RESEARCH ARTICLE | Agricultural Science Digest, Volume 42 Issue 1: 53-57 (February 2022)

Studies on Heterosis, Residual Heterosis and Inbreeding Depression for Yield and Related Traits in Sorghum (*Sorghum bicolor* L.)

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10.18805/ag.D-5249

ABSTRACT

Background: Selection of genotypically superior parents is most challenging task for the development of potential hybrids. In conventional plant breeding, magnitude of heterosis and inbreeding depression has been proved very effective in identifying vigorous parental combinations.

Methods: The present investigation was carried out to study the heterosis, residual heterosis and inbreeding depression of forty sorghum crosses (F1s and F2s) obtained by crossing of eight restorer lines with five cytoplasmic male sterile lines in Line x Tester mating design in 2013 and 2014. Observations were recorded on morphological traits *viz.* days to 50% flowering, days to maturity, plant height, flag leaf length, flag leaf width, panicle length, panicle width, panicle weight,1000 seed weight and grain yield per plant.

Result: Among all crosses, ICSA467 × UPC2 and MR750A2 × UPC2 were found to be best for most of the characters. Inbreeding depression was recorded as significantly positive for plant height for most of the crosses indicates the occurrence of transgressive segregants in F2 generation.

Key words: Heterosis, Inbreeding depression, Line × tester, Residual heterosis, Sorghum.

INTRODUCTION

For arid and semi-arid areas, sorghum is very important cereal crop with multiple uses and ranks fifth after wheat, rice, maize and pearlmillet in area and production among cereals worldwide. To fulfil the food demands of continuously increasing population, increased production is the major task to plant breeders. Heterosis is phenomenon of superiority of progenies over parents and has been exploited to increase the yield and other quality traits in several crops. Heterosis helps in identification of best parental combinations, either for exploitation of heterosis or accumulation of fixable genes through selection. The heterosis helps to understand various types of gene action for selection of suitable breeding methods for an effective crop improvement programme. The parents found to be good in *per se* performance may not produce heterotic progenies in hybridization programme (Allard, 1960). The combining abilities of parents depend on the complex interactions among the genes which cannot be judged by only yield performance.

Inbreeding is a phenomenon which influence many quantitative traits and increase homozygosity at particular *loci* with some degree of dominance (Charlesworth and Charlesworth, 1999). There may be two reasons in which increased homozygosity can cause reduced fitness: increased homozygosity for recessive detrimental gene mutations and increased homozygosity for alleles at *loci* with heterozygote advantage or can be said as overdominance. Deleterious alleles are generally present at low frequencies (mutation-selection balance) in populations, whereas overdominant alleles at a particular *locus* are maintained at intermediate frequencies by balancing selection (Charlesworth and Willis, 2009). In present study, the experiments were conducted to estimate the effect of heterosis, residual heterosis and inbreeding depresssion on different yield contributing characters for the parental selection and development of high yielding hybrids in sorghum.

MATERIALS AND METHODS

The experiments were conducted at the Instructional Dairy Farm of the G.B. Pant University of Agriculture and Technology, Pantnagar (U.S. Nagar) India, during *Kharif* season in 2013-14 and 2014-2015. The experimental materials for the present study consist of forty F_1 crosses developed through line × tester mating design involving five diverse CMS lines (female), eight pollinator (male) lines. The details of non-tillering parental lines (lines and testers) and their F_1s have been presented in Table 1.

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How to cite this article: Chauhan, P. and Pandey, P.K. (2022). Studies on Heterosis, Residual Heterosis and Inbreeding Depression for Yield and Related Traits in Sorghum (*Sorghum bicolor* L.). Agricultural Science Digest. 42(1): 53-57. DOI: 10.18805/ag.D-5249.

Submitted: 31-07-2020 **Accepted:** 23-02-2021 **Online:** 29-04-2021

Ten competitive plants were randomly taken, from each treatment/genotype in each replication in both the years. All the selected plants were tagged and observations for all the characters were taken. The means of different characters for the purpose of statistical analysis were calculated on the basis of the individual data recorded for each character, in each replication separately, for each cross. Days to 50% flowering were calculated by counting the number of days between planting when one half of the panicles in a plot reached the half bloom stage. Days to maturity were estimated when more than 90% of grain turned yellow, not more than 5% were green and not more than 2% were in milking stage. The plant height was measured from ground level to the tip of the uppermost leaf of each plant. Panicle length was measured at maturity, from the bottom panicle node to the upper most floret or the tip of panicle. Panicle weight was measured at maturity. Flag leaf length was measured from base to tip and flag leaf width was measured in middle of the leaf. Weight (grams) of one thousand random grains from total grain yield of tagged plants was recorded and mean was worked out. Average weight of grains obtained from ten random plants after threshing and sun drying was recorded. Heterosis expressed as percentage increase or decrease of F_1s over better parent was calculated as suggested by Fonseca and Petterson (1968).

Inbreeding depression in F2 was estimated by using the formula given by Kempthorne (1957)

$$\text{Inbreeding depression} = [(F1-F2)/F1] \times 100$$

Where,
F1= Mean value of F1 progeny.
F2 = Mean value of F2 progeny.

Residual heterosis was calculated by using the formula of Rao (1980):

$$\text{Residual heterosis} = [(F2-BP)/BP] \times 100$$

Where,
F2 = Mean value of F2 progeny.
BP= Mean value of better parent.

RESULTS AND DISCUSSION

For days to 50% flowering, significant heterobeltiosis was recorded for almost all the crosses while only eight crosses *i.e.* MR750A2 × PC5 (-19.35 H, -9.13 RH), ICSA276 × RS29 (-14.25 H, -12.39 RH), MR750A2 × RS29 (-12.90 H, -11.50 RH), ICSA467 x RS29 (-10.71 H, -4.42 RH), ICSA276 × M35-1 (-11.31 H, -8.43 RH), 11A2 × M35-1(-9.09 H, -7.23 RH), MR750A2 × M35-1(-12.73 H, -7.63 RH) and 11A2 x SPV1616 (-11.68 H, -5.31 RH) exhibited residual heterosis which was significantly lower than heterobeltiosis. All combinations exhibited positive values for inbreeding depression with high heterosis indicates the non-additive gene action for this character. Significant estimates of heterobeltiosis for day to maturity were ranged from -1.91 to -7.33 (over thirty two crosses, while significant residual heterosis was recorded only for MR750A2 × CS3541 (-6.64 H, -2.57 RH), ICSA469 × JJ1041 (-5.90 H, -2.30 RH), MR750A2 × JJ1041 (-7.15 H, -2.55 RH) and MR750A2 × SPV1616 (-7.33 H, -2.30 RH) with positive estimates of inbreeding depression (Table 2).

Positive and significant heterobeltiosis, residual heterosis and inbreeding depression for plant height was ranged from 10.91 to 42.84% (over twenty two crosses), 12.12 to 57.49% (over nineteen crosses) and 0.86 to 23.12 (over twenty five crosses), respectively. Most of the crosses among these include UPC2, M35-1 and SPV1616 as pollinator parent *i.e.*, ICSA467 × UPC2 (30.28 H and 57.29 RH), ICSA469 x UPC2 (24.70 H and 38.45 RH), ICSA276 × UPC2 (17.12 H and 37.34 RH), 11A2 × UPC2 (20.56 H and 38.29 RH), MR750A2 × UPC2 (11.55 H and 37.50 RH), ICSA467 x M35-1 (30.54 H and 41.87 RH), ICSA469 × M35-1 (15.05 H and 23.32 RH), ICSA276 x M35-1 (10.91 H and 21.61 RH), 11A2 × M35-1 (31.02 H and 39.01 RH), MR750A2 × M35-1 (18.53 H and 24.92 RH), ICSA467 × SPV1616 (22.90 H and 41.98 RH), ICSA469 × SPV1616 (21.35 H and 23.60 RH) and ICSA276 × SPV1616 (28.87 H and 41.59 RH) exhibited higher values of residual heterosis over heterobeltiosis with significant inbreeding depression

Table 1: Parentage, origin/source and important characteristic features of parental lines used for the study.

Name of the parental line	Parentage	Origin/Source
Male sterile lines		
ICSA 467	-	ICRISAT
ICSA 469	[(ICSB 37 × ICSV 702) × PS 19349B]3-3-4-2	ICRISAT
ICSA 276	(ICSB 101 × TRL 74/C 57) × PM17467B]2-5-1-3-3	ICRISAT
$11A_2$	Non-milo	DSR, Hyderabad
MR $750A_2$	Non-milo	DSR, Hyderabad
Pollinator lines		
Pant Chari 5	CS 3541 × IS 6953	Pantnagar
UPC 2	VIDISHA 60-1× ISC 953	Pantnagar
CSV15	SPV 475 × SPV 462	DSR, Hyderabad
CS3541	IS 3675 × IS3541	DSR, Hyderabad
RS 29	IS 108 × SPV 126	DSR, Hyderabad
M 35-1	Selection from Maldandi landraces	Mahol
JJ1041	-	Indore
SPV1616	-	DSR, Hyderabad

Table 2: Heterosis (H), residual heterosis (RH) and inbreeding depression (ID) in F1 and F2 generation for various traits in sorghum.

S. no.	Days to 50% flowering			Days to maturity			Plant height (cm)			Flag leaf length (cm)			Flag leaf width (cm)		
	BP	RH	ID	BP	RH	ID	BP	RH	ID	BP	RH	ID	BP	RH	ID
ICSA 467 × PC5	-13.44**	0.43	6.82	-0.26	1.85	-1.06	-5.32	-5.99	10.47	-6.29	-8.27	7.19	-13.41**	-14.71*	8.19
ICSA 469 × PC5	-5.50**	4.35	5.04	-1.91*	3.42**	1.80	-5.29	-3.42	10.81	17.29**	9.69	1.25	-28.56**	-23.39**	16.17
ICSA 276 × PC5	-8.35**	0.87	2.63	-5.26**	-0.26	0.26	-24.59**	-17.45**	17.54	-12.39**	-17.97*	1.53	-14.98**	-16.46*	-2.88
11A2 × PC5	-4.28**	6.09**	5.79	-1.05	1.85	1.85	7.40	-8.70	-1.60	5.69	-13.46*	-8.74	-0.39	-6.26	1.37
MR750A2 × PC5	-19.35**	-9.13**	4.93	-3.29**	0.79	2.69	-9.98*	-24.68**	-0.92	-1.04	-5.25	5.10	-17.39**	-17.59**	0.00
ICSA 467 × UPC2	-1.53	9.35**	3.49	-3.60**	1.33	1.33	30.28**	57.49**	8.76	-4.02	-4.74	7.13	18.90**	2.87	-4.37
ICSA469 × UPC2	-1.75	8.45**	1.33	-0.76	6.84**	6.45	24.70**	38.45**	13.08	-25.45**	-31.93**	0.68	-11.33*	-16.79*	2.82
ICSA 276 × UPC2	-4.60**	4.23	0.00	-3.50**	5.21**	7.73	17.12**	37.34**	10.18	-18.54**	-21.54**	1.07	-9.38*	-11.75	-1.10
11A2 × UPC2	-2.63*	7.98**	0.45	-2.57**	4.76**	6.39	20.56**	38.29**	4.22	-14.19**	-16.00	6.83	0.53	-4.89	-4.00
MR750A2 × UPC2	-7.44**	1.88	2.34	-4.12**	2.41*	1.33	11.55*	37.50**	12.61	-4.94	-7.04	3.03	19.35**	11.11	4.63
ICSA 467 × CSV15	-10.48**	-2.34	3.50	-3.28**	2.61*	3.08	14.08**	11.25	-2.11	-30.80**	-37.50**	2.41	-15.07**	-13.33	3.17
ICSA 469 × CSV15	-0.48	9.22**	6.48	-4.17**	3.66**	6.38	15.41**	11.40	-10.01	3.18	-3.81	0.16	-10.50*	-4.10	8.78
ICSA 276 × CSV15	-5.31**	0.49	2.02	-0.63	5.73**	2.49	9.23	6.83	7.49	-16.49**	-28.33**	-1.06	-12.10**	-7.34	4.57
11A2 × CSV15	-4.21**	5.31*	7.51	-3.54**	2.09	1.04	2.96	3.00	0.87	0.60	-0.32	8.72	4.93	-5.35	4.92
MR750A2 × CSV15	-5.85**	-3.88	1.03	-6.82**	-1.57	1.61	1.42	-4.95	-5.23	-36.19**	-41.23**	1.87	-23.70**	-23.61**	1.69
ICSA 467 × CS3541	-6.83**	-1.40	4.31	-4.60**	-0.77	1.33	40.37**	52.18**	12.30	-15.63**	-17.00**	13.55	-36.40**	-29.80**	9.55
ICSA 469 × CS3541	-7.83**	0.93	3.92	-3.18**	1.80	3.87	28.15**	9.17	23.12	-12.49**	-16.13**	1.74	-6.64	-10.98*	9.79
ICSBA276 × CS3541	-5.76**	0.93	4.31	-4.13**	0.77	2.07	30.00**	20.46**	0.86	-3.68	-10.75	13.50	-2.65	-18.04**	3.15
11A2 × CS3541	-9.22**	-2.80	3.00	-4.73**	-0.77	3.17	42.84**	24.06**	-25.51	-11.30**	-23.87**	-4.69	-10.84**	-12.55*	2.82
MR750A2 × CS3541	-6.45**	-4.21	1.95	-6.64**	-2.57*	2.96	20.77**	21.64*	-4.31	-36.70**	-36.68**	6.56	-25.70**	-25.49**	7.77
ICSA 467 × RS29	-7.24**	-1.33	10.19	-2.75**	-0.78	0.80	7.99	7.41	21.51	-8.16*	-10.21	14.67	-19.40**	-26.43**	-6.63
ICSA 469 × RS29	-5.66**	-1.77	4.23	-3.44**	0.78	0.79	20.34**	12.42*	1.35	-2.26	-9.24	-3.79	-15.13**	-17.62**	7.90
ICSA 276 × RS29	-14.25**	-12.39**	0.53	-2.50**	3.65**	2.28	16.56**	7.30	11.45	9.56*	3.70	6.14	-0.56	-8.81	-6.54
11A2 × RS29	-7.47**	-3.54	7.98	0.92	3.66**	3.84	7.88	-10.73	-7.37	1.82	-3.33	-0.26	-14.44**	-29.52**	-4.64
MR750A2 × RS29	-12.90**	-11.50**	-0.52	-3.68**	-2.09	2.70	7.71	-2.80	-0.58	18.17**	9.37	3.54	5.39	-6.17	2.82
ICSA 467 × M35-1	-10.71**	-4.42*	7.83	-6.20**	-1.28	4.49	30.54**	41.87**	-5.90	0.00	-12.61	-5.13	-1.13	0.84	14.49
ICSA 469 × M35-1	-4.24**	-2.41	1.67	-0.89	1.28	-0.77	15.05**	23.32**	18.15	3.30	-4.41	2.06	17.76**	8.47	0.46
ICSA 276 × M35-1	-11.31**	-8.43**	1.36	-2.38**	4.09**	6.45	10.91*	21.61**	3.94	-3.55	-18.89**	-0.75	9.68*	13.92*	3.11
11A2 × M35-1	-9.09**	-7.23**	3.49	-2.41**	2.81*	5.30	31.02**	39.01**	2.73	-24.66**	-30.09**	0.95	-29.15**	-30.50**	5.41
MR750A2 × M35-1	-12.73**	-7.63**	8.00	-3.29**	-1.53	0.00	18.53**	24.92**	-4.30	-11.67**	-20.92*	2.10	5.22	8.33	2.45
ICSA 467 × JJ1041	-7.29**	4.67	10.70	-3.39**	1.02	3.07	-11.43*	-10.69	7.11	10.03*	3.26	0.75	-1.78	1.55	7.00
ICSA 469 × JJ1041	-4.29**	2.43	0.99	-5.90**	-2.30*	0.53	4.68	2.63	7.01	8.50*	4.31	4.72	11.17**	9.79	13.05
ICSA 276 × JJ1041	-4.82**	0.49	0.51	-2.38	2.55*	2.03	0.00	-0.19	13.36	-5.30	-24.15**	1.04	9.93*	-6.33	-8.45
11A2 × JJ1041	7.71**	16.43**	5.49	-0.50	3.83**	2.74	-11.68*	8.71	1.97	16.03**	4.04	3.44	2.08	-3.98	7.01
MR750A2 × JJ1041	-5.30**	-0.97	2.51	-7.15**	-2.55*	2.14	-6.47	-16.32**	-1.76	17.01**	-3.67	0.79	-15.00**	-18.52**	12.02
ICSA 467 × SPV1616	-8.20**	0.00	3.41	-1.99*	2.30*	1.76	22.90**	41.98**	-11.48	-11.09**	-14.43	4.93	-12.89**	-18.34**	4.11
ICSA 469 × SPV1616	-4.05**	2.97	2.45	-4.10**	0.51	0.00	21.35**	23.60**	6.74	8.50*	0.14	2.72	6.94	-6.11	3.10
ICSA 276 × SPV1616	-9.18**	-2.91	1.06	-2.36**	4.34**	6.40	28.87**	41.59**	4.81	18.54**	5.99	-1.51	13.91**	1.22	4.80
11A2 × SPV1616	-11.68**	-5.31*	1.05	-2.61**	3.83**	5.94	9.08	17.86*	-8.14	-15.27**	-22.54**	-1.72	-20.17**	-25.93**	1.93
MR750A2 × SPV1616	-6.17**	-2.48	0.00	-7.33**	-2.30*	0.53	7.29	9.76	-14.29	6.00	-6.60	4.34	-24.57**	-30.56**	-15.53
CD			1.24**			0.92**			9.42*			1.38			0.28

Table 2: Continue....

S. no.	Panicle length (cm)			Panicle width (cm)			Panicle weight (g)			1000 Seed weight (g)			Grain yield/plant (g)		
	BP	RH	ID	BP	RH	ID	BP	RH	ID	BP	RH	ID	BP	RH	ID
ICSA 467 × PC5	-6.88	-7.52	0.24	5.50	6.63	-38.94	-27.60**	-29.73**	-30.80	-4.65**	-7.39**	1.26	-33.72**	-53.74**	-135.27
ICSA 469 × PC5	-4.68	-18.50**	-8.89	-21.44**	-46.53**	-30.91	15.82*	-41.51**	-63.79	-2.38*	-4.41*	0.00	12.64	-50.39**	-183.57
ICSA 276 × PC5	-3.59	-15.48*	-11.84	0.23	-39.50**	-44.23	25.10*	-22.76**	-8.29	3.63**	-1.51	-1.22	47.86**	-2.33	-8.28
11A2 × PC5	2.76	-18.24**	-10.34	-8.38	-38.98**	-9.45	27.14**	-2.37	-12.30	-3.05**	-6.57**	3.09	15.97**	-25.28**	-35.23
MR750A2 × PC5	4.69	-11.17	-1.27	9.80	-12.20	-11.67	64.36**	-9.76	-33.44	15.59**	6.95**	-0.21	80.26**	-11.13	-50.14
ICSA 467 × UPC2	11.77*	0.00	1.01	30.58**	-10.08	-1.11	43.54**	115.32**	45.41	4.83**	4.00*	1.94	14.88*	30.84**	-11.30
ICSA469 × UPC2	4.81	-11.93	6.71	1.03	-23.10**	6.32	34.44**	-12.01	0.90	18.97**	11.90**	-1.63	34.90**	-4.72	-46.85
ICSA 276 × UPC2	0.76	-10.11	1.27	1.61	-30.58**	-14.87	63.57**	8.77	-11.17	31.92**	25.24**	1.88	85.93**	7.82	-36.91
11A2 × UPC2	8.10	-7.39	-3.20	28.85*	-9.83	-17.49	75.39**	21.83**	-23.50	4.08**	-3.18*	-1.58	35.99**	-22.73**	-61.94
MR750A2 × UPC2	13.38**	-1.36	-0.41	12.90*	-14.32**	-2.97	116.92**	34.92**	-37.65	4.46**	-2.63	3.49	101.59**	17.59*	-8.84
ICSA 467 × CSV15	-15.01**	-10.69	10.76	-11.42	-39.02**	-60.13	-40.19**	-51.10**	-0.90	0.16	-2.48	-1.08	-51.41**	-72.09**	-66.00
ICSA 469 × CSV15	5.37	-11.15	-6.61	-33.40**	-54.79**	-15.33	-42.78**	-64.67**	-34.95	10.07**	7.44**	-0.59	-41.39**	-69.94**	-76.15
ICSA 276 × CSV15	2.91	-10.85	2.38	-20.47**	-48.76**	-10.86	-51.65**	-76.50**	-51.30	-15.56**	-20.69**	-0.26	-58.34**	-77.99**	-37.09
11A2 × CSV15	1.85	-15.54*	-7.02	-27.37**	-51.53**	-26.17	-53.61**	-77.01**	-66.67	3.66**	-2.48	-2.63	-53.51**	-74.50**	-69.90
MR750A2 × CSV15	14.41*	6.96	-1.26	-19.83**	-32.95**	-1.08	-50.13**	-66.25**	-1.88	4.04**	-0.75	2.45	-57.05**	-74.77**	-20.45
ICSA 467 × CS3541	-16.20**	-22.19**	-3.03	-19.07**	-51.23**	-32.80	27.10**	5.86	-67.99	11.04**	9.33**	-0.44	23.97**	-26.87**	-151.15
ICSA 469 × CS3541	-3.62	-22.77**	2.05	-31.30**	-59.40**	-37.90	-6.59	-55.68**	-43.87	47.66**	45.35**	-1.50	10.04	-39.10**	-95.14
ICSBA276 × CS3541	-2.23	-28.53**	-23.65	-4.62	-51.23**	-74.39	56.36**	-2.51	-7.09	13.25**	4.73*	-0.39	55.52**	12.79	-2.72
11A2 × CS3541	0.19	-21.84**	-14.73	-31.30**	-50.10**	-0.27	-6.91	-45.37**	-32.31	-2.94**	-9.97**	-1.13	-10.03	-50.08**	-78.50
MR750A2 × CS3541	-13.03*	-36.60**	-19.17	-31.30**	-57.43**	-21.66	-21.08*	-42.35**	6.40	-2.35*	-7.66**	0.25	-29.12**	-59.61**	10.27
ICSA 467 × RS29	-5.74	-24.02**	-11.48	-13.76*	-49.47**	-57.57	31.87**	-56.75**	-137.94	-5.37**	-7.88**	0.76	34.97**	-60.84**	-260.60
ICSA 469 × RS29	-5.80	-33.78**	-5.80	-15.04**	-53.16**	-41.96	-25.00**	-54.53**	-11.19	45.73**	36.99**	0.22	-28.91**	-54.88**	-0.34
ICSA 276 × RS29	5.50	-18.38**	-2.20	-18.62**	-51.84**	-20.39	-23.76**	-53.85**	6.93	19.37**	9.31**	-0.79	-21.09**	-42.11**	22.70
11A2 × RS29	0.66	-30.70**	-17.06	-23.26**	-47.89**	5.50	3.46	-51.42**	-55.38	2.67**	-1.53	-2.69	14.40*	-46.94**	-86.26
MR750A2 × RS29	0.97	-21.97**	-4.90	-26.79**	-54.21**	-2.76	-20.26**	-53.37**	-16.72	1.67	-4.19*	0.12	-3.93	-42.96**	-16.83
ICSA 467 × M35-1	-11.54*	-30.40**	-1.55	-7.94	-21.19**	8.78	1.51	-6.01	-16.31	22.93**	17.94**	0.10	-2.30	-5.73	-38.56
ICSA 469 × M35-1	8.99	-20.68**	-5.90	-8.66	-37.62**	-9.95	36.87**	-37.26**	-81.62	39.46**	26.51**	-2.83	52.36**	-6.19	-80.12
ICSA 276 × M35-1	5.63	-21.19**	1.63	2.43	-38.84**	-15.05	11.79	-42.23**	-29.17	20.55**	9.62**	-1.97	15.95	-38.95**	-57.46
11A2 × M35-1	-3.42	-31.42**	-0.91	-14.76*	-44.07**	-10.93	16.03*	-42.44**	-98.34	2.67**	-2.08	0.11	12.08*	-55.17**	-170.49
MR750A2 × M35-1	11.00	-22.21**	-7.63	32.41**	-7.63	-4.27	44.11**	-3.88	-7.28	20.42**	11.98**	1.43	81.12**	4.13	-9.11
ICSA 467 × JJ1041	-7.05	-13.63*	-5.66	0.75	-19.49*	-45.14	-22.46**	-27.63**	-52.24	12.72**	11.68**	-0.41	-26.88**	-49.34**	-136.75
ICSA 469 × JJ1041	11.70**	-6.86	-6.04	-19.75**	-47.19**	-44.47	-0.38	-56.92**	-101.83	15.26**	7.17**	1.19	25.79**	-45.48**	-173.18
ICSA 276 × JJ1041	0.87	-8.38	3.73	4.51	-29.92**	-0.89	44.31**	-40.11**	-78.43	7.83**	3.47*	-0.32	97.28**	-9.30	-116.61
11A2 × JJ1041	-1.32	-17.89**	-2.25	-26.99**	-50.85**	-6.46	-37.59**	-55.83**	-34.21	22.47**	19.17**	1.15	-41.66**	-63.12**	-36.67
MR750A2 × JJ1041	7.98	-4.56	-2.22	33.42**	1.46	-3.75	17.24	-34.50**	-21.14	14.39**	13.53**	1.30	26.38*	-47.49**	-91.83
ICSA 467 × SPV1616	0.68	-11.28	-9.34	-5.12	-17.24*	-14.89	-25.60**	-16.82	-5.55	-0.46	-7.37**	-2.91	-34.60**	-43.05**	-37.50
ICSA 469 × SPV1616	27.34**	0.49	-4.00	1.65	-32.01**	-24.09	0.68	-18.94**	27.27	-7.50**	-13.54**	1.97	11.21	-14.38*	21.52
ICSA 276 × SPV1616	10.99*	-12.34	-16.62	-10.38	-42.81**	-17.75	28.77**	-19.30*	10.92	1.43	-4.75**	0.30	28.73**	-3.62	10.16
11A2 × SPV1616	0.56	-21.41**	-15.53	-31.45**	-48.47**	1.89	-42.50**	-58.54**	-41.18	9.55**	4.44**	-0.75	-43.62**	-65.34**	-41.52
MR750A2 × SPV1616	18.14**	4.63	-17.59	-2.36	-24.14**	-15.93	-24.62*	-49.14**	-5.99	-9.95**	-16.77**	2.02	-39.86**	-64.16**	-2.16
CD			0.80**			0.38**			11.16**			0.89			7.68**

*, ** Significant at 5 and 1% levels of probability, respectively.

while crosses with CS3541 as pollinator *i.e.* ICSA276 × CS3541 (30.00 H and 20.46 RH), 11A2 × CS3541 (42.84 H and 24.06 RH) and MR750A2 × CS3541 (20.77H and 21.64 RH) gave lower residual heterosis values than heterobeltiosis (Table 2). The retention of high heterosis in F2 generation may be result of transgressive segregants and close linkage of some favourable genes controlling this character. High heterosis and positive values of inbreeding depression indicates towards the non-additive gene action for plant height.

For flag leaf length, significant values for heterobeltiosis and residual heterosis were ranged from -8.16 to 18.54% and -13.46 to -41.23%, respectively. Low and negative heterosis may be due to the presence of epistatic gene action or incomplete dominant gene effects. These results were in accordance with Umakant *et al*. (2003). In case of flag leaf width, significant heterobeltiosis and residual heterosis were ranged from -9.38 to 19.35% and -10.98 to 13.92%, respectively. Inbreeding depression was found to be non-significant for both the character. The presence of heterosis in the F1 and residual heterosis in F2 generation along with non-significant values of inbreeding depression determines the role of additive gene action. Also, low inbreeding depression may be due to residual heterosis (Kumar *et al*., 2004).

For panicle length, positive and significant heterobeltiosis was recorded for ICSA467 × UPC2 (11.77), MR750A2 × UPC2 (13.38), MR750A2 × CSV15 (14.41), ICSA469 × JJ1041 (11.70), ICSA469 × SPV1616 (27.34), ICSA276 × SPV1616 (10.99) and MR750A2 × SPV1616 (18.14), while no positive and significant values were observed for residual heterosis (ranged from -13.63 to -36.60% over twenty two crosses). Significant and negative values for inbreeding depression were observed for almost all the crosses. Significantly positive heterobeltiosis for panicle width was observed for ICSA467 × UPC2 (30.58), 11A2 × UPC2 (28.85), MR750A2 × UPC2 (12.90), MR750A2 × M35-1 (32.41) and MR750A2 × JJ1041 (33.42), while other crosses exhibited negative values. For residual heterosis, all F1s exhibited significantly negative values of residual heterosis and inbreeding depression. For panicle weight positive and significant heterobeltiosis was ranged from 15.82 to 116.92% (over eighteen crosses). Positive and significant residual heterosis was observed in ICSA467 × UPC2 (115.32 RH, 43.54 H, 45.41 ID), 11A2 × UPC2 (21.83 RH, 75.39 H, -23.50 ID) and MR750A2 × UPC2 (34.92 RH, 116.92 H, -37.65 ID) (Table 2). For the crosses having negative and significant estimates of inbreeding depression provide a scope for selection in the F2 population for sorghum improvement. The similar findings were attributed by Bhatt (2008).

For 1000 seed weight, twenty seven F1 crosses exhibited significant and positive values of heterobeltiosis ranged from 2.67 to 47.66%. However, nineteen crosses gave significantly positive estimates of residual heterosis (ranged from 3.47 to 45.35%) and inbreeding depression (ranged from 0.10 to 3.49). Maximum heterobeltiosis (47.66%) and heterosis (45.35%) with negative estimates of inbreeding depression (-1.50) was recorded in ICSA469 x CS3541. Highest significant heterosis with less inbreeding depression in this cross is indicating the occurrence of additive gene action. There was a decreased pattern of heterosis in F2 generation with positive estimates of inbreeding depression in most of the progenies.

For grain yield range for significantly positive heterosis was estimated from 12.08 to 101.59% (over twenty crosses). Residual heterosis was found to be significantly negative for all the crosses except ICSA467 × UPC2 (30.84 RH, 14.88 H) and MR750A2 x UPC2 (17.59 RH, 101.59 H). Inbreeding depression was recorded negatively significant for most of the progenies (Table 2). Negative values of inbreeding depression may be due to the occurrence of transgressive segregants in the F2 generation. Various degrees of inbreeding depression were earlier reported by Agarwal and Shrotria (2005) and Chiang and Smith (1967). Heterosis and inbreeding depression are the result of dominant gene action and heterosis is absent if the traits are governed only by additive gene action (Hunter and Anderson, 1997). The findings of present study can be use in various breeding programmes of sorghum.

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