8,10,11,12,13
			H_2=49.76**	1,2,3,5,7,8,13
			H_3=16.12**	5,8,13
14	ICS 733 A × AKR 529	70.65	H_1=63.91**	4,5,7,8,10,11,12,13
			H_2=54.92**	1,2,3,4,5,10,11,12,13
			H_3=14.72**	5,7,11,12
15	AKMS 30 A × AKR 560	69.31	H_1=46.64**	3,4,5,7,8,10,11,12,13
			H_2=40.91**	3,4,5,7,8,10,11,12,13
			H_3=12.55*	3,4,5,10,12,13

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Note: * - significant at 5% level of significance
** - significant at 1% level of significance
Note: 1: Days to 50 % flowering; 2: Days to maturity; 3: Plant height (cm); 4: Shoot fly dead heart percentage (at 28 days); 5: Panicle weight (g); 6: Panicle length (cm); 7: Panicle breadth (cm); 8: Number of grains per panicle; 9: Grain yield per plant (g); 10: Fodder yield per plant (g) 11: 1000 grain weight (g); 12: Grain hardness (kg/cm^2) 13: Threshed grain mold rating (%)

(29.31%) along with the other important traits like plant height, shoot fly dead heart percentage and 1000 grain weight. It also noted significant positive average heterosis (74.42%) and heterobeltiosis (66.77%) for grain yield per plant.

On fifth position, AKMS 70 A × AKR 560 cross showed significant positive standard heterosis (29.10%) over check CSH-35. This cross revealed significant positive average heterosis and heterobeltiosis (71.44% and 61.64%) respectively for grain yield per plant. This cross also exhibited desirable significant standard heterosis for other useful components like plant height, panicle weight, fodder yield per plant and threshed grain mold rating.

Besides these cross combinations, another ten crosses i.e. (AKMS 70 A × AKR 553, AKMS 30 A × AKR 553, AKMS 14 A × AKR 73, ICS 733 A × AKR 558, AKMS 30 A × AKR 545, AKMS 70 A × AKR 545, AKMS 14 A × AKR 524, ICS 733 A × AKR 73, ICS 733 A × AKR 529 and AKMS 30 A × AKR 560) displayed positive and significant standard heterosis for grain yield per plant over the check CSH-35 (26.61%, 23.33%, 21.59%, 20.15%, 19.54%, 19.18%, 18.53%, 16.12%, 14.72% and 12.55% respectively). Average heterosis of (78.78%, 70.67%, 68.27%, 67.81%, 55.41%, 57.90%, 78.95%, 62.11%, 63.91% and 46.64% respectively) and heterobeltiosis (78.57%, 67.51%, 56.81%, 55.08%, 49.03%, 48.58%, 76.98%, 49.76%, 54.92% and 40.91% respectively) was estimated in these above mentioned ten cross combinations for grain yield per plant.

This database clearly manifested that these cross combinations can be precisely utilized using heterosis breeding for development of high yielding potential *kharif* sorghum hybrids.

Tayade *et al.*, (2018) reported that out of 56 hybrids, the cross AKMS 90 A × AKR 337 recorded maximum grain yield per plant with 35.07%, 34.12% and 23.91% heterosis over the mid parent, better parent and standard check (CSH-35) respectively.

The identical results for high heterosis in the promising crosses for grain yield and yield contributing characters in sorghum were also investigated by Rajguru *et al.*, (2005); Umakanth *et al.*, (2006); Jhansi Rani *et al.*, (2008); Krishna Murthy *et al.*, (2010); Mahdy *et al.*, (2011); Hariprasanna *et al.*, (2012); Ghorade *et al.*, (2014); Kalpande *et al.*, (2014); Kalpande *et al.*, (2015); Choudhari *et al.*, (2016); Mangal *et al.*, (2017); Gawande *et al.*, (2020) and Sandeep and Biradar (2020).

Conclusion

The results of the present study indicated that potential amount of standard heterosis was evident for grain yield per plant coupled with considerable amount of mid parent and better parent heterosis in fifteen promising hybrids. On the basis of highest significant positive standard heterosis, AKMS 14 A × AKR 558 (42.45%), AKMS 70 A × AKR 558 (40.50%), ICS 733 A × AKR 545 (31.90%), AKMS 70 A × AKR 73 (29.31%) and AKMS 70 A × AKR 560 (29.10%) were emerged as the most excellent five heterotic cross combinations. Along with grain yield per plant, most of the promising hybrids recorded advantageous and significant standard heterosis for other important yield contributing characters.

Therefore, the present investigation recommended that these newly developed above fifteen promising hybrids need to be tested to find out the most stable genotypes in multilocation and multi season trials on large scale for assessing the yield and yield contributing characters and their further commercial exploitation.

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