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Identification of Good Combiner with Heterotic Group in Bread Wheat (*Triticum aestivum* L.)

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Abstract

The current study was carried out in rabi 2021–2022 at Crop Research Farm, Nawabganj, C.S. Azad University of Agriculture and Technology, Kanpur (Uttar Pradesh, India) to estimate the heterosis and analyze the combining ability in 8 × 8 diallel sets of bread wheat (*Triticum aestivum*). Analysis of variance (ANOVA) results showed that all traits had significant variance owing to general combining ability (GCA) among the parents and all traits except spike length had considerable variance due to specific combining ability (SCA) among the crosses. Combining ability research showed that most of the traits involved both additive and non-additive gene activity. Parents HD 3086, DBW 187, and DBW 252 were found to be the top general combiners for grain yield and yield-contributing characters based on GCA and per se performance. According to SCA and per se performance for most of the traits, crosses DBW 187 × DBW 303 and DBW 252 × DBW 303 were good specific combiners. There was significant heterosis over the economic parent for all the characters studied. On the basis of economic parent, the amount of heterosis was greatest for the character number of productive tillers per plant (NPT) (33.66%) whereas, for the majority of yield-contributing traits, the cross combinations HD 3086 × DBW 303, DBW 187 × ATLAS, DBW 187 × DBW 303, and DBW 252 × DBW 303 were highly significant and preferred over the economic parent.

Keywords

Heterosis, Combining ability, Diallel, Additive, Grain yield, Economic parent

Introduction

The most important cereal crop for the majority of people on earth is wheat (*T. aestivum* L.). It is about two billion people's most important staple food (36% of the world population). Worldwide, wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally [1]. Wheat is an annual plant of the family Gramineae (Subfamily Poaceae) that belongs to the genus *Triticum* grown in tropical, subtropical as well as temperate zones. Wheat is a naturally self-pollinated crop and is a native of Southwestern Asia. In terms of acreage and output, it is India's second most significant food crop after rice, contributing 12% to the world wheat production. Carbohydrates and protein are two main constituents of wheat. On average wheat contains 11 - 12% protein, the kernel contains 12% water, 70% carbohydrates, 2% fat, 1.8% minerals, and 2.2% crude fibers. In rabi 2022-2023, wheat is cultivated on 222.27 million hectares, yielding 780.59 million tons with productivity of 35.1 q/ha (USDA 2022-2023) and an output of 112.18 million tons. Punjab, Madhya Pradesh, and Uttar

Pradesh are the top three wheat producing states in India. The breeder is concentrating on increasing the potential wheat production by creating new divergent genotypes with a feature that may have both a positive and a negative impact on traits of other components. Various breeding approaches have been used to select parents and crosses in breeding programs. Even so, the most important stage is the identification of desirable parents as well as crosses with the highest combining ability and heterosis in the wheat yield improvement process. Combining ability analysis is one of the prevailing tools to compare the performance of parental genotypes in hybrid combinations and assists in the selection of promising parental genotypes and their hybrids in wheat [2]. GCA can determine superior combiner parents whereas the SCA effect helps in identifying good cross combinations that may eventually lead to the development of the hybrids [3]. The value of heterosis relative to better economic parent in wheat and its components many investigators, such as Beche et al. [4]. In a crop like wheat, heterosis depends mainly on the direction and magnitude of heterosis. The degree of heterosis directly impacts the breeding techniques used for varietal improvement. Heterosis is crucial for revealing details about the parents' capacity for merging offspring and their value in wheat breeding programs. The heterosis research aids breeders in the early generation elimination of ineffective hybrids. The breeder would be able to concentrate on a smaller number of potentially more fruitful crossings by rejecting crosses that do not exhibit heterosis. The exploitation, application, and viability of hybrid seed development determine the degree of heterosis in a crop. In a crop like wheat, heterosis could not be beneficial unless it can be used to create a hybrid. So, wheat heterosis is used to select desirable crosses to obtain superior progenies in advanced generations for additional enrichment of grain yield.

Materials and Methods

The genetic materials, for the present investigation comprised eight bread wheat varieties HD 3086 (average yield 54.6 q/ha, protein 12.8%, and highly resistant to yellow rust), DBW 187 (average yield 48.8 q/ha, and iron 43.1 ppm), HD 3298 (average yield 43.7 q/ha, protein 12.1% and iron 43 ppm), KRL 210 (Suitable for saline and alkaline soil, average yield 33.7 q/ha, protein 12.8%), DBW 252 (average yield 36.7 q/ha, protein 10.3% and resistant to drought and foliar diseases), PBW 757 (early maturing variety with average yield 47.2 q/ha and resistant to yellow and leaf rust), ATLAS (high protein content and drought tolerant variety), and DBW 303 (biofortified variety with protein 12 ppm, zinc 42 ppm and iron 43 ppm, average yield 81.20 q/ha, resistant to all major disease of wheat) and 28 F_1s hybrids generated by crossing the above varieties in all possible combinations excluding reciprocals were evaluated in randomized block design with 3 replications. The experiment was conducted at Crop Research Farm, Nawabganj, C.S. Azad University of Agriculture and Technology, Kanpur (Uttar Pradesh, India) during rabi, 2021-22. The entries were sown in a 3 m length with inter and intra-row spacing of 23 cm and 10 cm, respectively. Appropriate agronomical operations were adopted (including field preparation, irrigation and weed management, etc.) to obtain a good crop. The observations were recorded in each plot on 10 randomly selected plants in parent and F_1 generation for grain yield and it's contributing traits viz., days to 75% heading (DH), days to maturity (DM), plant height (cm) (PH), NPT, spike length (cm) (SL), number of spikelets per spike (NSplts/S), number of grains per spike (G/S), 1000-grain weight (g) (1000-GW), biological yield per plant (g) (BY), harvest index (%) (HI), and grain yield per plant (g) (GY).

Statistical Analysis

Combining ability

GCA is a measure of additive gene activity that relates to the average performance of a genotype in a series of hybrid combinations, whereas SCA is the performance of a parent in a specific cross in reference to GCA [5]. The combining ability analysis was carried out by the procedure suggested by Griffing [6]. Method two, model first: The mathematical model for the combining ability analysis is assumed to be.

$$Xijkl = \mu + gi + gj + Sij + 1/bc\ \Sigma E\ \Sigma I\ eijkl$$

ij = 1,2,3, ...n; k = 1,2,3, ...b; l = 1,2,3, ...c

Where, μ = the population mean, gi = the GCA effect of i^{th} parent, gi = the GCA effect of j^{th} parent, Sij = the SCA effect for the cross between i^{th} and j^{th} parents such that Sij = Sji, b = number of replications, c = number of plants per replication. ijkl = the environmental effect associated with the $ijkl^{th}$ individual observation on i^{th} individual in the k^{th} block with i^{th} as the female parent and j^{th} as a male parent.

Estimates of various effects

The various effects were estimated as follows:

GCA effect of i^{th} parent (g_i) = $1/(n+2)\ [(x_i+x_{ii}) - (2/n)\ x..)$

SCA effect of ij^{th} cross (S_{ij}) = $x_{ij} - 1/(n+2)\ [x_i+x_{ii}+x_j+x_{jj}) + 2x./(n+1)\ (n+2)]$

Where, gi and S_{ij} = the estimates of the general and SCA effect, respectively; x_i, x_{ii}, $x...x_{ij}$ = the same as explained earlier; x_j = total of the arrays involving j^{th} parents as a male; and x_{ij} = the value of the j^{th} parent of the array.

Heterosis

The nature and magnitude of heterosis was computed as percent increase or decrease of the mean value of F_1 over mid parent (MP), better parent (BP) and economic parents/standard variety/check (check), was estimated with the help of following formula. Average heterosis or MP heterosis refers to a hybrid's superiority over the mean of its parents [7].

Heterosis (%) over $MP = \left(\overline{F_1} - \overline{MP}/\overline{MP}\right)$ x 100

Where $\overline{F_1}$ = mean of the F_1 and $\overline{MP}$ = mean of the MP.

Heterobeltiosis or BP heterosis is the hybrid's advantage over the best parent, as measured in comparison to the superior or a BP [8].

Heterosis (%) over $BP = \left(\overline{F_1} - \overline{BP}/\overline{BP}\right)$ x 100

Where $\overline{F_1}$ = mean of the F_1 and $\overline{BP}$ = mean of the BP.

Standard heterosis or economic heterosis refers to a hybrid's higher performance in terms of desired features above a standard commercial hybrid variety as a check [9].

Heterosis (%) over check = $\left(\overline{F_1} - \overline{Check}/\overline{Check}\right)$ x 100

Where $\overline{F_1}$ = mean of the F_1 and $\overline{Check}$ = mean of the check/economic parent.

Test of significance:

significance of heterosis over better parents was tested as.

SE = $(2Me_1/r)^{0.5}$

CD = SE x 't' ('t' value at 5% and 1%)

Where, Me_2 = Error variation obtained from parents + F_1s; r = Number of replications.

Results and Discussion

Combining ability analysis

The present study revealed a significant contribution of both the additive and non-additive components of genetic variance for all the characters in the F_1 generation. All the characters showed highly significant variances due to GCA and SCA except SL in the F_1 generation. indicated additive, as well as non-additive genetic effects, were involved in determining of these traits. The ratio of average degree of dominance $(\delta^2s/\delta^2g)^{0.5}$ was observed to be more than the unity for all the characters except SL and NSplts/S in F_1 generation (Table 1), indicating that the major contribution was due to non-additive genetic variance in the expression of all the attributes. Similar results were also reported by Singh et al. [10] and Nageshwar et al. [11].

GCA effect

Evaluation of GCA is important for the selection of parents with superior performance. Genotypes PBW 757 followed by DBW 252, KRL 210 and HD 3298 for DH and PBW 757 followed by KRL 210 and HD 3298 for DM showed highly significant negative GCA effects and were found to be good general combiners for earliness. The findings of Nageshwar et al. [11] and Sharma et al. [12] were similar. Parents, namely, PBW 757 (-4.00), ATLAS (-2.63), HD 3298 (-1.21), and HD 3086 (-1.10) showed negative and highly significant GCA effects for PH they may contribute height reducing genes that could be beneficial in the development dwarf wheat variety. Genotype DBW 303, DBW 187 and HD 3086 show positive and highly significant GCA effects for the NPT, SL, NSplts/S (except HD 3086), G/S, BY, HI and GY indicating their ability as good general combiners for yield and yield contributing character. Similar findings were reported by Nageshwar et al. [11] and Raj and Kandalkar [13]. Positive and significant GCA effects were shown by parents namely, DBW 187 and ATLAS while positive and highly significant showed by HD 3086 and DBW 303 for 1000-GW. Genotype namely, KRL 210 showed positive and highly significant BY (Table 2, table 3, and figure 1). They were indicating good inbred with superior performance. Similar findings were reported by Nageshwar et al. [11] Raiyani et al. [14], Gupta et al. [15], Kumari et al. [16] and Chaudhary et al. [17].

SCA

The relative performance of a cross is related to non-additive gene activity, which is mostly contributed by dominance, epistasis, or genotype-environment interaction effects. On the basis of highly significant negative value of SCA effects top five cross namely, HD 3086 × DBW 252, KRL 210 × DBW 303, HD 3086 × ATLAS, HD 3298 × KRL 210 and DBW 187 × PBW for DH; HD 3298 × DBW 303, PBW 757 × DBW 303, DBW 187 × PBW 757, HD 3086 × DBW 252 and KRL 210 × DBW 252 for DM, these crosses were good in early flowering and early maturity; HD 3298 × KRL 210, DBW 252 × ATLAS, PBW 757 × DBW 303, ATLAS × DBW 303 and DBW 187 × HD 3298 for PH were found to be good specific combiners as well as a dwarf hybrid in F_1 generation (Table 4) similar result were reported by Nageshwar et al. [11]. On the basis of positive and significant value of SCA effect top five cross namely, DBW 252 × DBW 303, HD 3086 × PBW 757, HD 3298 × DBW 303, DBW 187 × ATLAS and DBW 187 × DBW 303 for NPT; HD 3086 × PBW 757, DBW 187 × DBW 252, DBW 252 × DBW 303, DBW 187 × ATLAS and DBW 187 × HD 3298 for SL; KRL 210 × DBW 252, KRL 210 × ATLAS, DBW 252 × DBW 303, PBW 757 × DBW 303 and DBW 187 × ATLAS for NSplts/S; HD 3086 × PBW 757, KRL 210 × PBW-757, DBW 252 × DBW 303, DBW 187 × ATLAS and DBW 187 × DBW 303 for G/S; KRL 210 × ATLAS, HD 3086 × ATLAS, HD 3298 × DBW

Table 1: ANOVA for combining ability for eleven characters in a set 8 × 8 parents diallel cross in bread wheat.

Source of variation	DH	DM	PH (cm)	NPT	SL (cm)	NSplts/S	G/S	1000-GW (g)	BY (g)	HI %	GY (g)
GCA	44.81**	115.26**	88.66**	29.33**	1.12**	6.45**	55.66**	9.85**	25.59**	13.88**	8.61**
SCA	6.52**	16.71**	22.24**	4.03**	0.16	0.83**	7.98**	6.85**	3.39**	5.19**	1.03**
Error	0.38	0.30	1.32	0.13	0.12	0.28	0.35	0.11	0.33	0.28	0.11
δ^2g	4.44	11.50	8.73	2.92	0.10	0.62	5.53	0.97	2.53	1.36	0.85
δ^2s	6.14	16.42	20.92	3.90	0.05	0.55	7.63	6.73	3.06	4.90	0.92
δ^2g/δ^2s	0.72	0.70	0.42	0.75	2.23	1.11	0.72	0.14	0.82	0.28	0.92
$(\delta^2s/\delta^2g)^{0.5}$	1.17	1.95	1.54	1.15	0.66	0.94	1.17	2.67	1.10	1.88	1.04

Note: Significant at 5% level (*); significant at 1% level (**); general combining ability (GCA); specific combining ability (SCA); average degree of dominance ($(\delta^2s/\delta^2g)^{0.5}$); ratio of GCA variance to SCA variance (δ^2g/δ^2s); days to 75% heading (DH); days to maturity (DM); plant height (cm) (PH); number of productive tillers per plant (NPT); spike length (cm) (SL); number of spikelets per spike (NSplts/S); number of grains per spike (G/S); 1000-grain weight (g) (1000-GW); biological yield per plant (g) (BY); harvest index (%) (HI); and grain yield per plant (g) (GY).

Table 2: Estimates of GCA effects of parents for eleven characters in a set 8 × 8 parents diallel cross in bread wheat.

Parents	DH	DM	PH (cm)	NPT	SL (cm)	NSplts/S	G/S	1000-GW (g)	BY (g)	HI %	GY (g)
HD 3086	3.13**	1.52**	-1.10**	0.95**	0.34**	0.07	1.75**	0.38**	1.08**	0.90**	0.69**
DBW 187	0.86**	4.86**	3.75**	1.64**	0.41**	0.82**	2.49**	0.25*	1.04**	1.56**	0.85**
HD 3298	-0.57**	-1.14**	-1.21**	-0.24*	-0.16	-0.39*	0.67**	0.08	0.12	-0.28	-0.05
KRL 210	-1.37**	-1.17**	0.61	-0.60**	-0.09	-0.37*	-0.21	-0.91**	0.71**	-1.41**	-0.07
DBW 252	-1.74**	0.03	-0.10	-1.63**	-0.16	-0.72**	-1.70**	-0.37**	-0.38*	-0.33*	-0.29**
PBW 757	-3.07**	-6.71**	-4.00**	-1.47**	-0.31**	-0.31*	-1.90**	-1.51**	-2.52**	-0.81**	-1.29**
ATLAS	0.33	-0.04	-2.63**	-1.64**	-0.43**	-0.68**	-3.88**	0.24*	-2.10**	-1.15**	-1.16**
DBW 303	2.46**	2.66**	4.69**	3.00**	0.40**	1.58**	2.77**	1.84**	2.06**	1.52**	1.31**
SE (gi)	0.18	0.16	0.34	0.11	0.10	0.16	0.17	0.10	0.17	0.16	0.10
SE (gi - gj)	0.275	0.244	0.515	0.163	0.153	0.236	0.264	0.149	0.257	0.238	0.146

Note: Significant at 5% level (*); significant at 1% level (**).

Table 3: Ranking of top three desirable parents based on GCA effect and per se performance for eleven characters in bread wheat.

Traits	Good general combiners based on the GCA effect	Desirable parents based on per se performance	Common parents based on GCA and per se performance
DH	PBW 757	PBW 757	PBW 757
	DBW 252	DBW 252	DBW 252
	KRL 210	HD 3298	-
DM	PBW 757	PBW 757	PBW 757
	KRL 210	HD 3298	KRL 210
	HD 3298	KRL 210	HD 3298
PH (cm)	PBW 757	ATLAS	PBW 757
	ATLAS	PBW 757	ATLAS
	HD 3298	HD 3086	-
NPT	DBW 303	DBW 303	DBW 303
	DBW 187	DBW 187	DBW 187
	HD 3086	HD 3086	HD 3086
SL (cm)	DBW 187	DBW 303	DBW 303
	DBW 303	DBW 187	DBW 187
	HD 3086	KRL 210	-
NSplts/S	DBW 303	DBW 303	DBW 303
	DBW 187	DBW 187	DBW 187
	HD 3086	HD 3086	HD 3086
G/S	DBW 303	DBW 303	DBW 303
	DBW 187	DBW 187	DBW 187
	HD 3086	HD 3086	HD 3086
1000-GW (g)	DBW 303	DBW 303	DBW 303
	DBW 187	DBW 187	DBW 187
	HD 3086	HD 3086	HD 3086
GY (g)	DBW 303	DBW 303	DBW 303
	DBW 187	DBW 187	DBW 187
	HD 3086	HD 3086	HD 3086
BY (g)	DBW 303	DBW 303	DBW 303
	DBW 187	HD 3086	HD 3086
	HD 3086	HD 3298	-
HI (%)	DBW 187	DBW 187	DBW 187
	DBW 303	DBW 303	DBW 303
	HD 3086	HD 3086	HD 3086

303, HD 3086 × DBW 303 and DBW 187 × DBW 252 for 100 grain weight; KRL 210 × ATLAS, HD 3086 × PBW 757, DBW 187 × DBW 303, DBW 187 × ATLAS and DBW 252 × DBW 303 for BY; PBW 757 × ATLAS, DBW 252 × PBW 757, DBW 187 × ATLAS, HD 3086 × DBW 303 and HD 3298 × DBW 252 for HI; DBW 187 × ATLAS, DBW 187 ×

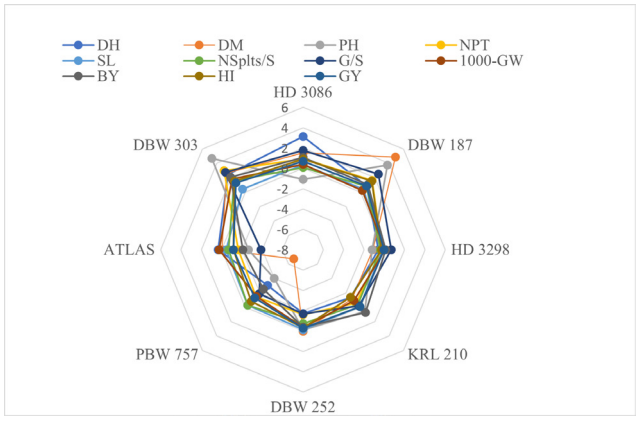


Figure 1: GCA for all 11 characters.

DBW 303, HD 3086 × PBW 757, KRL 210 × ATLAS and DBW 252 × DBW 303 for GY, these cross combinations may give high yields during hybrid seed production (Figure 2a and 2b). Similar results given by Nageshwar et al. [11], Gupta et al. [15], Kumari et al. [16], Chaudhary et al. [17] and Tayade et al. [18].

Heterosis

Heterosis breeding has come to play a pivotal role in crop improvement programs for obtaining higher production. The first important step in the exploitation of heterosis is to know its magnitude and direction. Heterosis was calculated in percent over economic parent (DBW 187), Mather and Jinks [19] in the F_1 generation for all eleven characters. Estimates of heterosis are presented in table 5. Negative and significant values of heterosis were considered desirable for DH, DM, and PH, on the other hand, positive and significant values were considered desirable for remaining characters.

In order of merit, the best five F_1 hybrids, which gave the highest performance over economic parent in relation to earliness includes. DBW 252 × PBW 757, KRL 210 × PBW 757, HD 3298 × KRL 210, DBW 187 × PBW 757 and HD 3086 × DBW 252 for DH; KRL 210 × PBW 757, PBW 757 × DBW 303, KRL 210 × PBW 757, HD 3298 × DBW 303 and DBW 187 × PBW 757 for DM, these hybrids were earlier in flowering and maturity over economic parent. The result was like Thomas et al. [20]. While PBW 757 × ATLAS, DBW 252 × ATLAS and HD 3298 × PBW 757, HD 3086 × ATLAS and DBW 252 × PBW 757 were in the order of merit for dwarfness, these crosses may contribute their dwarfness in future wheat hybrid seed development program. Cross combination DBW 187 × DBW 303, HD 3298 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303 and DBW 187 × KRL 210 were better for NPT; HD 3086 × PBW 757, DBW 187 × DBW 303, DBW 187 × DBW 252, HD 3086 × KRL 210 and DBW 187 × HD 3298 were found preferable for SL; DBW 187 × DBW 303, PBW 757 × DBW 303, HD 3298 × DBW 303, DBW 252 × DBW 303 and KRL 210 × DBW 252 hybrids are suitable for NSplts/S; DBW 187 × DBW 303 and DBW 187 × DBW 252 were found superior for G/S; KRL 210 × ATLAS, HD 3086 × DBW 303, HD 3298 × DBW 303, HD 3086 × ATLAS and DBW 187 × DBW 303 were found better for 1000-GW; DBW 187 × DBW 303, HD 3086 ×

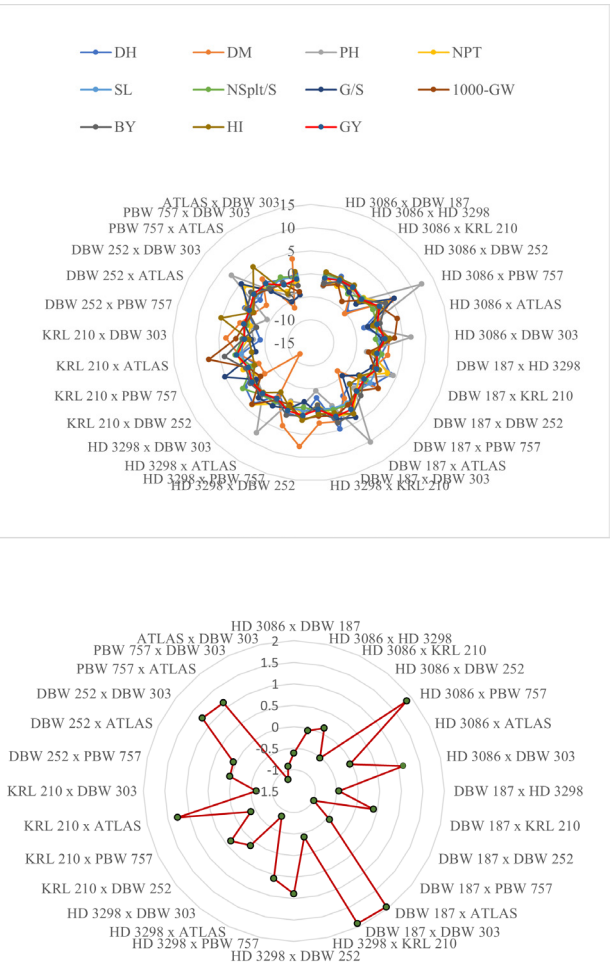


Figure 2: (a) SCA for all 11 characters and **(b)** SCA for GY.

DBW 303, DBW 252 × DBW 303, KRL 210 × DBW 303 and KRL 210 × ATLAS were in the order of merit for BY; HD 3086 × DBW 303, DBW 187 × DBW 303, DBW 252 × PBW 757, PBW 757 × ATLAS and DBW 187 × ATLAS were found superior for HI and DBW 187 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303 and DBW 187 × ATLAS were found best hybrids for GY. These above cross combinations can used to improve yield and yield-related characters in wheat. Similar results were observed by Desale and Mehta [21] and Kumar and Kerkhi [22].

Top five F_1 crosses showing the highest significant desirable amount of heterosis over better parent for yield in order of merit were PBW 757 × ATLAS, DBW 252 × ATLAS and HD 3298 × PBW 757, HD 3086 × ATLAS and DBW 252 × PBW 757 for PH, these crosses had dwarfness over better parent and may serve their height reducing gene in future wheat improvement program. DBW 187 × DBW 303, HD 3298 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303 and DBW 187 × KRL 210 for NPT; HD 3086 × PBW 757, DBW 187 × DBW 303, DBW 187 × DBW 252, HD 3086 × KRL 210, and DBW 187 × HD 3298 for SL; DBW 187 × DBW 303, PBW 757 × DBW 303, HD 3298 × DBW 303, DBW 252 × DBW 303 and KRL 210 × DBW 252 for NSplts/S; DBW 187 × DBW 303 and DBW 187 ×

Table 4: Estimates of SCA effects and per se performance of 28 F_1s for eleven characters in a set 8 × 8 parents diallel cross in bread wheat.

Crosses	DH		DM		PH (cm)		NPT		SL (cm)		NSplts/S	
	SCA	Per se	SCA	Per se	SCA	Per se	SCA	Per se	SCA	Per se	SCA	Per se
HD 3086 × DBW 187	-1.25**	85.33	-0.80**	134.33	-2.37**	92.97	-0.62**	13.70	-0.50**	11.67	0.15	20.93
HD 3086 × HD 3298	0.85**	86.00	-1.13**	128.00	-0.01	90.37	-1.48**	10.97	0.10	11.70	0.36	19.93
HD 3086 × KRL 210	-0.69**	83.67	-0.43*	128.67	-0.56	91.63	-0.35*	11.73	0.29*	11.97	-1.69**	17.90
HD 3086 × DBW 252	-4.65**	79.33	-5.30**	125.00	-0.89	90.60	0.05	11.10	-0.14	11.47	-0.12	19.13
HD 3086 × PBW 757	3.68**	86.33	4.77**	128.33	12.25**	99.83	3.55**	14.75	1.15**	12.60	0.25	19.90
HD 3086 × ATLAS	-3.05**	83.00	-0.23	130.00	-2.22**	86.73	-1.14**	9.90	-0.30*	11.03	-0.09	19.20
HD 3086 × DBW 303	2.15**	90.33	2.07**	135.00	6.79**	103.07	1.92**	17.60	-0.26	11.90	-0.91**	20.63
DBW 187 × HD 3298	0.45	83.33	1.87**	134.33	-2.73**	92.50	-1.43**	11.70	0.30*	11.97	0.60**	20.93
DBW 187 × KRL 210	3.58**	85.67	-0.43*	132.00	4.25**	101.30	2.84**	15.60	0.29*	12.03	-0.48*	19.87
DBW 187 × DBW 252	1.28**	83.00	2.70**	136.33	-1.51**	94.83	-2.27**	9.47	0.60**	12.27	-0.54*	19.47
DBW 187 × PBW 757	-2.72**	77.67	-6.57**	120.33	-1.40**	91.03	-0.59**	11.30	-0.45**	11.07	-0.14	20.27
DBW 187 × ATLAS	-1.45**	82.33	-0.90**	132.67	10.19**	104.00	2.84**	14.57	0.31*	11.70	0.66**	20.70
DBW 187 × DBW 303	4.75**	90.67	3.07**	139.33	-0.53	100.60	1.90**	18.27	0.04	12.27	0.37	22.67
HD 3298 × KRL 210	-2.99**	77.67	2.57**	129.00	-4.49**	87.60	-1.42**	9.47	-0.47**	10.70	-0.14	19.00
HD 3298 × DBW 252	1.38**	81.67	7.70**	135.33	-1.66**	89.73	0.84**	10.70	-0.23	10.87	-0.86**	17.93
HD 3298 × PBW 757	1.05**	80.00	4.10**	125.00	-1.58**	85.90	-1.28**	8.73	-0.11	10.83	-0.13	19.07
HD 3298 × ATLAS	-1.69**	80.67	-1.23**	126.33	7.78**	96.63	0.45**	10.30	0.24	11.07	-0.03	18.80
HD 3298 × DBW 303	3.18**	87.67	-11.60**	118.67	0.12	96.30	3.55**	18.03	0.28*	11.93	0.58**	21.67
KRL 210 × DBW 252	2.18**	81.67	-2.93**	124.67	-0.91*	92.30	-1.86**	7.63	-0.41**	10.77	2.79**	21.60
KRL 210 × PBW 757	-2.15**	76.00	-2.87**	118.00	-1.03*	88.27	0.81**	10.47	-0.22	10.80	-1.25**	17.97
KRL 210 × ATLAS	0.45	82.00	0.80**	128.33	0.76	91.43	0.95**	10.43	0.27	11.17	1.62**	20.47
KRL 210 × DBW 303	-4.02**	79.67	3.43**	133.67	-2.53**	95.47	-1.26**	12.87	-0.33*	11.40	-0.07	21.03
DBW 252 × PBW 757	-2.45**	75.33	0.93**	123.00	-1.59**	87.00	-1.39**	7.23	-0.48**	10.47	-0.67**	18.20
DBW 252 × ATLAS	1.15**	82.33	-1.07**	127.67	-4.30**	85.67	0.85**	9.30	-0.10	10.73	-0.47*	18.03
DBW 252 × DBW 303	-0.65**	82.67	-2.43**	129.00	7.54**	104.83	3.91**	17.00	0.57**	12.23	0.88**	21.63
PBW 757 × ATLAS	1.48**	81.33	2.33**	124.33	-0.79	85.27	-0.41**	8.20	-0.11	10.57	0.09	19.00
PBW 757 × DBW 303	0.01	82.00	-6.70**	118.00	-3.75**	89.63	-2.79**	10.47	0.26	11.77	0.67**	21.83
ATLAS × DBW 303	0.28	85.67	3.63**	135.00	-3.62**	91.13	-1.25**	11.83	-0.42**	10.97	-0.36	20.43
SE (Sij)	0.24	-	0.22	-	0.45		0.14	-	0.14	-	0.21	-
SE (Sij - Sik)	0.826	-	0.732	-	1.544	-	0.490	-	0.459	-	0.707	-

Crosses	G/S		1000-GW (g)		BY (g)		HI (%)		GY (g)	
	SCA	Per se	SCA	Per se	SCA	Per se	SCA	Per se	SCA	Per se
HD 3086 × DBW 187	0.67**	59.20	-2.28**	40.53	-1.83**	26.67	0.69**	45.60	-0.62**	45.60
HD 3086 × HD 3298	0.37	57.07	-1.01**	41.63	-0.38	27.20	0.40	43.47	-0.06	43.47
HD 3086 × KRL 210	-1.19**	54.63	-3.75**	37.90	-0.01	28.17	0.60**	42.53	0.13	42.53
HD 3086 × DBW 252	-2.14**	52.20	-0.70**	41.50	-0.55*	26.53	-1.09**	41.93	-0.52**	41.93
HD 3086 × PBW 757	5.50**	59.63	1.84**	42.90	3.36**	28.30	1.56**	44.10	1.86**	44.10
HD 3086 × ATLAS	-2.16**	50.00	4.46**	47.27	0.63**	26.00	-0.96**	41.23	-0.05	41.23
HD 3086 × DBW 303	0.56*	59.37	3.20**	47.60	0.98**	30.50	2.17**	47.03	1.11**	47.03
DBW 187 × HD 3298	-0.48*	56.97	-2.28**	40.23	-0.41	27.13	-1.06**	42.67	-0.45	42.67
DBW 187 × KRL 210	-0.64**	55.93	-0.09	41.43	0.30	28.43	1.07**	43.67	0.40**	43.67
DBW 187 × DBW 252	-2.42**	52.67	2.60**	44.67	-1.04**	26.00	-2.08**	41.60	-0.98**	41.60
DBW 187 × PBW 757	-5.04**	49.83	-0.56**	40.37	0.83**	25.73	-2.60**	40.60	-0.44**	40.60
DBW 187 × ATLAS	3.90**	56.80	0.76**	43.43	2.77**	28.10	3.04**	45.90	1.95**	45.90
DBW 187 × DBW 303	2.48**	62.03	1.73**	46.00	3.35**	32.83	1.11**	46.63	1.92**	46.63
HD 3298 × KRL 210	0.32	55.07	1.11**	42.47	-1.32**	25.90	0.64**	41.40	-0.40**	41.40
HD 3298 × DBW 252	-2.09**	51.17	1.67**	43.57	1.01**	27.13	1.96**	43.80	0.89**	43.80
HD 3298 × PBW 757	0.08	53.13	-0.69**	40.07	1.59**	25.57	-0.36	41.00	0.59**	41.00
HD 3298 × ATLAS	1.02**	52.10	-0.51**	42.00	-0.61**	23.80	-2.41**	38.60	-0.85**	38.60
HD 3298 × DBW 303	1.48**	59.20	3.46**	47.57	0.34	28.90	-0.05	43.63	0.12	43.63
KRL 210 × DBW 252	-0.72**	51.67	-1.87**	39.03	0.78**	27.50	0.19	40.90	0.37**	40.90
KRL 210 × PBW 757	4.99**	57.17	-0.46**	39.30	0.12	24.70	-1.83**	38.40	-0.39**	38.40
KRL 210 × ATLAS	-2.90**	47.30	7.42**	48.93	3.90**	28.90	-2.05**	37.83	1.27**	37.83
KRL 210 × DBW 303	-2.12**	54.73	1.22**	44.33	-0.23	28.93	-1.62**	40.93	-0.63**	40.93
DBW 252 × PBW 757	-0.09	50.60	-0.21	40.10	-2.78**	20.70	5.16**	46.47	0.03	46.47
DBW 252 × ATLAS	0.09	48.80	-0.96**	41.10	0.66**	24.57	-0.87**	40.10	0.06	40.10

DBW 252 × DBW 303	4.74**	60.10	1.05**	44.71	1.94**	30.00	1.33**	44.97	1.22**	44.97
PBW 757 × ATLAS	-0.91**	47.60	-0.28*	40.63	-0.27	21.50	5.65**	46.13	1.13**	46.13
PBW 757 × DBW 303	-5.19**	49.97	-1.05**	41.47	-0.66**	25.27	-3.39**	39.77	-1.20**	39.77
ATLAS × DBW 303	-4.38**	48.80	-3.70**	40.57	-2.32**	24.03	0.82**	43.63	-0.91**	43.63
SE (Sij)	0.23	-	0.13	-	0.23	-	0.21	-	0.13	-
SE (Sij - Sik)	0.792	-	0.447	-	0.771	-	0.713	-	0.439	-

Table 5: Percent heterosis over economic parent (DBW 187) for eleven characters in bread wheat.

Crosses	DH	DM	PH (cm)	NPT	SL (cm)	NSplts/S	G/S	1000-GW (g)	BY (g)	HI (%)	GY (g)
HD 3086 × DBW 187	4.06**	-3.36**	-4.39*	0.24	-2.23	-1.41	-1.39	-5.15**	0.76	0.22	0.83
HD 3086 × HD 3298	4.88**	-7.91**	-7.06**	-19.76**	-1.95	-6.12	-4.94**	-2.57*	2.77	-4.47*	-1.94
HD 3086 × KRL 210	2.03	-7.43**	-5.76**	-14.15**	0.28	-15.70**	-9.00**	-11.31**	6.42*	-6.52**	-0.56
HD 3086 × DBW 252	-3.25**	-10.07**	-6.82**	-18.78**	-3.91	-9.89*	-13.05**	-2.89*	0.25	-7.84**	-7.74*
HD 3086 × PBW 757	5.28**	-7.67**	2.67	7.95	5.59	-6.28	-0.67	0.39	6.93*	-3.08	3.59
HD 3086 × ATLAS	1.22	-6.47**	-10.80**	-27.56**	-7.54	-9.57*	-16.71**	10.61**	-1.76	-9.38**	-11.05**
HD 3086 × DBW 303	10.16**	-2.88**	6.00**	28.78**	-0.28	-2.83	-1.11	11.39**	15.24**	3.37	19.06**
DBW 187 × HD 3298	1.63	-3.36**	-4.87**	-14.39**	0.28	-1.41	-5.11**	-5.85**	2.52	-6.23**	-3.87
DBW 187 × KRL 210	4.47**	-5.04**	4.18**	14.14**	0.84	-6.43	-6.83**	-3.04*	7.43**	-4.03*	3.03
DBW 187 × DBW 252	1.22	-1.92*	-2.47	-30.73**	2.80	-8.32*	-12.27**	4.53**	-1.76	-8.57**	-10.23**
DBW 187 × PBW 757	-5.28**	-13.43**	-6.38**	-17.32**	-7.26	-4.55	-16.99**	-5.54**	-2.77	-10.77**	-14.09**
DBW 187 × ATLAS	0.41	-4.56**	6.96**	6.59	-1.95	-2.51	-5.39**	1.64	6.17*	0.88	6.90*
DBW 187 × DBW 303	10.57**	0.24	3.46*	33.66**	2.80	6.75	3.33*	7.65**	24.05**	2.49	27.07**
HD 3298 × KRL 210	-5.28**	-7.19**	-9.91**	-30.73**	-10.33**	-10.52**	-8.27**	-0.62	-2.14	-9.01**	-11.05**
HD 3298 × DBW 252	-0.41	-2.64**	-7.71**	-21.71**	-8.93*	-15.54**	-14.77**	1.95	2.52	-3.74*	-2.21
HD 3298 × PBW 757	-2.44*	-10.07**	-11.66**	-36.10*	-9.22*	-10.20**	-11.49**	-6.24**	-3.40	-9.89**	-12.99**
HD 3298 × ATLAS	-1.63	-9.11**	-0.62	-24.64**	-7.26	-11.46**	-13.21**	-1.72	-10.08**	-15.16**	-23.76**
HD 3298 × DBW 303	6.91**	-14.63**	-0.96	31.95**	0.00	2.04	-1.39	11.31**	9.19**	-4.10**	4.69
KRL 210 × DBW 252	-0.41	-10.31**	-5.07**	-44.15**	-9.77*	1.73	-13.94**	-8.66**	3.90	-10.11**	-6.63*
KRL 210 × PBW 757	-7.32**	-15.11**	-9.22**	-23.41**	-9.49*	-15.38**	-4.77**	-8.03**	-6.68*	-15.60**	-21.27**
KRL 210 × ATLAS	0.00	-7.67**	-5.97**	-23.66**	-6.42	-3.61	-21.21**	14.51**	9.19**	-16.85**	-6.36
KRL 210 × DBW 303	-2.85*	-3.84**	-1.82	-5.85	-4.47	-0.94	-8.83**	3.74**	9.32**	-10.04*	-1.66
DBW 252 × PBW 757	-8.13**	-11.51*	-10.52**	-47.08**	-12.29**	-14.28**	-15.71**	-6.16**	-21.79**	2.13	-19.62**
DBW 252 × ATLAS	0.41	-8.15**	-11.90**	-31.95**	-10.06**	-15.07**	-18.71**	-3.82**	-7.18**	-11.87**	-18.23**
DBW 252 × DBW 303	0.81	-7.19**	7.82**	24.39**	2.51	1.88	0.11	4.62**	13.35**	-1.17	11.88*
PBW 757 × ATLAS	-0.81	-10.55**	-12.31**	-40.00**	-11.45**	-10.52**	-20.71**	-4.91**	-18.77**	1.39	-17.68**
PBW 757 × DBW 303	0.00	-15.11**	-7.82**	-23.41**	-1.39	2.83	-16.77**	-2.96**	-4.53	-12.60**	-16.57**
ATLAS × DBW 303	4.47**	-2.88**	-6.27**	-13.42*	-8.10*	-3.77	-18.71**	-5.07**	-9.20**	-4.10**	-12.99*
SE ±	0.871	0.772	1.628	0.516	0.484	0.745	0.835	0.471	0.812	0.752	0.463
CD at 5%	1.799	1.594	3.361	1.066	1.000	1.538	1.724	0.972	1.678	1.553	0.957

Note: Significant at 5% level (*); significant at 1% level (**).

DBW 252 for G/S; KRL 210 × ATLAS, HD 3086 × DBW 303, HD 3298 × DBW 303, HD 3086 × ATLAS and DBW 187 × DBW 303 for 1000-GW; DBW 187 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303, KRL 210 × DBW 303 and KRL 210 × ATLAS for BY; HD 3086 × DBW 303, DBW 187 × DBW 303, DBW 252 × PBW 757, PBW 757 × ATLAS and DBW 187 × ATLAS for HI; DBW 187 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303 and DBW 187 × ATLAS for GY (Table 6 and table 7). Similar findings were observed by Desale and Mehta [21] and Ilker et al. [23] for NPT, Patil et al. [24] for SL, Thomas et al. [20] for DM and NSplts/S, Kumar and Kerkhi [22] for PH, Shrief et al. [25] for GY and G/S and Murugan and Kannan [26] for 1000-GW (Figure 3).

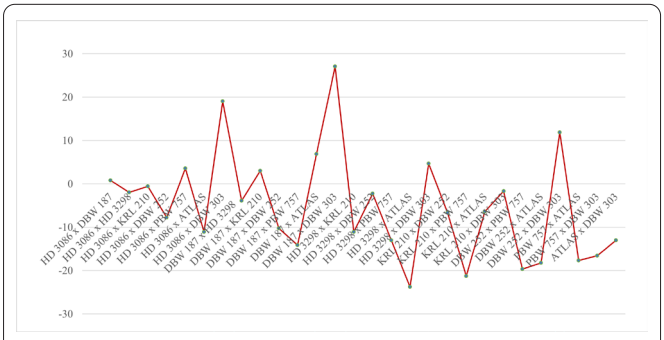


Figure 3: Economic heterosis for GY.

Table 6: Ranking top three desirable combinations based on SCA effect and per se performance for eleven characters in bread wheat.

Traits	Good specific combiners based on SCA effect	Superior crosses on the basis of per se performance
DH	HD 3086 × DBW 252, KRL 210 × DBW 303 and HD 3086 × ATLAS	DBW 252 × PBW 757, KRL 210 × PBW 757 and DBW 187 × PBW 757
DM	HD 3298 × DBW 303, PBW 757 × DBW 303 and DBW 187 × PBW 757	KRL 210 × PBW 757, HD 3298 × DBW 303 and DBW 187 × PBW 757
PH (cm)	HD 3298 × KRL 210, DBW 252 × ATLAS and PBW 757 × DBW 303	PBW 757 × ATLAS, DBW 252 × ATLAS and HD 3298 × PBW 757
NPT	DBW 252 × DBW 303, HD 3298 × DBW 303 and DBW 187 × ATLAS	DBW 187 × DBW 303, HD 3298 × DBW 303 and DBW 252 × DBW 303
SL (cm)	HD 3086 × PBW 757, DBW 187 × DBW 252 and DBW 252 × DBW 303	HD 3086 × PBW 757, DBW 187 × DBW 303 and DBW 252 × DBW 303
NSplts/S	KRL 210 × DBW 252, KRL 210 × ATLAS and DBW 252 × DBW 303	DBW 187 × DBW 303, PBW 757 × DBW 303 and DBW 252 × DBW 303
G/S	HD 3086 × PBW 757, KRL 210 × PBW 757 and DBW 252 × DBW 303	DBW 187 × DBW 303, DBW 252 × DBW 303 and HD 3086 × DBW 303
1000-GW (g)	HD 3086 × ATLAS, HD 3298 × DBW 303 and HD 3086 × DBW 303	KRL 210 × ATLAS, HD 3298 × DBW 303 and HD 3086 × DBW 303
GY (g)	DBW 187 × ATLAS, DBW 187 × DBW 303 and HD 3086 × PBW 757	DBW 187 × DBW 303, HD 3086 × DBW 303 and DBW 252 × DBW 303
BY (g)	KRL 210 × ATLAS, HD 3086 × PBW 757 and DBW 187 × DBW 303	DBW 187 × DBW 303, HD 3086 × DBW 303 and DBW 252 × DBW 303
HI (%)	PBW 757 × ATLAS, DBW 252 × PBW 757 and DBW 187 × ATLAS	HD 3086 × DBW 303, DBW 252 × PBW 757 and PBW 757 × ATLAS

Table 7: Significant economic crosses for GY in order to merit and their performance in related parameters in wheat.

Genetic parameter	Crosses			
Mean performance	**HD 3086 × DBW 303**	**DBW 187 × ATLAS**	**DBW 187 × DBW 303**	**DBW 252 × DBW 303**
EP	12.07	12.07	12.07	12.07
F_1	14.37	12.90	15.33	13.50
Heterosis % over economic parents	19.06**	6.90**	27.07**	11.88**
Other traits for this cross exhibited desirable heterotic response over economic parent	II**, IV**, VIII**, IX**, XI**	II**, IX**, XI*	IV**, VII* VIII**, IX**, XI**	II**, IV**, VIII**, IX**, XI*
GCA effect	-	-	-	-
P_1	0.69**	0.85**	0.85**	-0.29**
P_2	1.31**	-1.16**	1.31**	1.31
SCA effect	2.15**	-1.45**	4.75**	-0.65**
Other characters for this cross showed desirable SCA effects	IV**, VII*, VIII**, IX**, X**, XI**	I**, II*, IV**, V*, VI**, VII**, VIII**, IX**, X**, XI**	III**, IV**, VII*, VIII**, IX**, X** XI**	I**, II**, IV**, V**, VI**, VII**, VIII**, IX**, X**, XI**

Conclusion

The combining ability analysis provides useful information in screening desirable strains and their cross combinations for their utilization. Such knowledge is a pre-requisite in order to frame a systematic breeding program leading to rapid and sustained improvement. GCA is the measurement to determine the potentiality of the parent/progenies for mobilizing them in appropriate hybridization programs through per se performance, and hybrid performance. The GCA effects of various characters and their mean values of parents indicate that there was a close relationship between parental mean performance and GCA effects for almost all the characters. Based on the GCA effect and per se performance parents namely, DBW 303, DBW 187, and HD 3086 observed good combiner for yield and yield contributed trait. A breeding program could further exploit these parents for improved grain yield and quality attributes. SCA is rarely used in the improvement of autogamous crops except where there is a possibility of commercial exploitation of heterosis. Significant yield performance in the specific crosses was due to the involvement of the best general combiners in our study. Based on the SCA effect and per se performance crosses namely, DBW 187 × ATLAS, DBW 187 × DBW 303, HD 3086 × PBW 757 for GY and some other characters. These crosses could be further exploited in a breeding program for improved grain yield and quality attributes. On the basis of heterosis over an economic parent, mean performance GCA and SCA Four cross combinations namely, DBW 187 × DBW 303, HD 3086 × DBW 303, DBW 252 × DBW 303, and DBW 187 × ATLAS were observed desirable with highly significant value over economic parent DBW 187.

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Conflict of Interest

None.

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