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Combining ability and heterosis analysis for yield traits in bread wheat (*Triticum aestivum*)

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ABSTRACT

In order to realize the combining ability and heterosis of wheat, 21 hybrids were synthesised in a 7 × 7 diallel fashion excluding reciprocals. Analyses of combining ability and heterosis over mid parent (MP) as well as economic parent (HD 2733) were undertaken for yield and its component traits. The experiment was conducted in 2007–08 and 2008–09 at Crop Research Farm of CSAUA &T, Kanpur, UP. The results revealed that non-additive genetic variance played a predominant role in the inheritance of most of the traits. The best combinations mostly involved high × low and low × low general combiners for the characters under study. There was very rare case in which high × high general combiners were involved for best combinations. On the basis of *gca* and *sca* effects, 3 parents (i e K 7903, K 9465 and HUW 234) and 14 cross combinations (i.e. 5 top crosses namely HD 2733 × K 7903, HUW 234 × K 9423, HD 2285 × K 2021, HUW 234 × K 2021 and K 9423 × K 2021) were found good general and specific combiners for higher grain yield and also for various yield contributing traits, respectively.

Key words: Combining ability, Diallel, Heterosis, *Triticum aestivum*

Wheat (*Triticum aestivum* L. emend Fiori & Paol.) is a predominant cereal crop of the world and constitutes important source of carbohydrate and protein. At global level, India ranks second largest wheat producing nation with 13.43% global wheat production after China which contributes 17.7% to the world wheat production (USDA 2012). The other major wheat producing countries are Russian Federation, United States of America and Canada and these 5 countries together contribute more than half of the global wheat production (Singh *et al.* 2010). To fulfil the increasing demand of world population, wheat production and productivity must be increased. Hybrid wheat is an alternative approach to increase the productivity and most important step in the hybrid breeding program is the detection of suitable parents with high general (*gca*) and specific combining ability (*sca*) for grain yield and then the exploitation of heterosis. The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement and also provides useful information about usefulness of the parents in breeding programs. So a large number of researches on heterosis for grain yield and its components in wheat have been carried out (Singh *et al.* 2004; Dreisigacker *et al.* 2005), since the phenomenon in wheat was first reported in 1919. Hybrid technology in crop plants, especially cross-pollinated crops is successfully used for enhanced production. However, it remains unutilized in the self-pollinated crops, especially wheat. The future scope of hybrid technology in wheat depends on the male sterility systems, floral biology, level of combining ability, heterosis and its exploitation of commercial level that may be useful in breaking yield barriers and enhancing the productivity in the major wheat belt of the country (Singh *et al.* 2010). Keeping in view of all above, in the present study, an attempt has been made to examine the combing ability as well as heterosis of some wheat varieties and their crosses on yield related traits.

MATERIALS AND METHODS

Genetic materials, for the present investigation comprised of seven wheat varieties (K 9465, K 9423, K 2021, K 7903, HD 2733, HD 2285 and HUW 234) and 21 hybrids generated by crossing the above varieties in all possible combinations excluding reciprocals, were evaluated in randomized block design with 3 replications and the experiment was conducted

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in 2007–08 and 2008–09 at Crop Research Farm of CSAUA & T Kanpur, UP. All recommended agronomic practices were adopted in the trial shown in 3 rows of 3 m length with inter- and intra- row spacing of 25 cm and 15 cm, respectively. Five randomly selected competitive plants were observed for 14 traits namely days to flowering (from date of sowing to date of 75% flowering stage), days to maturity (from the date of sowing to its 75% maturity), duration of reproductive phase (days to maturity - days to flowering.), number of productive tillers/plant (total numbers of ear bearing tillers per plant at the time of maturity), plant height (from ground level to tip of ear avoiding awns of the panicle of the main shoot at maturity in cm), spike length (from base of spike to the tip of the ear avoiding awns in cm at maturity), number of spikelets per spike (the spikelets bearing the grains in each spike), number of grains per spike (average number of grains per spike of selected plants), biological yield (weight of whole selected plants including root in gram), harvest index (%), test weight (gram), seed hardness (by O.S.K. 201 grain hardness Tester, type E capacity 50 kg in kg/Seed), protein content (by Micro-Kjeldahl method in %) and grain yield per plant (gram). The mean values were used for estimating the heterosis and combining ability according to Griffing's (1956, a) model 1 method 2, which is a fixed effect model.

RESULTS AND DISCUSSION

Average as well as economic heterosis

Heterosis for all the 14 traits studied was found with all crosses. A wide variation of heterosis range, heterosis mean, number of desired hybrids and best hybrid was found for most of the traits (Table 1). Singh *et al*. (2004) stated that the superiority of hybrids particularly over high parent is more useful for commercial exploitation of heterosis and also indicated the parental combinations capable of producing the highest level of transgressive segregants. However, for

Table 1 Heterosis range, heterosis mean, number of desirable hybrids and best hybrid [over economic variety (HD 2733 and mid parent (MP)] for 14 traits in bread wheat

Trait	Heterosis hybrids	Heterosis range (%)	Heterosis mean	No. of desired hybrids	Best hybrids
Days to flowering	E V	–18.87 to 4.21	–5.0	17	HD 2285 × K 7903
	M P	–6.67 to 15.99	3.27	7	HD 2285 × K 7903
Days to maturity	E V	–31.07 to 0.37	–9.50	20	K 9423 × K 7903
	M P	–5.91 to 20.65	5.52	4	HD 2733 × K 9465
Duration of reproductive phase	E V	–63.43 to –0.82	–16.10		K 2021 × K 7903
	M P	–20.25 to 32.27	8.79	13	HD 2733 × K 9423
Number of productive tillers/plant	E V	1.97 to 113.18	36.48	21	HD 2285 × K 2021
	M P	–1.75 to 113.13	29.97	17	HD 2285 × K 2021
Plant height	E V	–4.66 to 48.13	10.96	4	HUW 234 × K 2021
	M P	–20.85 to 39.91	2.64	12	HUW 234 × K 2021
Spike length	E V	19.32 to 13.19	–0.96	10	K 9423 × K 9465
	M P	–14.81 to 33.07	10.12	16	K 2021 × K 7903
Number of spikelets/spike	E V	–7.18 to 9.20	0.11	9	HD 2285 × K 7903
	M P	–3.58 to 16.23	5.34	15	HD 22895 × K 7903
Number of grains/spike	E V	–24.20 to 28.41	–1.20	6	HD 2285 × K 7903
	M P	–21.6 to 41.26	3.82	13	HD 22895 × K 7903
Biological yield	E V	–20.05 to 69.20	30.34	19	HUW 234 × K 9465
	M P	–22.47 to 105.04	31.51	19	HUW 234 × HD 2285
Harvest index	E V	–17.32 to 50.23	16.35	15	HUW 234 × K 2021
	M P	–24.08 to 73.54	23.45	17	K 9423 × K 7903
Test weight	E V	–4.94 to 49.74	20.84	20	K 9423 × K 9465
	M P	–12.16 to 40.39	12.08	17	HD 2733 × HUW 234
Seed hardness	E V	–18.99 to 0.34	8.80		K 9423 × K 9465
	M P	–14.54 to 21.08	3.17	11	HD 2733 × HUW 234
Protein content	E V	–10.10 to 4.22	–2.77	3	K 9465 × K 7903
	M P	–6.76 to 11.72	1.25	7	HD 2285 × K 7903
Grain yield/plant	E V	1.14 to 79.35	51.56	19	HUW 234 × K 9423
	M P	2.58 to 114.64	59.22	19	HD 2285 × K 2021

E V, Average value of economic variety (HD 2733); M P, average value of mid parent grain yield per plant, economic and average heterosis ranged from 1.14 to 79.35 and from 2.58 to 114.64 with mean value of 51.56 and 59.22, respectively. Early flowering, early maturity and short stature are the desirable traits in wheat. HD 2285 × K 7903 and HUW 234 × K 2021 showed highest negative heterosis for days to flowering and plant height, respectively both over economic variety and mid parent. K 9423 × K 7903 and HD 2733 × K 9465 showed highest negative heterosis for days to maturity over economic variety and mid parent, respectively. Significantly highest positive economic and average heterosis was observed in HUW 234 × K 9423 and HD 2285 × K 2021 for grain yield/plant, respectively.

Combining ability variances and effects

General and specific combining ability variances and effects were estimated with a view to decipher the genetic architecture of the characters under study. Combining ability describes the breeding value of parental lines to produce hybrids (Romanus *et al.* 2008). The general combining ability has been equated with additive gene action and specific combining ability with non-additive gene action (Griffing 1956 a). The analysis of variance for combining ability was done for all the 14 characters (Table 2). Highly significant variances, of both general and specific combining ability, were observed which indicated the importance of both additive and non-additive gene effects for all the traits except number of productive tillers per plant (where only sca variance was highly significant indicating non-additive gene action), spike length, number of spikelets per spike, seed hardness and protein content. The estimated value of σ_g^2 was higher than its σ_s^2 for days to maturity which indicated the predominance of additive gene action as the ratio of σ_g^2/σ_s^2 was more than unity while rest of the traits showed preponderance of non-additive gene action. The value of average degree of dominance $(\sigma_s^2/\sigma_g^2)^{0.5}$ for days to maturity indicated partial dominance while rest of the traits showed over dominance. In the same way, preponderance of non-additive gene effects were reported by several researchers (Singh 2003, Chaman 2005, Heidari *et al.* 2006 and Kumar *et al.* 2011) for plant height, number of tillers per plant, spike length, number of spikelets per spike, test weight, seed hardness, protein content and grain yield.

Selection of suitable genotypes and their crosses in effective hybridization is a pre requisite in order to formulate a systematic breeding programme leading to rapid and sustained improvement. The combining ability effects (Tables 3, 4) furnish information on these aspects. Thus, the genetic material available in the present study is suitable for evolving desirable hybrids as well as varieties. In the later case, some sort of intermating within segregating progenies at various stages would be more desirable to harness additive and additive × additive type of variance.

While considering *gca* effects of the parents, it was

Table 2 Analysis of variance (ANOVA) for combining ability along with estimates of genetic components of variance and degree of dominance for 14 characters in bread wheat

Sources of variation	df	Characters													
		Days to flowering	Days to maturity	Duration of reproductive phase (days)	Number of productive tillers/ plant	Plant height (cm)	Spike length (cm)	Number of spikelets/ spike	Number of grains/ spike	Biological yield (g)	Harvest index (%)	Test weight (g)	Seed hardness (kg/seed)	Protein content (%)	Grain yield (g)
Gca	6	45.85**	477.85**	252.04**	0.5	36.76**	0.63	1.23	17.31**	49.89**	52.39**	19.26**	0.29	0.62	6.55**
Sca	21	10.06**	43.67**	41.20**	4.10**	65.89**	1.51	1.13	34.45**	47.06**	97.93**	23.54**	0.67	0.24	16.15**
Error	54	0.03	0.03	0.02	0.02	0.04	0.01	0.03	0.14	0.04	0.07	0.02	0.01	0.01	0.16
σ_g^2		5.09	53.09	28	0.05	4.08	0.07	0.13	1.91	5.54	5.81	2.14	0.03	0.07	0.71
σ_s^2		10.03	43.64	41.18	4.08	65.85	1.5	1.1	34.31	47.02	97.86	23.52	0.66	0.23	15.99
σ_g^2/σ_s^2		0.51	1.22	0.68	0.01	0.06	0.05	0.12	0.06	0.12	0.06	0.09	0.05	0.3	0.04
$(\sigma_s^2/\sigma_g^2)^{0.5}$		1.4	0.91	1.21	9.03	4.02	4.63	2.91	4.24	2.91	9.11	3.32	4.69	1.81	4.75

* Significant at 5% level, ** significant at 1% level; gca, general combining ability; sca, specific combining ability; σ_g^2/σ_s^2, ratio of gca variance to sca variance; $(\sigma_s^2/\sigma_g^2)^{0.5}$, degree of dominance

found that none of the parents was observed as good general combiner for all the 14 traits. However, K 7903 and K 9423 for early flowering and early maturity, K 2021 and HD 2733 for longer duration of reproductive phase, HUW 234 and HD 2285 for more number of productive tillers per plant, HUW 234, HD 2733 and HD 2285 for short stature, HD 2733, K 9465 and K 9423 for lengthy spikes, HD 2733 and K 9423 for more number of spikelets per spike, K 9423 and HD 2733 for more number of grains per spike, K 7903 and K 9465 for more biomass, HUW 234, K 9423 and HD 2733 for high harvest index, K 7903, K 9465 and K 9423 for bolder seed size, HD 2285 and K 9423 for hard seed, K 7903 and K 2021 for high protein content and K 7903, K 9465 and HUW 234 for high grain yield were G.P. (as in descending order for each characters, Table 3). Further, the comparison of *per se* performance with *gca* effects of the genotype provide a wholesome view of its breeding worth. In the present study, it was noticed that there was close relationship between parental mean performance and *gca* effects for almost all the characters. Hence, these parents can be employed in breeding programmes for overall improvement.

Among the 21 hybrids, only 14 cross combinations were found significant and desirable for higher grain yield and also for other traits (Table 4). On the basis of *sca* effects and *per se* performance of the hybrids, it was noted that the crosses were not exactly in the same order of ranking. In the present findings, best combinations mostly involved high × low and low × low general combiners for the characters under study. There was very rare case in which high × high general combiners were involved for best combinations (Table 4). The same type of result was also observed by Kumar and Maloo (2012). Thus, it is evident that high specific combiners are not always obtained between high general combiners but may occur between low × low or high × low general combiners. This might be probably due to the presence of dominant and epistatic gene interactions.

In general, *sca* effects do not make any significant contribution in the improvement of self-pollinated crops except where there is possibility of commercial exploitation of heterosis. Breeder's interest normally, however, vests in obtaining transgressive segregants through crosses in order to produce homozygous lines in self-pollinated crops. Therefore, crosses involving high × low general combiners in respect of different characters in the present study may be utilized for obtaining transgressive segregants in the next generation resulting from dominance gene interaction. Thus based on gca, the varieties K 7903, K 9465 and HUW 234 could be a better choice for the improvement of yield and component traits through hybridization. The crosses HD 2733 × K 7903, HUW 234 × K 9423, HD 2285 × K 2021, HUW 234 × K 2021, K 9423 × K 2021, HD 2285 × K 9465, HUW 234 × HD 2285, K 9423 × K 9465, HD 2285 × K 9423, HD 2733 × HUW 234, K 2021 × K 9465, K 2021 × K 7903, HD 2733 × HD 2285 and HUW 234 × K 7903 which had

Table 3 Estimates of gca effects and *per se* performance as well as their ranking (only desired)of the parents for 14 characters in bread wheat

Parents	Days to flowering		Days to maturity		Duration of reproductive phase (days)		Number of productive tillers/plant		Plant height (cm)		Spike length (cm)		Number of spikelets/ spike		Number of grains/ spike		Biological yield (g)		Harvest index (%)		Test weight (g)		Seed hardness (kg/seed)		Protein content (%)		Grain yield (g)	
	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*	gca	*Per se*
I	2.76**	71.3	7.09**	127.7	4.34**	57.1	-0.08	6.6	-0.97**	62.8	0.43**	10.9	0.47**	20.3	1.71**	58.9	-3.71**	25.1	0.31**	46.5	-0.80**	33.2	0.08	11.9	0.07	12.6	-1.65**	11.7
II	0.34**	66.7	1.26**	113.5	0.99**	47.5	0.18*	6.6	-3.54**	71.9	-0.11*	9.5	-0.23**	19.1	-0.57**	52.5	-1.27**	17.7	3.98**	54.7	-0.45**	34.8	-0.36**	10.1	-0.19**	11.9	0.43*	9.7
III	0.04	69.5	1.96**	117.9	1.72**	49.2	0.41**	6.9	-0.36**	68.4	-0.13**	10.1	0.02	19.7	0.05	56.9	0.51**	19.4	-0.26*	50.2	-0.63**	34.8	0.14*	11.4	-0.45**	10.7	0.2	9.7
IV	-1.36**	62.7	-10.02**	84.4	-8.47**	23.1	0.04	7.3	3.12**	68.9	0.08*	10.3	0.54**	19.9	2.00**	64.1	-1.12**	26.7	1.57**	40.8	0.78**	35.0	0.12*	10.3	0.08	12.8	-0.03	10.9
V	2.03**	67.1	7.63**	122.9	5.67**	56.6	-0.30**	6.3	0.92**	79.9	-0.23**	8.8	-0.43**	18.3	-1.24**	53.7	-0.05	27.2	-2.55**	32.2	-2.15**	36.0	0	10.1	0.23**	12.6	-0.46**	8.9
VI	0.28**	67.9	2.08**	116.1	1.89**	48.5	-0.13*	7.1	0.27**	62.3	0.25**	11.0	-0.23**	19.5	-1.63**	57.1	3.28**	30.5	-3.16**	46.6	0.90**	37.0	0.12*	9.5	-0.06	11.7	0.62**	14.2
VII	-4.10**	54.5	-10.00**	83.1	-6.14**	29.3	-0.12	7.9	0.55**	64.1	-0.29**	8.2	-0.14	18.5	-0.32*	50.3	2.36**	35.5	0.12	39.6	2.36**	39.7	-0.10*	10.8	0.32**	12.3	0.90**	13.9
A	0.05		0.06		0.05		0.05		0.06		0.03		0.06		0.12		0.06		0.08		0.04		0.04		0.04		0.12	
B	0.08		0.09		0.07		0.07		0.1		0.04		0.09		0.18		0.09		0.12		0.07		0.06		0.05		0.19	
G.P.	VII, IV		IV, VII		V, I, VI, III, II		II , III		II, I, III		I, VI, IV		IV, I		IV, I		VI, VII, III		II, IV, I		VII, VI, IV		III , IV, VI		VII, V		VII, VI, II	
H.P.	VII, IV		VII, IV		I, V		III, II		I, III		I, VI, IV		I, IV		IV, I		VII, VI		II, III, VI, I		VII, VI, V, IV		I, III, VII, IV		IV, V, I, VII		VI, VII, I	
C.P.	VII, IV		VII, IV		I, V		III, II		I, III		I, VI, IV		I, IV		IV, I		VII, VI		II, I		VII, VI, IV		III, IV		V, VII		VI, VII	

A = SE (gi) +, B = SE (gi-gj) +, G.P. = good general combiner parents, H.P. = High *per se* performance parents, C.P. = Common parents based on gca and *per se* performance

* Significant at 5% level, ** significant at 1% level, I = HD 2733, II = HUW 234, III = HD 2285, IV = K 9423, V = K 2021, VI = K 9465, VII = K 7903

Table 4 Estimates of sca effects and *per se* performance of 21 F_1s for 14 characters in bread wheat

F_1s	Days to flowering		Days to maturity		Duration of reproductive phase (days)		Number of productive tillers/plant		Plant height (cm)		Spike length (cm)		Number of spikelets/ spike		Number of grains/ spike		Biological yield (g)		Harvest index (%)		Test weight (g)		Seed hardness (kg/seed)		Protein content (%)		Grain yield (g)	
	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*	sca	*Per se*
I x II	-2.26**	68.1	1.96**	123.9	4.10**	56.5	0.27	8.9	-3.02**	61.8	1.16**	12.0	1.40**	21.7	2.21**	61.1	0.21	26.8	7.49**	63.5	9.98**	47.7	-0.86**	9.7	0.61**	12.6	2.14**	17.0
Ix III	2.30**	72.3	-3.53**	119.1	-5.63**	47.5	1.31**	10.1	5.67**	73.7	0.01	10.8	-0.65**	19.9	2.65**	62.1	6.69**	35.1	-6.57**	45.2	0.23	37.8	-0.76**	10.3	-0.23*	11.6	1.20**	15.8
I x IV	-0.36*	68.3	12.71**	123.3	12.90**	55.8	-0.25	8.2	-0.11	71.4	-0.20*	10.8	-0.44*	20.7	-1.03**	60.4	-6.68**	20.1	5.74**	59.3	-2.16**	36.8	-0.17	10.8	0.18	12.5	-2.50**	11.9
I x V	2.12**	74.1	-0.13	128.1	-2.31**	54.7	0.49**	8.6	0.42*	69.7	0.54**	11.3	0.67**	20.8	0.61	58.8	-0.95**	26.9	-5.55**	43.9	0.91**	37.0	0.87**	11.8	-0.71**	11.8	-2.17**	11.8
I x VI	-2.27**	68.0	-8.05**	114.7	-5.59**	47.7	2.05**	10.3	11.20**	79.9	-1.91**	9.3	-0.34	20.0	-0.68	57.1	-3.08**	28.1	-1.77**	47.1	0.33*	39.4	0.09	11.1	-0.25*	11.9	-1.78**	13.3
I x VII	3.31**	69.2	-2.84**	107.8	-6.16**	39.1	-0.42**	7.9	-4.98**	64.0	1.43**	12.1	0.77**	21.2	0.68	59.8	1.91**	32.1	12.21**	64.3	-0.83**	39.7	-1.09**	9.7	-0.1	12.5	5.33**	20.7
II x III	-1.74**	65.9	-2.38**	114.4	-0.74**	49.0	-2.09**	7.0	6.71**	72.2	1.42**	11.7	-0.88**	19.0	1.14**	58.3	7.19**	38.0	-3.80**	51.6	6.91**	77.8	0.98**	11.6	-0.24**	11.3	3.02**	19.7
II x IV	1.06**	67.3	-1.07**	103.7	-2.15**	37.4	3.69**	12.4	-7.90**	61.0	0.67**	11.2	0.53**	20.9	3.26**	62.4	6.62**	35.8	1.24**	58.5	-0.57**	38.8	0.14	10.7	-0.57**	11.5	4.46**	20.9
II x V	4.74**	74.3	1.82**	124.3	-3.22**	50.5	-0.77**	7.6	-6.84**	59.9	0.05	10.2	-0.56**	18.9	2.69**	58.6	-2.05**	28.2	16.78**	69.9	-1.64**	34.8	-0.48**	10.0	0.24*	12.5	3.65**	19.7
II x VI	-0.25	67.6	0.64**	117.5	1.36**	51.3	2.12**	10.7	-2.43**	63.7	-0.73**	9.9	0.90**	20.5	-1.85**	53.7	11.48**	45.1	-14.04**	38.5	-7.92**	31.5	0.24*	10.8	0.40**	12.3	0.21	17.3
II x VII	0.80**	64.3	4.25**	109.1	3.59**	45.5	1.31**	9.9	-4.81**	61.6	-1.03**	9.1	-0.26	19.5	0.64	57.5	-0.73**	31.9	2.21**	58.0	-0.21	40.7	0.02	10.4	-0.55**	11.8	1.05**	18.5
III x IV	-1.85**	64.1	1.77**	107.3	3.59**	43.9	0.12	9.1	-8.24**	63.9	-1.21**	9.3	-0.39*	20.3	-9.10**	50.7	2.97**	33.9	1.47**	54.5	4.31**	43.5	-0.2	10.9	-0.1	11.7	2.22**	18.5
III x V	2.44**	71.7	0.53**	123.7	-1.82**	52.6	5.46**	14.1	-2.22**	67.7	0.94**	11.1	1.65**	21.3	0.47	57.0	8.63**	40.7	0.39	49.3	-2.22**	34.0	-1.19**	9.8	0.14	12.1	4.21**	20.0
III x VI	-0.28	67.3	-0.13	117.5	0.23	50.9	-0.91**	7.9	-5.60**	63.7	-0.58**	10.1	-1.02**	18.9	-11.48**	44.7	-2.10**	33.3	12.27**	60.5	-0.70**	38.6	0.83**	11.9	0.70**	12.4	3.16**	20.1
III x VII	-5.31**	57.9	2.96**	108.5	6.93**	49.5	0.88**	9.7	4.15**	73.7	-0.31**	9.8	2.22**	22.2	18.21**	75.7	3.02**	37.5	-1.75**	49.8	-2.66**	38.1	-0.35**	10.5	0.82**	12.9	-0.32	16.9
IV x V	-3.43**	64.5	2.50**	113.7	5.84**	50.1	0.18	8.4	-0.70**	72.7	-1.61**	8.8	0.87**	21.1	-0.21	58.3	1.86**	32.3	8.43**	59.1	-2.37**	35.3	0.87**	11.8	0.24*	12.7	3.48**	19.1
IV x VI	2.12**	68.3	7.85**	113.5	5.42**	45.9	-0.2	8.2	10.22**	83.0	1.44**	12.3	1.53**	21.9	4.84**	62.9	8.73**	42.5	-5.19**	44.9	8.98**	49.7	0.92**	12.0	-0.63**	11.6	2.40**	19.1
IV x VII	6.16**	67.9	-5.53**	88.0	-11.55**	20.9	-0.94**	7.5	20.04**	93.1	1.75**	12.1	0.50**	21.0	-2.47**	56.9	-8.15**	24.7	16.36**	69.7	3.02**	45.2	-0.09	10.7	-0.05	12.5	0.25	17.2
V x VI	-0.67**	68.9	-6.06**	117.2	-4.99**	49.6	-1.33**	6.7	-2.29**	68.3	1.42**	12.0	-0.44*	19.0	3.35**	58.2	-2.14**	32.7	9.59**	55.6	0.49**	38.2	0.60**	11.5	-0.09	12.3	1.89**	18.1
V x VII	3.11**	68.3	13.09**	124.3	10.04**	56.6	-0.80**	7.3	-5.83**	65.0	1.26**	11.3	-0.39*	19.1	-3.90**	52.3	3.18**	37.1	-0.93**	48.3	2.23**	41.4	0.69**	11.4	0.27*	13.0	1.38**	17.9
VI x VII	1.06**	64.5	9.04**	114.7	8.10**	50.9	062**	8.9	4.15**	74.3	0.48**	11.0	-0.27	19.5	0.49	56.3	2.45**	39.7	-3.38**	45.3	6.48**	48.7	0.48**	11.3	0.66**	13.1	0.36	18.0
A	0.14		0.17		0.13		14		0.18		0.08		0.17		0.34		0.18		0.24		0.13		0.11		0.1		0.36	
B	0.21		0.25		0.2		0.21		0.27		0.11		0.25		0.51		0.27		0.35		0.19		0.16		0.15		0.53	

I = HD 2733, II = HUW 234, III = HD 2285, IV = K 9423, V = K 2021, VI = K 9465, VII = K 7903,

A = SE (gi) ±, B = SE (gi-gj) ±, * Significant at 5% level, ** significant at 1% level highly significant *sca* effect for most of the yield contributing traits may be exploited for the development of single cross hybrids and also through the population improvement programme for the development of suitable high-yielding varieties after knowing the extent of depression which inbreeding could reign in the F_2 and subsequent generations.

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