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GENETIC ANALYSIS IN F_1 GENERATION OF DIALLEL CROSSES FOR YIELD AND YIELD COMPONENTS IN HEXAPLOID WHEAT (*Triticum aestivum* L.)

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Abstract

Experimental materials comprised 10 F_1 from a diallel crosses involved five parents was grown in Randomized Block Design with the objective to estimation of heterosis and combining ability. The analysis of variance worked out for grain yield per plant and its components in bread wheat indicated that the mean sum of squares due to genotypes were highly significant for all the characters. Among the parents, the gca effects of the parents, DL-153-2 showed positive significant effect for most of the traits followed by PBW-226. Out of 10, seven of the cross combinations showed positive significant SCA effect for grain yield per plant. Entire cross combinations exhibited significantly desirable heterobeltiosis for grain yield per plant. On the basis of per se performance and estimates of heterosis, the cross DL-153-2 × PBW-226 was found most promising for grain yield per plant, hence could be evaluated further to exploit the heterosis or utilized in future breeding programme to obtain desirable segregants for the development of superior genotypes.

Key words: Yield, Heterosis, Combining ability, Grains, GCA and SCA

Introduction

Bread wheat (*Triticum aestivum* L.) member of family Gramineae is so important crop; multipurpose use and nutritional value make bread wheat strategic and stable food in the world. Wheat (*Triticum aestivum* L.) originated from the natural hybrids of three diploids wild progenators native to the Middle East these are *Triticum monococcum*, *Triticum tauschii* and *Aegilopes speltoides* (Negasa *et al.* 2016). Major cultivated species of wheat is *Triticum aestivum*, which is hexaploid (2n = 6x = 42), (Bhutto *et al.* 2016)

India is one of the most wheat producing and consuming country of the world. After the Green Revolution, the production of wheat has shown a huge increase (Kumar *et al.*, 2014). Uttar Pradesh, Punjab, Haryana, major wheat producing states in the country. These states contribute about 87.5% of total wheat production in the country (Kumar *et al.*, 2013). Productivity highest in Punjab and Haryana because of the availability of better irrigation facilities.

In plant breeding programs, Diallel cross technique is a good tool for identification of hybrid combinations that have the potentiality of producing maximum improvement and identifying superior lines among the progeny in early segregation generations. Combining ability analysis of Griffing (1956) is most widely used as a biometrical tool for identifying parental lines in terms of their ability to combine in hybrid combinations. With this method, the resulting total genetic variations is partitioned into the variance of general combining ability, as a measure of additive gene action and specific combining ability, as a measure of non-additive gene action.

The present investigation was undertaken to study the combining ability of varieties/ lines and to quantify the magnitude and direction of heterosis in hybrid for yield and its contributing traits.

Table 1: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for days to booting, days to heading, days to anthesis

Cross combinations	Days to booting			Days to heading			Days to anthesis		
	Mean	Better Parent	Standard Check	Mean	Better Parent	Standard Check	Mean	Better Parent	Standard Check
DL-153-2 x CPAN-1796	86.00	-9.65**	4.88	92.50	-10.51**	4.51	99.30	-11.42**	4.20
DL-153-2 x RAJ-1972	87.00	-8.60**	6.10*	93.50	-9.54**	5.65*	100.30	-10.53**	5.24*
DL-153-2 x PBW-226	85.00	-10.71**	3.65	91.50	-11.47**	3.39	98.30	-12.31**	3.15
DL-153-2 x PBW-396	85.00	-10.70**	3.66	91.50	-11.47**	3.39	98.30	-12.31**	3.15
CPAN-1796 x RAJ-1972	88.00	2.33	7.32**	94.50	2.16	6.77**	101.30	2.02	6.30**
CPAN-1796 x PBW-226	84.67	-4.51	3.26	91.17	-4.20	3.02	97.97	-3.93	2.80
CPAN-1796 x PBW-396	86.00	1.18	4.88	92.50	1.65	4.52	99.30	1.53	4.20
RAJ-1972 x PBW-226	85.00	-4.14	3.66	91.50	-3.86	3.38	98.30	-3.60	3.15
RAJ-1972 x PBW-396	86.00	0.01	4.88	92.50	0.00	4.52	99.30	0.00	4.20
PBW-226 x PBW-396	82.33	-7.15**	0.40	88.83	-6.66**	0.37	95.63	-6.22**	0.35
S.E±		2.063	2.063		1.926	1.926		1.876	1.876
CD at 95%		4.666	4.666		4.356	4.356		4.244	4.244
CD at 99%		5.700	5.700		5.321	5.321		5.185	5.185

Methods and Materials

Experiment Material:

The experiments were conducted at Research Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib. The experimental material consisted of five varieties (DL-153-2, CPAN-1796, RAJ-1972, PBW-226, PBW-396) of wheat (*Triticum aestivum* L.) received from IIWBR, Karnal and their ten crosses involving diallel (excluding reciprocals) method and one check variety. The parents were selected on the basis of promising agronomic attributes and disease resistance. The parents were crossed in diallel method design during Rabi season of 2016-2017.

Experimental Details and data recorded

The experiment consisting ten crosses of wheat along with their five parents and one check variety seeds were sown in randomized block design with three replications in fully irrigated condition on 19 November, 2017. Each genotype was grown in double row, with row to row 22.5 centimeter with appropriate plant to plant distance of 5-6 centimeter in each replication. The recommended packages of practices were adopted for optimum crop growth. The fertilizer was applied at the dose of 120:60:40 kg NPK/ha. Five competitive plants were selected randomly and tagged from each genotype in all replications for the purpose of recording observations. The observations were recorded on the fourteen yield characters *viz* Days to booting, Days to heading, Days to anthesis, Number of tillers per plant, Plant height (cm), Spike length (cm), Days to maturity, Number of spikelets per spike, Number of grains per plant, Number of grain per spike, Test weight (g), Biological yield per plant (g), Grain yield per plant (g), Harvest index (%).

Table 2: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for days to maturity, productive tillers/ plant, Plant height

Cross combinations	Days to maturity			Productive tillers/ plant			Plant height		
	Mean	Better Parent	Standard Check		Mean	Better Parent	Standard Check		Mean
DL-153-2 x CPAN-1796	124.20	-18.36**	3.32	14.40	19.17**	38.46**	93.77	-8.23**	-4.50
DL-153-2 x RAJ-1972	125.20	-17.71**	4.15	12.05	2.55	15.87**	100.50	5.40*	2.36
DL-153-2 x PBW-226	123.20	-19.02**	2.49	13.78	18.62**	32.50**	91.10	-4.47	-7.22**
DL-153-2 x PBW-396	123.20	-19.02**	2.49	11.93	2.70	14.71**	101.50	6.44**	3.38
CPAN-1796 x RAJ-1972	126.20	1.61	4.99*	11.60	-4.00	11.54**	93.00	-8.98**	-5.28*
CPAN-1796 x PBW-226	122.87	-3.15	2.22	11.93	-1.27	14.71**	83.67	-18.11**	-14.78**
CPAN-1796 x PBW-396	124.20	1.22	3.32	10.00	-17.24**	-3.85	94.03	-7.97**	-4.23
RAJ-1972 x PBW-226	123.20	-2.89	2.49	11.95	1.70	14.90**	90.00	1.12	-8.33**
RAJ-1972 x PBW-396	124.20	-0.01	3.32	12.25	4.28	17.82**	100.00	14.81**	1.85
PBW-226 x PBW-396	120.53	-5.00*	0.27	12.03	32.93**	15.67**	91.83	3.18	-6.47**
S.E±		2.490	2.490		0.416	2.490		2.158	2.158
CD at 95%		5.633	5.633		0.941	0.941		4.882	4.882
CD at 99%		6.881	6.881		1.149	1.149		5.963	5.963

Table 3: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for spike length, spikelets/ spike, number of grain/ spike

Cross combinations	Spike length			Spikelets/spike			Number of grains/spike		
	Mean	Better Parent	Standard Check		Mean	Better Parent	Standard Check		Mean
DL-153-2 x CPAN-1796	14.30	-6.72	15.88**	22.00	0.86	-4.33	68.70	12.75**	7.46
DL-153-2 x RAJ-1972	14.27	19.51**	15.64**	24.00	20.04**	4.36	70.20	2.22	9.81**
DL-153-2 x PBW-226	15.15	15.71**	22.74**	22.00	-4.40	-4.33	71.63	8.61*	12.04**
DL-153-2 x PBW-396	14.25	7.55	15.48**	24.00	25.15**	4.36	60.83	2.78	-4.85
CPAN-1796 x RAJ-1972	12.78	-16.63**	3.57	20.00	-8.31*	-13.03**	67.25	-2.08	5.19
CPAN-1796 x PBW-226	12.64	-17.55**	2.43	22.33	-2.97	-2.90	71.58	8.54*	11.97**
CPAN-1796 x PBW-396	12.45	-18.79**	0.89	21.67	-0.66	-5.77	68.90	13.08**	7.77*
RAJ-1972 x PBW-226	13.08	-0.08	6.00	22.50	-2.23	-2.16	75.98	10.63**	18.85**
RAJ-1972 x PBW-396	13.28	0.23	7.62	24.00	20.04**	4.36	71.60	4.26	12.00**
PBW-226 x PBW-396	13.46	1.58	9.08	20.25	-12.01**	-11.94**	71.70	8.72*	12.15**
S.E±		0.561	0.561		0.752	0.752		2.166	2.166
CD at 95%		1.269	1.269		1.700	1.700		4.901	4.901
CD at 99%		1.550	1.550		2.077	2.077		5.986	5.986

Results and Discussion

Analysis of Variance

Analysis of variance showed highly significant differences among the genotypes for all characters exhibiting abundant variability for these traits. This revealed that genotypes differ from each other for all the characters. The observed significant differences among genotypes allow conducting further genetic analysis. These results are in general agreement with the findings of Kaddem *et al.* (2014) and Ghuttai *et al.* (2015).

Magnitude of heterosis

Exploitation of heterosis in cultivated plants is one of the most important accomplishments of the science of genetics in agriculture (Dobzhansky, 1952). The exploitation of heterosis requires intensive evaluation of germplasm to find out diverse donors with high nicking of genes and further identification of highly heterotic F_1 which may also subsequently leads to obtain desirable segregants from various combinations. Although production of hybrids may be the best way to exploit the heterosis in F_1 in Indian conditions, such attempts have not met with success due to problems of instability of male sterility, pollen fertility, free pollen dispersal and seed setting.

In the present investigation, the magnitude of relative heterosis (RH), heterobeltiosis (HB) and economic heterosis (EH) have been calculated. The magnitude of heterosis have been expressed as per cent increase or decrease of F_1 value over mid parent (relative heterosis), over better parent (heterobeltiosis) and over standard check (standard or economic heterosis). The character wise results of mid parent, better parent and economic heterosis are presented in table 4.2.1 to 4.2.13. The trait wise results are summarized as following:

Heterobeltiosis for days to booting indicated that out of 10 crosses, five crosses combinations varies from -10.71 (DL-153-2 × PBW-226) to -7.15 (PBW-226 × PBW-396) over better parents, none of the crosses exhibited negative significant useful heterosis for this trait. Two crosses showed significant positive useful heterosis ranging from 7.32 (CPAN-1796 × RAJ-1972) to 6.10 (DL-153-2 × RAJ-1972) over the commercial check.

For days to heading, out of 10 cross combinations, five cross combinations shows significant negative heterobeltiosis varies from -11.47 (DL-153-2 × PBW-226, DL-153-2 × PBW-396) to -6.66 (PBW-226 × PBW-396) over better parents. None of the cross combinations exhibited significant negative useful heterosis for this trait. Two crosses showed significant positive useful heterosis ranging from 5.65 (DL-153-2 × RAJ-1972) to 6.77 (CPAN-1796 × RAJ-1972) over the commercial check. Similar findings were reported by Devi *et al.* (2013) and Rahul (2017).

Heterobeltiosis for days to anthesis, five cross combinations exhibited significant negative heterobeltiosis ranging from -12.31 (DL-153-2 × PBW-226, DL-153-2 × PBW-396) to -6.22 (PBW-226 × PBW-396). None of the cross combinations exhibited significant negative useful heterosis while two of the cross combinations were found significant positive heterosis ranging from 5.24 (DL-153-2 × RAJ-1972) to 6.30 (CPAN-1796 × RAJ-1972) over the commercial check. Similar results on the importance of negative heterosis for days to anthesis have been reported by Beche *et al.* (2013), Barot *et al.* (2014) and Baloch *et al.* (2016).

For days to maturity, five cross combinations were found to be negative significant heterosis over better parent ranges from -19.02 (DL-153-2 × PBW-226, DL-153-2 × PBW-396) to -5.00 (PBW-226 × PBW-396). Only one cross combination exhibited significant positive useful heterosis 4.99 (CPAN-1796 × RAJ-1972) over the commercial check while none of the cross combinations exhibit significant negative heterosis for days to maturity. Negative estimates of heterosis for maturity were earlier reported by Lal *et al.* (2013) and Rahul (2017).

For number of productive tillers/plant, three cross combinations exhibited significant positive heterobeltiosis ranging from 18.62 (DL-153-2 × PBW-226) to 32.93 (PBW-226 × PBW-396) over better parent. Nine of the cross combinations exhibited significant positive useful heterosis ranging from 11.54 (CPAN-1796 × RAJ-1972) to 38.46 (DL-153-2 ×

CPAN-1796) over the commercial check. Similarly significant positive heterosis for number of tillers per plant has been reported by Kumar and Kerkhi (2014) and Hei *et al.* (2016).

The plant height is an important trait by which growth and vigour of plants are measured. A significant and high degree of heterosis for plant height was observed in comparison to the better parent and the commercial variety as well. Three cross combinations exhibited significant positive heterobeltiosis ranging from 5.40 (DL-153-2 × RAJ-1972) to 14.81 (RAJ-1972 × PBW-396) over better parent while four cross combinations were found to be negatively significant heterosis from -18.11 (CPAN-1796 × PBW-226) to -7.97 (CPAN-1796 × PBW-396) over better parent. Five of the crosses combination exhibited negative useful heterosis ranges from -14.78 (CPAN-1796 × PBW-226) to -5.28 (CPAN-1796 × RAJ-1972) over commercial check. Similar findings were reported by Singh *et al.* (2013) and Kumar *et al.* (2015) who reported negative heterosis for plant height.

Spike length is one of the important components of yield. Since it contributes towards productivity therefore it should be taken into consideration during selection. Two cross combinations showed significant positive heterosis ranging from 15.71 (DL-153-2 × PBW-226) to 19.51 (DL-153-2 × RAJ-1972) over better parent. Four cross combinations exhibited significant positive useful heterosis varies 15.48 (DL-153-2 × PBW-396) to 22.74 (DL-153-2 × PBW-226) over the commercial check.

Out of ten crosses, three cross combinations exhibited significant positive heterosis for number of spikelets/spike ranging from 20.04 (RAJ-1972 × PBW-396, DL-153-2 × RAJ-1972) to 25.15 (DL-153-2 × PBW-396) over better parent. None of the cross combinations exhibited significant positive useful heterosis over commercial check for number of spikelets/spike. Similar findings were given by Kumar *et al.*, (2017) which are in agreement with this study results.

Number of grains/spike are one of the important component characters of yield. Thus, positive heterosis for this character is desirable for increasing yield. Six crosses were found to be positively significant heterobeltiosis ranging from 8.54 (CPAN-1796 × PBW-226) to 13.08 (CPAN-1796 × PBW-396) over better parent. Seven cross combinations exhibited significant positive useful heterosis which ranging from 7.77 (CPAN-1796 × PBW-396) to 18.85 (RAJ-1972 × PBW-226) over the commercial check for number of grains/spike. Similar findings had been reported by Barot *et al*. (2014).

For number of grains/plant, four cross combinations were found to be positively significant heterobeltiosis ranging from 5.93 (CPAN-1796 × PBW-226) to 26.72 (DL-153-2 × PBW-226). Eight cross combinations exhibited significant positive useful heterosis which ranging from 7.31 (DL-153-2 × PBW-396) to 38.00 (DL-153-2 × PBW-226) over the commercial check for number of grains/plant. Similar results were given by Kalhoro *et al.* (2015) and Baloch *et al.* (2016) in wheat.

Positive heterosis is favored in case of test weight. Since the increase in grain weight increases yield potential. High grain yield/plant is the ultimate goal of any breeding programme, so require higher consideration. Four cross combinations were found to be positive significant heterosis ranging from 8.63 (DL-153-2 × CPAN-1796) to 16.42 (DL-153-2 × RAJ-1972) over better parent. Three cross combination exhibited significant positive useful heterosis ranges from 8.88 (DL-153-2 × PBW-226) to 16.11 (CPAN-1796 × PBW-226). Similar findings were given by Barot *et al.* (2014).

While selecting the plants, grain yield/plant receives the maximum attention of plant breeder. Therefore, positive heterosis grain yield is desirable. High grain yield/plant is the ultimate goal of any breeding programme, so require higher consideration. Eight cross combinations showed significant positive heterobeltiosis ranging from 11.44 (CPAN-1796 × PBW-226) to 48.01 (DL-153-2 × PBW-226) over better parent while one cross exhibited significant negative heterosis varies from -5.26 (CPAN-1796 × PBW-396). Nine cross combinations showed significant positive useful heterosis ranging from 13.61 (CPAN-1796 × RAJ-1972) to 53.76 (DL-153-2 × PBW-226). While none of the cross combinations were found to be significant useful negative heterosis over the commercial check has been reported by Garg *et al*. (2015) and Thomas (2017).

In general, higher the biological yield higher is the economic yield. Hence, a positive heterosis is desired. Seven cross combination shows significant positive heterosis ranging from 16.07 (PBW-226 × PBW-396) to 52.64 (DL-153-2 × PBW-396). Nine cross combinations exhibited significant positive useful heterosis which ranging from 11.11 (CPAN-1796 × RAJ-1972) to 50.89 (DL-153-2 × CPAN-1796) over commercial check for biological yield/plant. Similar results for biological yield/plant were reported by Kumar and Kerkhi (2014).

Higher the harvest index better is the economic yield, so efforts should be concerned for higher positive heterosis for harvest index. None of the cross combinations shows significant positive heterosis while four of the cross combinations were found to be significant negative heterosis ranging from -29.06 (DL-153-2 × PBW-396) to -18.95 (DL-153-2 × PBW-226) over better parents. None of these cross combinations exhibited significant positive and negative useful heterosis over the commercial check for harvest index for this trait. Significant positive heterosis for harvest index is reported by Singh *et al.* (2013).

Combining Ability

Combining ability analysis is an effective tool to identify the superior parents for breeding programme (Padhar *et al.,* 2013). Accordingly the parents differ in their combining ability and the use of good combiners is expected to give useful segregants. In the same way superior cross combinations can be discriminated in respect of their sca effects. Thus, availability of information regarding the combining ability of the parents, for yield and yield attributes is necessary for devising an effective and efficient breeding methodology.

The genotypic mean squares were further portioned into variation due to general combing ability (*gca*) and specific combining ability (*sca*). It may be stated that *gca* is due to the average performance of a line in a series of crosses and *sca* is the deviations in the performance of a cross combinations from that predicted on the basis of general combining ability of the parents involved in a series of crosses. Variances due to *gca* and *sca* were significant for all the characters indicating that both additive and dominance gene action were important in the expression of characters. Further, the ratio *gca/sca* was above unity for all the characters which indicated that there is preponderance of additive gene action in comparison to dominance gene action. This finding has important implication because additive gene effects are of fixable nature therefore one can expect larger genetic gain due to selection.

Further *gca* and *sca* effects were computed and tested for their significance. A perusal of data on *gca* effects allowed concluding that the experimental material lacked good general combiners for days to booting, days to heading, days to anthesis, and number of spikelets/spike. This is important consideration from the agro climatic conditions of Punjab, where short duration and dwarf varieties would be given preferance on account of its cultivation under limited moisture condition.

Therefore in future, attempts must be done to broaden the genetic base for these three important characters. Considering other economic traits, parents DL-153-2, PBW-226 and PBW-396 may be considered as good general combiners. However statistically, for grain yield/plant, two parents CPAN-1796 and PBW-396 showed significant negative *gca* effect.

However for grain yield/plant certain crosses such as DL-153-2 × CPAN-1796, DL-153-2 × RAJ-1972, DL-153-2 × PBW-226, DL-153-2 × PBW-396, CPAN-1796 × PBW-396, RAJ-1972 × PBW-226, RAJ-1972 × PBW-396 and PBW-226 × PBW-396 showed higher magnitude of significantly higher *sca* effect. But all crosses were also supported by highly significant and higher magnitude of *sca* effects for other important yield characters such as number of grains/spike, number of grains/plant, test weight, biological yield/plant and grain yield/plant. Cross, DL-153-2 × PBW-226 was associated with highly significant *sca* value of grain yield/plant as well. Similar findings were reported by Gite *et al.* (2014) and Hei *et al.*

(2016). Therefore, on this ground this cross deserves more attention.

The potentiality of a parent in hybridization may be assessed by its *per se* performance and *gca* effects. The results revealed that most of the genotypes had relatively high degree of correspondence between *per se* performance and *gca* effects for the observed characters. This can be ascribed to the predominant role of additive and additive × additive type of gene action for the inheritance of these traits.

The estimates of specific combining ability effects revealed that as many as two cross combinations exhibited significant and positive *sca* effects for grain yield/plant. The maximum significant positive *sca* effect was exhibited by hybrid 7.03 (DL-153-2 × PBW-226) and 6.29 (RAJ-1972 × PBW-396) thus they were good hybrid combinations, contributing towards higher grain yield/plant.

Since among the parents DL-153-2 and PBW-226 showed significant *gca* effect, it is not possible to classify the crosses on the basis of high/low *gca* value of the parents.

A cross combination exhibiting high *sca* effects as well as high *per se* performance involving at least one parent as good general combiner for a particular trait, is expected to throw desirable segregants in the segregating generations. Significant *sca* effects of those combinations involving good × good combiners showed the major role of additive type of gene effects, which is fixable. However, two good general combiners may not necessarily yield desirable segregants. Similarly, from the superior crosses involving both the poor × poor general combiners, very little gain is expected in their segregating generation because high *sca* effects may dissipate with increased homozygosity.

Better performance of hybrids involving average × poor general combiners indicated dominance × dominance (epistasis) type of gene action (Jinks, 1956). Such crosses could be utilized in the production of high yielding homozygous lines by Darrah and Hallauer, (1972).

In the present study, one of the top four crosses which exhibited high *sca* effects for yield/plant, the cross, DL-153-2 × PBW-226 involved one good general combiner indicating additive × additive type of gene interaction which is expected to produce desirable transgressive segregants in subsequent generations. Singh *et al.* (2013) and Kumar *et al.* (2015) have reported the involvement of additive × additive, additive × dominance and epistatic type of gene action in expression of yield and other traits in bread wheat.

The crosses, where poor × poor and poor × good general combiners produced high *sca* effects may be attributed due to presence of genetic diversity in the form of heterozygous loci for specific traits. Thus, the ideal crosses would be the one, which have good *per se* performance, high heterosis or heterobeltiosis, at least one good general combiner parent and high *sca* effects. On the basis of combining ability, the parent DL-153-2 was good general combiner.

Conclusively, these three crosses were also found promising for other desirable traits, hence could be further evaluated in heterosis breeding programme. Simultaneously these hybrids could be selfed to obtain desirable recombinants in segregating generations for the development of superior genotypes.

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Table 4: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for number of grains per plant, test weight, biological yield

Cross combinations	Number of grains/ plant			Test weight			Biological yield		
	Mean	Better Parent	Standard Check		Mean	Better Parent	Standard Check		Mean
DL-153-2 x CPAN-1796	867.21	20.22**	35.45**	48.69	8.63*	3.49	95.10	27.74**	50.89**
DL-153-2 x RAJ-1972	789.72	-1.27	23.35**	48.14	16.42**	2.32	81.58	29.84**	29.43**
DL-153-2 x PBW-226	883.49	26.72**	38.00**	51.23	6.73	8.88**	95.05	39.52**	50.81**
DL-153-2 x PBW-396	687.00	-1.46	7.31**	53.25	10.36**	13.18**	86.40	52.64**	37.07**
CPAN-1796 x RAJ-1972	770.95	-3.62	20.42**	44.18	-1.43	-6.10	70.03	-5.94**	11.11**
CPAN-1796 x PBW-226	764.12	5.93*	19.35**	54.63	13.81**	16.11**	76.68	3.00	21.66**
CPAN-1796 x PBW-396	663.77	-7.98**	3.68	46.06	-4.53	-2.10	64.35	-13.57**	2.09
RAJ-1972 x PBW-226	668.97	-16.36**	4.49	49.72	3.58	5.67	84.23	23.64**	33.64**
RAJ-1972 x PBW-396	770.58	-3.66	20.36**	48.78	1.10	3.68	85.75	36.48**	36.05**
PBW-226 x PBW-396	784.43	23.25**	22.53**	44.08	-8.64**	-6.31	79.08	16.07**	25.46**
S.E±		15.70242	15.70242		1.45454	1.45454		1.13386	1.13386
CD at 95%		35.52107	35.52107		3.29038	3.29038		2.56494	2.56494
CD at 99%		43.39007	43.39007		4.01929	4.01929		3.13315	3.13315

Table 5: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for grain yield per plant, harvest index

Cross combinations	Grain yield/plant			Harvest index		
	Mean	Better Parent	Standard Check	Mean	Better Parent	Standard Check
DL-153-2 x CPAN-1796	39.79	32.24**	43.28**	41.85	-24.34**	1.16
DL-153-2 x RAJ-1972	35.61	23.42**	28.22**	43.56	-21.25**	5.29
DL-153-2 x PBW-226	42.70	48.01**	53.76**	44.84	-18.95**	8.38
DL-153-2 x PBW-396	33.92	17.57**	22.15**	39.24	-29.06**	-5.15
CPAN-1796 x RAJ-1972	31.55	4.85	13.61**	43.66	-0.40	5.54
CPAN-1796 x PBW-226	33.53	11.44**	20.75**	44.98	1.93	8.73
CPAN-1796 x PBW-396	28.51	-5.26*	2.65	43.75	-1.71	5.74
RAJ-1972 x PBW-226	38.05	35.18**	37.03**	44.28	0.35	7.03
RAJ-1972 x PBW-396	37.31	35.59**	34.35**	45.23	1.61	9.32
PBW-226 x PBW-396	34.44	22.34**	24.02**	44.72	0.48	8.11
S.E±		0.68719	0.68719		2.86032	2.86032
CD at 95%		1.55452	1.55452		6.47045	6.47045
CD at 99%		1.89890	1.89890		7.90385	7.90385

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Table 5: General combining ability of diallel analysis in bread wheat (*Triticum aestivum* L.)

Characters / Genotypes	Days to booting	Days to heading	Days to anthesis	Number of tillers /plant	Plant height (cm)	Spike length (cm)	Number of spikelets /spike	Number of grains / spike	Days to maturity	Number of grains /plant	Test weight (g)	Biological yield/ plant (g)	Grain yield / plant	Harvest index (%)
DL-153-2	2.38**	2.79**	3.23**	0.75**	2.80 **	-0.28 *	0.07	-4.06**	6.69**	27.23 **	0.12	1.36**	1.66 **	2.06**
CPAN-1796	-0.30	-0.51	-0.62	0.28**	1.55 **	0.45 **	-0.04	-0.47	-1.48*	11.08 **	0.01	0.30	-0.65 **	-1.55*
RAJ-1972	0.18	0.11	0.00	0.17	-0.03	-0.34 *	0.08	2.97**	-0.86	24.11 **	-2.70 **	-0.82**	-0.08	-0.18
PBW-226	-0.34	-0.41	-0.52	-0.38**	-3.33 **	0.12	0.46*	3.03**	-1.39*	-8.18*	1.79 **	2.62**	0.99 **	0.20
PBW-396	-1.92**	-1.98**	-2.09**	-0.83**	-0.99	0.04	-0.57**	-1.46**	-2.96**	-54.23 **	0.79 *	-3.46**	-1.92 **	-0.53
Gi--Gj at 95%	2.16**	2.02**	1.97**	0.44**	2.26 **	0.59 **	0.79**	2.27**	2.61**	16.48 **	1.53 **	1.19**	0.72 **	3.00**
Gi--Gj at 99%	3.59**	3.35**	3.27**	0.72**	3.76 **	0.98 **	1.31**	3.77**	4.33**	27.32 **	2.53 **	1.97**	1.20 **	4.98**
h^2 Narrow Sense	0.39	0.41	0.41	0.27	0.21	0.07	0.04	0.35	0.42	0.24	0.20	0.04	0.11	0.16
h^2 Broad Sense	0.80	0.86	0.90	0.97	0.95	0.93	0.94	0.95	0.95	0.99	0.96	1.00	0.99	0.72