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Heterosis study for yield and yield attributes in sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract
The present investigation was carried out with a view to study the *per se* performance and magnitude of heterosis using L × T analysis. The experimental material consisted of eight parents (3 females and 5 males) and their resultant fifteen crosses with standard check CSH-25 were evaluated in a randomized block design with three replications. at Main Sorghum Research Station, Navsari Agricultural University, Athwa farm, Surat during *Kharif*-2019. In the present investigation, a variable degree of heterosis was observed for almost all the characters. Total eight promising hybrids *viz*., GJ-38 × GNJ-1, IS-5476 × ICSV-17044, GJ-42 × GNJ-1, GJ-38 × ICSV-17044, GJ-42 × ICSV-17041, IS-5476 × GNJ-1, GJ-38 × ICSV-17041 and IS-5476 × ICSV-17041 were identified with high heterosis and heterobeltiosis and high *per se* performance for grain yield and significant useful heterosis for some other important traits. From the top-ranking hybrids for grain yield, Cross combinations GJ-38 × GNJ-1, IS-5476 × ICSV-17044, GJ-42 × GNJ-1 and GJ-38 × ICSV-17044 depicted significant standard heterosis for panicle length. This hybrid can be used in further breeding programme for high yield with long panicle.

Keywords: Replication, line × tester, hybrids, heterosis, heterobeltiosis

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop in India used for dual purpose i.e. feed and fodder. Sorghum is one of the most important cereal crops of the semi-arid tropics. Cultivated sorghum is diploid (2n=2x=20) species. Sorghum is often cross-pollinated crop and cross-pollination averaging about six to ten percent and may be as high as 30 percent in Sudan grass. The USA is the world's leading producer of sorghum. India is the second largest producer of sorghum in the world. In India, sorghum ranks third in production, next to rice and wheat. Sorghum is cultivated in 4.09 million hectares during 2018-19 with production of 3.47 million tones and productivity of 849 kg per hectares in India (Anon., 2019) [1]. In Gujarat, sorghum is cultivated in 0.075 million hectares during 2018-19 with production of 0.096 million tones and productivity of 1278 kg per hectares (Anon., 2019) [1]. Sorghum is nutritionally superior to the other fine cereals such as rice and wheat. Sorghum is a dual-purpose crop; the grain is used for human consumption, while the fodder is utilized as feed to the cattle. Sorghum grain provides a good amount of protein (11%) carbohydrate (72%) and fat (4%). The present study is an attempt to assess the possibilities of commercial exploitation of heterosis and to develop better hybrids and identify elite lines for the further breeding program.

Materials and Methods

The experimental material consisted of eight parents 3 females (GJ-38, GJ-42 and IS-5476) and 5 males (ICSV-17022, ICSV-17041, ICSV-17044, GJ-43 and GNJ-1), and their resultant fifteen crosses with standard check CSH-25 were evaluated in a randomized block design with three replications at the College farm, N. M. College of Agriculture, Navsari Agricultural Universirty, Navsari during summer-2019 and evaluation was carried out during *Kharif*-2019 at the Main Sorghum Research Station, Navsari Agricultural University, Athwa farm, Surat. For recording observation, five competitive plants were randomly selected in each plot in all the three replications and mean observations were taken. Total eleven character studied in this experiment *viz.*, days to 50 percent flowering, days to maturity, plant height (cm), panicle length (cm), primary branches per panicle, secondary branches per panicle, 100 seeds weight (g), grain yield per plant (g), protein content (%), fe content (ppm) and zn content (ppm). The mean performance of parents, as well as hybrids, were subjected to statistical analysis. Analysis of variance was carried out to test the significance for each character as per the methodology suggested by Panse and Sukhatme (1985) [5]. Heterobeltiosis (BH) was calculated using the method given by Fonseca and Patterson (1968) [3]. and Standard heterosis by Meredith and Bridge (1972) [4].

Results and Discussion

The analysis of variance was performed to test the difference amongst parents and hybrids for all the eleven characters and is presented in Table 1. The results revealed that the mean squares due to genotypes were highly significant for all the characters, indicating the considerable amount of variability present among genotypes for various characters. This validated that the material was appropriate for present study. The mean squares due to genotypes were further partitioned into parents, hybrids and parents *vs*. hybrids. The differences among parents were highly significant for all characters under investigation except days to 50 percent flowering and days to maturity. The differences among, the hybrids were found significant for all characters. Differences due to parents *vs* hybrids were found highly significant for all the traits under study except Zn content, it revealed that the performance of hybrids were different from that of parents, there by supporting the presence of substantial amount of heterosis for these traits.

Grain yield per plant is an attribute of economic importance which the breeders attempt to improve by evolving new high yielding hybrids. The results revealed that heterobeltiosis ranged from -0.82 (GJ-38 × GJ-43) to 92.84 (IS-5476 × ICSV-17044) percent. Twelve hybrids revealed positive and significant heterobeltiosis. Cross combinations IS-5476 × ICSV-17044 (92.84%), IS-5476 × ICSV-17041 (82.56%), GJ-42 × ICSV-17041 (76.68%), GJ-42 × ICSV-17044 (71.71%), GJ-42 × GJ-43 (41.39%) and GJ-38 × GNJ-1 (34%) emerged as topper. It is interesting to note that, GJ-42 contributed as female parent in three crosses among these top crosses. The variation observed in standard heterosis for grain yield was -13.92 (IS-5476 × GJ-43) to 22.43 (GJ-38 × GNJ-1) percent. Total four hybrids *viz*., GJ-38 × GNJ-1 (22.43%), IS-5476 × ICSV-17044 (18.13%), GJ-42 × GNJ-1 (16.53%) and GJ-38 × ICSV-17044 (15.99%) exhibited positive and significant standard heterosis in grain yield. From these top cross combinations, GJ-38 and GNJ-1 were involved as parent in two crosses each. Among the heterotic crosses, GJ-38 × GNJ-1 exhibited positive and significant standard heterosis for panicle length, test weight, number of primary branches per panicle, number of secondary branches per panicle, protein and Fe content. Total eight promising hybrids *viz*., GJ-38 × GNJ-1, IS-5476 × ICSV-17044, GJ-42 × GNJ-1, GJ-38 × ICSV-17044, GJ-42 × ICSV-17041, IS-5476 × GNJ-1, GJ-38 × ICSV-17041 and IS-5476 × ICSV-17041 were identified with high heterosis and heterobeltiosis and high *per se* performance for grain yield and significant useful heterosis for some other important traits.

For days to 50 percent flowering and maturity, negative heterobeltiosis were reported in large number of crosses which pinpointed higher growth rate in a hybrid. Cross combinations GJ-38 × ICSV-17044, GJ-42 × ICSV-17044, GJ-42 × GJ-43 and IS-5476 × GJ-43 depicted significant negative standard heterosis for these characters of earliness. While the cross combinations GJ-42 × GNJ-1 and IS-5476 × ICSV-17041 depicted significant heterobeltiosis for days to 50 percent flowering and days to maturity, these can be uses for further breeding programme to develop high yielding with early maturity genotypes. From the top-ranking hybrids for grain yield, Cross combination GJ-38 × ICSV-17044 depicted significant heterobeltiosis and standard heterosis for days to 50 percent flowering and days to maturity in desirable direction coupled with panicle length, test weight, Zn content and primaries and secondary branches, this hybrid can be further evaluated on large scale before commercialization for early maturing, high yielding hybrids with good grain quality. From the top-ranking hybrids for grain yield, Cross combinations GJ-38 × GNJ-1, IS-5476 × ICSV-17044, GJ-42 × GNJ-1 and GJ-38 × ICSV-17044 depicted significant standard heterosis for panicle length. This hybrid can be used in further breeding programme for high yield with long panicle.

Bold grain is of consumer’s preference. From the top-ranking hybrids for grain yield, Cross combinations GJ-38 × GNJ-1, IS-5476 × ICSV-17044, GJ-42 × GNJ-1, GJ-38 × ICSV-17044, GJ-42 × ICSV-17041 and GJ-38 × ICSV-17041 depicted significant standard heterosis for test weight. This hybrids can be used in further breeding programme to develop high yielding genotypes coupled with bold grain. The hybrid, IS-5476 × GNJ-1 depicted significant standard heterosis for quality parameters *viz.* protein, Fe and Zn content and can be further evaluated and utilize in breeding programme to develop bio-fortified genotypes.

Table 1: Analysis of variance for various characters in sorghum

Source of variation	d.f.	Mean sum of squares					
		Days to 50 percent flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Primary branches per panicle	Secondary branches per panicle
Replication	2	5.86	6.55	201.52	8.29	55.62	816.90
Genotypes	22	36.26**	54.77**	3669.60**	55.57**	513.81**	69468.34**
Parents	7	1.36	4.28	1411.06**	57.78**	186.32**	23422.29**
Females	2	0.79	0.78	251.80	1.45	128.37*	10972.11*
Males	4	1.54	6.67	2340.77**	39.57**	261.59**	33744.98**
Females *vs* Males	1	1.78	1.72	10.72	243.25**	1.15	7031.87
Parents *vs* Hybrids	1	397.23**	809.40**	42777.63**	354.24**	1695.46**	179737.50**
Hybrids	14	27.92**	26.11*	2005.43**	33.13**	593.15**	84614.99**
Females effects	2	1.86	4.88	2871.90**	3.46	96.71	2152.70
Males effects	4	21.75	23.98	5095.28**	63.65	1872.71**	290210.60**
Female x Male effect	8	37.52**	32.49*	243.89	25.28**	77.48	2432.78
Error	44	6.15	11.42	408.99	5.57	38.76	2402.66

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Source of variation	d.f.	Mean sum of squares				
		100 seeds weight (g)	Grain yield per plant (g)	Protein Content (%)	Fe Content (ppm)	Zn Content (ppm)
Replication	2	0.06	5.18	0.19	1.29	0.18
Genotypes	22	1.12**	482.33**	8.83**	672.58**	69.67**
Parents	7	0.32**	218.49**	8.86**	439.25**	149.55**
Females	2	0.15	270.70**	8.58**	198.81**	64.13**
Males	4	0.38**	244.32**	5.91**	669.22**	171.53**
Females *vs* Males	1	0.45*	10.72	21.20**	0.25	232.47**
Parents *vs* Hybrids	1	0.83**	6893.39**	27.71**	6358.01**	0.30
Hybrids	14	1.55**	156.32**	7.47**	383.14**	34.68**
Females effects	2	1.07	36.16	2.83	59.81	1.80
Males effects	4	3.89**	454.02**	15.48	1061.55**	71.18
Female x Male effect	8	0.49**	37.51	4.62**	124.76**	24.65**
Error	44	0.06	23.56	0.15	7.98	1.28

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Table 2: Estimation of heterosis in F_1 hybrid over BP (Better parents) and SC (Standard check) for various characters in sorghum

Sr. No.	Crosses	Days to 50 percent flowering		Days to maturity	
		BP	SC	BP	SC
1	GJ-38 x ICSV-17022	-6.61*	-3.26	-6.53*	-3.13
2	GJ-38 x ICSV-17041	-6.22*	-4.24	-4.23	-2.51
3	GJ-38 x ICSV-17044	-12.27**	-9.13**	-8.08**	-5.59*
4	GJ-38 x GJ-43	-5.47	-2.55	-5.64*	-2.21
5	GJ-38 x GNJ-1	-1.90	1.62	-3.26	0.26
6	GJ-42 x ICSV-17022	-6.19*	-3.75	-5.68*	-2.82
7	GJ-42 x ICSV-17041	1.44	3.58	-0.30	1.49
8	GJ-42 x ICSV-17044	-11.54**	-9.25**	-9.58**	-7.13**
9	GJ-42 x GJ-43	-10.48**	-8.15*	-8.96**	-6.20*
10	GJ-42 x GNJ-1	-7.15*	-4.73	-6.57*	-3.75
11	IS-5476 x ICSV-17022	-8.61**	-6.68*	-7.19**	-4.67
12	IS-5476 x ICSV-17041	-6.70*	-4.73	-5.13*	-3.44
13	IS-5476 x ICSV-17044	1.44	3.58	-1.50	1.18
14	IS-5476 x GJ-43	-12.92**	-11.08**	-9.58**	-7.13**
15	IS-5476 x GNJ-1	-4.79	-2.78	-4.79	-2.21
S.E. (±)		2.03	2.03	2.76	2.76

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Sr. No.	Crosses	Plant height (cm)		Panicle length(cm)	
		BP	SC	BP	SC
1	GJ-38 x ICSV-17022	55.40**	16.28*	11.86	-9.65
2	GJ-38 x ICSV-17041	38.29**	8.28	12.46	7.16
3	GJ-38 x ICSV-17044	32.41**	20.05*	4.36	19.09**
4	GJ-38 x GJ-43	50.14**	36.12**	-3.82	-5.71
5	GJ-38 x GNJ-1	19.19*	7.84	14.41*	15.82*
6	GJ-42 x ICSV-17022	43.91**	7.68	10.36	-10.86
7	GJ-42 x ICSV-17041	40.33**	9.87	12.02	6.74
8	GJ-42 x ICSV-17044	35.84**	22.99**	-12.63*	-0.31
9	GJ-42 x GJ-43	48.77**	34.70**	9.87	7.72
10	GJ-42 x GNJ-1	14.23	3.35	14.87*	16.28*
11	IS-5476 x ICSV-17022	33.47**	-0.12	26.95**	2.54
12	IS-5476 x ICSV-17041	36.14**	6.59	-5.63	-10.08
13	IS-5476 x ICSV-17044	36.43**	13.46	7.99	23.22**
14	IS-5476 x GJ-43	40.74**	17.05*	10.43	8.27
15	IS-5476 x GNJ-1	9.57	-8.87	10.09	11.44
S.E. (±)		16.51	16.51	1.93	1.93

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Sr. No.	Crosses	Number of primary branches		Number of secondary branches	
		BP	SC	BP	SC
1	GJ-38 x ICSV-17022	-1.77	-16.16*	-12.54	-27.44**
2	GJ-38 x ICSV-17041	11.24	1.67	37.37**	13.96*
3	GJ-38 x ICSV-17044	21.53**	22.54**	26.22**	12.11*
4	GJ-38 x GJ-43	-2.82	-17.06*	-29.31**	-41.35**
5	GJ-38 x GNJ-1	21.38**	17.64*	32.54**	14.23*
6	GJ-42 x ICSV-17022	-9.44	-10.38	-12.61	-23.87**
7	GJ-42 x ICSV-17041	4.95	3.86	15.36*	0.49
8	GJ-42 x ICSV-17044	19.77**	20.77**	29.72**	15.22*
9	GJ-42 x GJ-43	-2.24	-3.26	-36.04**	-44.28**
10	GJ-42 x GNJ-1	21.40**	20.13**	31.80**	14.81*
11	IS-5476 x ICSV-17022	-20.67*	-34.41**	-3.57	-32.38**
12	IS-5476 x ICSV-17041	9.74	0.30	25.47**	1.02
13	IS-5476 x ICSV-17044	27.71**	28.77**	30.81**	16.19*
14	IS-5476 x GJ-43	-0.01	-16.61*	-18.87*	-43.11**
15	IS-5476 x GNJ-1	23.68**	19.86**	30.25**	12.25*
S.E. (±)		5.08	5.08	40.02	40.02

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Sr. No.	Crosses	100 Seeds Weight		Grain yield per plant	
		BP	SC	BP	SC
1	GJ-38 x ICSV-17022	-2.30	-6.88	14.50	-0.28
2	GJ-38 x ICSV-17041	33.10**	17.29*	24.10**	8.08
3	GJ-38 x ICSV-17044	9.10	16.15*	33.19**	15.99*
4	GJ-38 x GJ-43	-1.54	-0.21	-0.82	-13.62*
5	GJ-38 x GNJ-1	20.02**	16.15*	34.00**	22.43**
6	GJ-42 x ICSV-17022	-35.74**	-38.75**	23.06**	0.71
7	GJ-42 x ICSV-17041	25.96**	16.77*	76.68**	9.69
8	GJ-42 x ICSV-17044	4.50	11.25	71.71**	6.61
9	GJ-42 x GJ-43	-45.22**	-44.48**	41.39**	-4.46
10	GJ-42 x GNJ-1	20.56**	16.67*	27.54**	16.53*
11	IS-5476 x ICSV-17022	-3.17	-7.71	8.03	-11.59
12	IS-5476 x ICSV-17041	36.68**	7.92	82.56**	8.08
13	IS-5476 x ICSV-17044	10.86	18.02**	92.84**	18.13**
14	IS-5476 x GJ-43	-39.98**	-39.17**	27.39**	-13.92*
15	IS-5476 x GNJ-1	9.58	6.04	18.93*	8.65
S.E. (±)		0.20	0.20	3.96	3.96

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Sr. No.	Crosses	Protein Content		Fe Content	
		BP	SC	BP	SC
1	GJ-38 x ICSV-17022	5.64	-15.02**	22.20**	-10.20**
2	GJ-38 x ICSV-17041	4.91	3.58	16.15**	10.55**
3	GJ-38 x ICSV-17044	-8.40*	-26.31**	11.00**	-18.43**
4	GJ-38 x GJ-43	29.78**	4.40	33.41**	-1.96
5	GJ-38 x GNJ-1	23.77**	15.32**	32.82**	7.06*
6	GJ-42 x ICSV-17022	8.16*	16.69**	37.39**	-8.63**
7	GJ-42 x ICSV-17041	11.33**	20.10**	12.07**	6.67*
8	GJ-42 x ICSV-17044	-20.97**	-14.74**	20.81**	-26.67**
9	GJ-42 x GJ-43	-10.50**	-3.45	24.35**	-16.87**
10	GJ-42 x GNJ-1	-2.59	5.09	35.26**	9.02**
11	IS-5476 x ICSV-17022	-31.71**	-23.21**	37.23**	9.02**
12	IS-5476 x ICSV-17041	5.58	18.74**	0.53	-4.31
13	IS-5476 x ICSV-17044	-21.43**	-11.64**	-5.73	-25.10**
14	IS-5476 x GJ-43	5.58	18.74**	8.09*	-14.12**
15	IS-5476 x GNJ-1	1.03	13.62**	36.72**	10.20**
S.E. (±)		0.31	0.31	2.31	2.31

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Sr. No.	Crosses	Zn Content	
		BP	SC
1	GJ-38 x ICSV-17022	-4.49	27.45**
2	GJ-38 x ICSV-17041	-25.83**	-1.03
3	GJ-38 x ICSV-17044	-12.29**	17.05**
4	GJ-38 x GJ-43	-34.70**	-12.86**
5	GJ-38 x GNJ-1	-28.75**	-2.44
6	GJ-42 x ICSV-17022	2.21	14.46**
7	GJ-42 x ICSV-17041	-5.54	-4.67
8	GJ-42 x ICSV-17044	-4.63	-3.75
9	GJ-42 x GJ-43	5.81	6.79
10	GJ-42 x GNJ-1	-6.72*	27.71**
11	IS-5476 x ICSV-17022	-5.97*	22.90**
12	IS-5476 x ICSV-17041	-30.34**	-8.95*
13	IS-5476 x ICSV-17044	-23.15**	0.44
14	IS-5476 x GJ-43	-23.37**	0.16
15	IS-5476 x GNJ-1	-15.94**	15.10**
S.E. (±)		0.92	0.92

* and ** indicates significance at 5 and 1 percent levels of probability, respectively

Table 3: Best heterotic cross combinations and their performance for grain yield and other characters

Promising hybrids	Grain yield per plant (g)	Heterosis		Significant heterosis for other traits over	
		HB	SH	BP	SC
GJ-38 x GNJ-1	75.83	34.00**	22.43**	PL,PBP,SBP,TW,GY, PC,FC	PL,PBP,SBP,TW,GY, PC,FC
IS-5476 x ICSV-17044	73.17	92.84**	18.13**	PBP,SBP,GY	PL,PBP,SBP,TW,GY
GJ-42 x GNJ-1	72.17	27.54**	16.53*	DFF,DM,PL,PBP,SBP,TW,GY,FC	PL,PBP,SBP,TW,GY, FC,ZC
GJ-38 x ICSV-17044	71.84	33.19**	15.99*	DFF,DM,PBP,SBP, GY,FC	DFF,DM,PL,PBP,SBP,TW,GY,ZC
GJ-42 x ICSV-17041	67.94	76.68**	9.69	PBP,TW,GY,PC,FC	TW,PC,FC
IS-5476 x GNJ-1	67.29	18.93*	8.65	PBP,SBP,FC	PBP,SBP,GY,PC,FC,ZC
GJ-38 x ICSV-17041	66.94	24.10**	8.08	DFF,SBP,TW,GY,FC	SBP,TW,FC
IS-5476 x ICSV-17041	66.94	82.56**	8.08	DFF,DM,SBP,TW,GY	PC

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

Where,
DFF = Days to 50 percent flowering, DM = Days to maturity, PH = Plant height, PL = Panicle length, PBP = primary branches per panicle, SBP = Secondary branches per panicle, TW = Test weight, GY = Grain yield, PC = Protein content, FC = Fe content, ZC = Zn content, BP = Better parent, HB = Heterobeltiosis, SC = Standard check, SH = Standard heterosis, P1 - Female parent, P2– Maleparent

Conclusion
In conclusion, the analysis of variance conducted on eleven characters demonstrated significant variability among genotypes, validating the suitability of the material for the study. Notably, differences among parents and hybrids were observed, with several hybrids displaying positive and significant heterobeltiosis and standard heterosis for grain yield and other essential traits. Promising hybrids like GJ-38 × GNJ-1, IS-5476 × ICSV-17044, and others exhibited desirable characteristics such as early maturity, high yield, long panicle, and bold grain, making them valuable candidates for further breeding programs. Additionally, hybrids like IS-5476 × GNJ-1 showed potential for enhancing quality parameters like protein and mineral content, suggesting their utility in developing bio-fortified genotypes. These findings underscore the potential for breeding superior crop varieties to meet consumer preferences and nutritional needs. Further evaluation and large-scale testing of these hybrids are warranted before commercialization to ensure their efficacy and success in agricultural production.

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