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COMBINING ABILITY AND HETEROSIS ANALYSIS FOR GRAIN YIELD TRAITS IN FINE LONG GRAIN RICE (*ORYZA SATIVA* L.)

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ABSTRACT

Experiment was conducted to study combining ability and heterosis for major yield traits namely days to 50% flowering (DF50), growth duration (GD), plant height (PH), effective panicles per plant (EP/Pl), panicle length (PL), grains per panicle (G/P), filled grains/panicle (FG/P), seed setting rate (SSR), 1000-grains weight (TGW), grain yield/plot (GY/plot), grain yield/hectare (GY/ha). From Griffing's analysis maximum general combining ability was found in L-203, CB-15 and CB-42 for PL, SSR, PH and G/P. The maximum specific combining ability was found in L-203 × CB-42 for PH, L-203 × Jasmine-85 for G/P, FG/P and CB-15 × CB-40 for GY/ha. The results revealed that for hybrid breeding, maximum heterosis could be exploited in crosses 'Jasmine-85 × CB-42', 'CB-15 × CB-42' and 'Jasmine-85 × CB-15' for major yield related traits. Taken together the results suggested potential use of the parents/crosses used herein for breeding commercial hybrid rice varieties as well as for the enhancement of the germplasm resources.

Keywords: Rice, Combining Ability, Heterosis, Traits, Diallel, Hybridization.

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INTRODUCTION

Rice ranks as 2nd most important staple food crop worldwide likely to feed > 50% of global population and supplements > 20 % of their daily requirements (Seck *et al*., 2012; FAO, 2018). Grain yield in cereals is determined by various quantitative characters including grain weight, grain numbers per panicle and panicles *per se* (Zhang, 2007; Sajjad *et al*., 2017). To ensure food security for exponentially increasing population a significant increase in rice yield potential is indispensible as the area under cultivation is decreasing due to urbanization and industrialization. Thus far, 3.1% decrease in area and 3.3% decrease in production have been observed in Pakistan (Anonymous, 2018-19), therefore we need to promote breeding and cultivation of single cross rice hybrids to ensure future food security.

Heterosis and combining ability are the key strategies/methods for increasing the yield potential of the crop and its utilization in breeding programmes that ensure the success rate of the experiment and identification of new potential rice lines for breeding hybrid varieties (Haung *et al*., 2015). To assess the genetic potential of parental combination heterosis breeding is a fundamental tool for the expression of commercial exploitation of heterosis in the changing environment with the desired characteristics.

On the other hand, conventional breeding approach enhances the chances of selection, screening, identification and development of high yielding hybrids and exploitation of their specific combining ability in a series of potential combinations (Melchinger *et al*., 2008; Gartner *et al*., 2009; Xangsayasane *et al*., 2010). Plant breeders have the desire to produce high yielding hybrids with better characteristics over the parents on the basis of their diversity. In plant breeding experiments diallel analysis is the most powerful tool for the estimation of the general combining ability (GCA), specific combining ability (SCA) and the exploitation of the heterosis (Bhatti *et al*., 2015; Fasahat *et al*., 2016). Heterosis is the hybridization of genetically two different parents used for the production of new offspring and plant breeders face major challenge to sort out the best combinations from the thousand crosses (Gartner *et al*., 2009). Selection of hybrids based on breeding strategies that required expected level of heterosis, performance of F_1 hybrids and choice of the diverse parents. Several methods tried for this purpose i.e. performance, genetic diversity, morphological and agronomic traits, geographical origin, molecular analysis, combining ability, but in general assumption is that high yielding hybrids comes from the high yielding parents and low yielding from low yielding parents (Tiwari *et al*., 2011). Plant breeders are working on this task with different breeding programs and to establish an efficient breeding method for the determination of mode of gene action is very crucial to the success of program. The analysis of combining ability help with the screening of specific parents for hybridization and then selection of promising hybrids among several cross combinations so GCA and SCA is very important for the efficient breeding program (Fischer *et al*., 2008). One of the most powerful tool to estimate the combining ability is Diallel analysis and also for the estimation of heterosis in different cross combinations.

The research objectives of the study were to (1) To analyze the combining ability effect for yield and yield related traits for the hybrids and their specific parents (2) To evaluate the yield performance of different heterotic combinations.

MATERIALS AND METHODS

Plant Material: Fine long grain rice lines L-203, Jasmine-85, CB-15, CB-40 and CB-42 were used in this experiment. The lines L-203 and Jasmine-85 were exotic, collected from USDA Arkansas, USA and the lines CB-15, CB-40 and CB-42 were local, collected from Rice Research Institute (RRI) Kala Shah Kaku. These five parents were crossed in diallel fashion including parents and direct crosses which produced 15 entries i.e. 10 crosses and 5 parents in a Randomized Complete Block Design (RCBD) with three replications at field area of Institute of Agricultural Sciences (IAGS), University of Punjab Lahore in 2018. The seeds of the parents and their crosses are shown in the figure 1.

Diallel Crosses: At the time of panicle emergence stage, all the five genotypes were crossed in a half diallel fashion to produce F_1 seed excluding reciprocal crosses to get the maximum seed during the year 2018. For further genetic studies, the various traits of parents and hybrids were analyzed to determine the combining ability and heterosis (mid parent and better parent). A replication comprised of 15 entries (10 F_1+5parents) and data of five plants were recorded randomly from each entry to differentiate the parents and hybrids on the basis of their traits studied during the experiment in the year 2019.

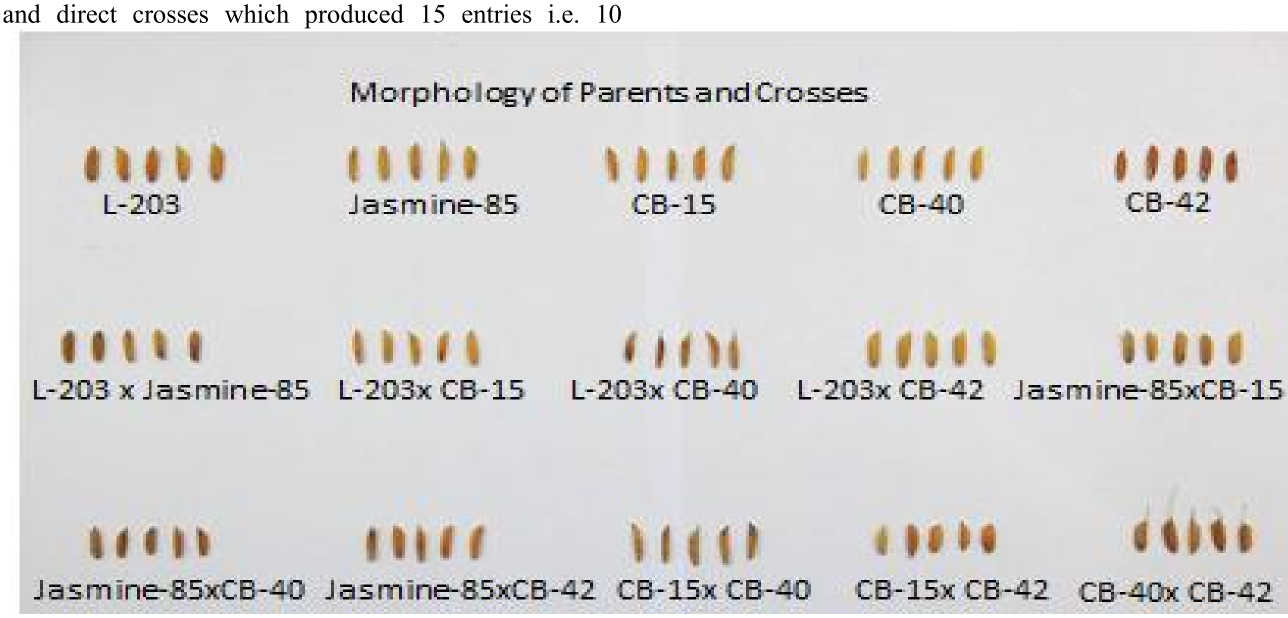

Figure 1. Seed Morphology of Parents and Their Crosses

Nursery Preparation: The seeds of all the genotypes along with crosses were treated with fungicides i.e. Topson M (Nippon Chemical Industrial Co., Ltd, Japan) 2gm fungicides is required for 1 kg seeds. Before sowing seeds were soaked with mixed fungicides water for 24 hours. After this seeds of each line were separately sown under puddled field condition through broadcasting method. The seeds were sown in three sets after one week interval. After 25 days nursery of each rice line was prepared for transplantation in to the next field.

Transplantation and recording observation: Nursery of each rice line was transplanted in RCBD design with three replications in a diallel fashion. The distance between row to row and plant to plant was kept 22.5 x 22.5 cm^2. At the time of maturity and after harvesting data of different plant parameters were recorded i.e. Days to 50% flowering (DF50), growth duration (GD, days), plant height (PH,cm), effective panicles per plant (EP/P), panicle length (PL, cm), grains per panicle (G/P), filled grains/panicle (FG/P), seed setting rate (SSR, %), 1000 grains weight (TGW, g), grain yield per plot (GY/plot, kg/10m^2), grain yield per hectare (GY/ ha, Kg/ ha). All the recorded observations were analyzed by using (Griffing, 1956) approach.

Statistical Analysis: The data recorded on the 10 F_1 hybrids plant population and 5 parents were subjected to study the variances between parents and their respective crosses by using statistical analysis SAS version 9.2. Five plants data of each parent and their respective crosses were recorded randomly for further genetic analysis on the basis of various morphological traits. Variance analysis of different morphological traits was done by (Steel *et al*., 1997). General combining ability and specific combining ability was also calculated by Grifing,s approach (1956). Heterosis was calculated by using following formulas described by (Dan *et al*., 2014).

$$\text{Mid Parent Heterosis} = \frac{(\text{F1 - Mid Parent})}{\text{Mid Parent}} \times 100$$

$$\text{Better Parent Heterosis} = \frac{(\text{F1 - Better Parent})}{\text{Better Parent}} \times 100$$

RESULTS

Analysis of variance of different genotypes and their crosses were analyzed at the time of maturity all the genotypes showed positive significant results along with desired traits for genotypes, general combining ability and specific combining ability except DF50 (Table 1).

Days to 50% flowering: General combining ability effects for this character were non-significant (Table 2) but crosses L-203 × CB-42 and CB-15 × CB-40 showed positive and highly significant results of 4.24 and 3.10 respectively but in rice early maturing verities are desired so the crosses with negative significant GCA effects are desired which were 'CB-40 × CB-42' and 'L-203 × Jasmine-85' with GCA effects of -2.48 and -1.62, respectively (Table 3). For mid parent heterosis and heterosis over better parent, 'L-203 × CB-42' cross showed positive significant results of 5.91% and 5.26%, respectively but no cross exhibited significant and negative heterosis for DF50 (Table 4).

Growth duration (GD, days): Early maturing varieties are favored in rice crop so parents with negative and significant general combing ability effects were selected i.e. L-203 and Jasmine-85 which showed GCA effects value of -3.69 and -2.26 respectively (Table 2). CB-42, CB-40 and CB-15 showed positive significant value of 2.65, 2.08 and 1.22 respectively. While crosses CB-42 × CB-40, CB-15 × CB-40, CB-15 × CB-42 and L-203 × CB-42 showed highly significant and negative SCA effects of -6.97, -5.21. -5.11 and -4.54 respectively but no cross showed positive significant results for growth duration (Table 3). All the crosses showed negative and highly significant results for growth duration except L-203 × Jasmine-85, while some promising crosses for mid parent heterosis were CB-40 × CB-42, CB-15 × CB-42 and CB-15 × CB-40 with the value of -12.37%, -10.16% and -9.73% respectively. Crosses L-203 × CB-42, CB-40 × CB-42, Jasmine-85 × CB-42 showed desirable results for heterosis over better parent value of -15.89%, -13.28% and -13.02% respectively (Table 4).

Plant height (PH, cm): Parents CB-40, Jasmine-85 and L-203 showed significant and negative results of -3.80, -3.18 and -1.80 respectively which are desirable for the trait of plant height in rice since short statured plants are less prone to lodging and uptake nutrients more efficiently (Table 2). While crosses L-203 × CB-40, L-203 × CB-15, CB-15 × CB-40 and CB-15 × CB-42 showed significant and negative results of -14.89, -6.75, -6.75 and -2.60 respectively while all the other crosses showed positive and significant results for plant height (Table 3). All the crosses showed significant results for plant height except L-203 × CB-15 for mid parent heterosis but crosses with negative value were desired which are L-203 × CB-40 and CB-15 × CB-40 with heterosis over better parent value of -14.25%, -12.85% and -11.60% respectively (Table 4).

Effective panicles per plant (EP/Pl): Among parents L-203 showed positive significant results with GCA effect value of 0.89 while all other parents showed non-significant results (Table 2). Among crosses L-203 × CB-15 showed significant and negative result and L-203 × CB-40 and CB-40 × CB-42 showed non-significant results while all other crosses showed positive significant results and were desirable for effective panicles per plant (Table 3). Jasmine-85 × CB-42, Jasmine-85 × CB-15 and CB-15 × CB-42 showed highly significant and positive results for both mid parent heterosis and heterosis over better parent for effective panicles per plant (Table 4).

Panicle length (PL, cm): General combining ability effects showed positive and significant results for L-203 and CB-40 with GCA value of 1.22 and 1.08 respectively (Table 2). Specific combining ability results showed CB-15 × CB-42, CB-40 × CB-42, Jasmine-85 × CB-15 and Jasmine-85 × CB-42 were positive and significant with SCA values of 3.00, 2.76, 1.86 and 1.67 respectively (Table 3). For heterosis over mid parent crosses CB-15 × CB-42, Jasmine-85 × CB-42 and CB-40 × CB-42 showed positive significant results with values of 23.19%, 16.31% and 14.65% respectively. The cross CB-15 × CB-42 showed positive heterosis over better parent value of 16.44%, while all other crosses showed negative non-significant results (Table 4).

Grains per panicle (G/P): Among parents CB-42 showed positive significant results of 3.27 while other parents showed non-significant and negative results for general combining ability effects (Table 2). Among crosses Jasmine-85 × CB-15 and L-203 × Jasmine-85 showed positive and highly significant results and specific combining ability values of 23.67 and 23.05 respectively while all other crosses showed non-significant and negative values for SCA effects (Table 3). L-203 × Jasmine-85 and Jasmine-85 × CB-15 showed highly significant and positive results for both mid parent heterosis and better parent heterosis (Table 4).

Filled grains per panicle (FG/P): All the parents showed negative and non-significant results for GCA effects (Table 2), on the other hand positive and significant results were observed in crosses Jasmine-85 × CB-15 and L-203 × Jasmine-85 with SCA effect value of 16.05 and 12.57 respectively (Table 3). For heterosis over mid parent crosses Jasmine-85 × CB-15 and L-203 × Jasmine-85 showed positive significant results with value of 11.53% and 8.39% respectively while only one cross Jasmine-85 × CB-15 was observed to show significant and positive better parent heterosis value of 9.34% (Table 5).

Seed setting rate (SSR, %): General combing ability effects were observed and 2 parents L-203 and Jasmine-85 showed positive significant results with GCA effect value of 2.13 and 0.95 respectively (Table 2). In crosses Jasmine-85 × CB-40, L-203 × CB-40, CB-15 × CB-40 and L-203 × CB-15 observed significant and positive results with SCA effect value of 7.04, 4.07, 2.19 and 1.77 respectively (Table 3). Jasmine-85 × CB-40, L-203 × CB-40 and CB-15 × CB-40 showed significant and positive results with value of 11.09%, 8.60% and 6.36% respectively for mid parent heterosis but no cross showed the significant and positive better parent heterosis for seed setting rate (Table 5).

1000 grain weight (TGW, g): General combining ability effects were observed in CB-42, Jasmine-85 and CB-40 with significant and positive value of 0.71, 0.35 and 0.12 respectively (Table 2). Among crosses Jasmine-85 × CB-40, L-203 × CB-42, L-203 × CB-40 and CB-15 × CB-42 showed positive and significant SCA effects value of 2.74, 2.48, 0.89 and 0.81 respectively for 1000 grain weight (Table 3). For mid parent heterosis positive significant results were observed in crosses L-203 × CB-42, Jasmine-85 × CB-40 and L-203 × CB-40 with value of 11.25%, 10.42% and 7.07% respectively. One cross Jasmine-85 × CB-40 showed positive significant value of 5.25% for better parent heterosis while all other crosses showed non-significant and negative results (Table 5).

Grain Yield/plot (GY/plot, Kg/10m^2): Among parents CB-15 and CB-40 showed positive significant results with GCA effects value of 0.30 and 0.10 respectively (Table 2) while crosses CB-15 × CB-40, Jasmine-85 × CB-42, CB-15 × CB-42 and L-203 × Jasmine-85 showed positive significant results for specific combining ability effects with values 1.26, 087, 0.72 and 0.23 respectively (Table 3). For heterosis over mid parent crosses Jasmine-85 × CB-42, CB-15 × CB-40 and CB-15 × CB-42 showed positive and significant results. Crosses CB-15 × CB-40, Jasmine-85 × CB-42, CB-15 × CB-42 and Jasmine-85 × CB-15 showed positive significant results for heterosis over better parent with values of 10.11%, 7.81%, 6.75% and 3.22% respectively (Table 5).

Grain Yield/hectare (GY/ha, Kg/ha): Positive and significant results were observed in parents CB-15 and CB-40 with general combining ability effects value of 296.87 and 95.51 respectively (Table 2). While crosses CB-15 × CB-40, Jasmine-85 × CB-42, CB-15 × CB-42, L-203 × CB-42 and L-203 × Jasmine-85 showed positive and significant specific combining ability effects of 1242.21, 857.84, 711.52, 557.68 and 222.69 respectively (Table 3). For heterosis over mid parent crosses Jasmine-85 × CB-42, CB-15 × CB-40 and CB-15 × CB-42 showed positive and significant results. Crosses CB-15 × CB-40, Jasmine-85 × CB-42, CB-15 × CB-42 and Jasmine-85 × CB-15 showed positive significant better parent heterosis value of 25.22%, 21.63%, 15.62% and 7.42% respectively for the trait yield per acre (Table 5).

Table 1. General and specific combining ability analysis of mean square values of all the traits studied in the experiment.

S.O.V	D.F	DF50	GD	PH	EP/Pl	PL	G/P	FG/P	SSR	TGW	GY/plot	GY/ha
Rep.	2	1.41 NS	1.09 NS	20.70**	0.55 NS	1.27 NS	110.06**	33.80**	9.76**	0.13 NS	0.03 ^{ns}	35349.33^{ns}
Genotype	14	10.96**	118.55**	872.14**	17.35**	18.09**	836.70**	313.29**	57.60**	9.97**	1.43*	1395715**
GCA	4	0.62NS	55.09**	122.34**	2.19**	7.91**	53.80**	14.34**	23.97**	2.42**	0.29*	284737.12**
SCA	10	4.87*	33.28**	358.06**	7.22**	5.28**	368.94**	140.46**	17.30**	3.68*	0.55*	537452.62**
Error	28	1.60	2.34	1.82	0.75	0.73	9.59	10.65	1.60	0.02	0.01	13838.23

Level of significance at 1% and 5%

DF50%= Days to 50% Flowering, GD= Growth Duration (days), PH= Plant Height (cm), EP/P= Effective Panicles per Plant, PL= Panicle Length (cm), G/P= Grains per Panicle, FG/P= Filled Grains/Panicle, SSR= Seed Setting Rate (%), TGW= 1000 Grains weight (g), Grain Yield/plot= (kg/10m^2), Y/H= Grain Yield/hectare (Kg/ ha)

Table 2. Estimates of general combining ability effects of the parents.

Parents	DF50%	GD	PH	EP/P	PL	G/P	FG/P	SSR	TGW	GY/plot	GY/ha
L-203	0.09NS	-3.69**	-1.80**	0.89**	1.22**	-3.92**	-0.10NS	2.13**	-0.75**	-0.18**	-174.55**
Jasmine-85	0.47 NS	-2.26**	-3.18**	0.22NS	-0.50NS	0.08NS	1.52NS	0.95*	0.35**	-0.03NS	-33.87NS
CB-15	-0.30 NS	1.22*	5.72**	-0.30NS	-0.83**	-1.21NS	0.43NS	0.80NS	-0.42**	0.30**	296.87**
CB-40	-0.20 NS	2.08**	-3.80**	-0.45NS	1.08**	1.79NS	-2.33**	-2.02**	0.12*	0.10*	95.51*
CB-42	-0.06 NS	2.65**	3.06**	-0.35NS	-0.97**	3.27**	0.48NS	-1.87**	0.71**	-0.19**	-183.96**

Level of significance at 1% and 5%

DF50= Days to 50% Flowering, GD= Growth Duration (days), PH= Plant Height (cm), EP/P= Effective Panicles per Plant, PL= Panicle Length (cm), G/P= Grains per Panicle, FG/P= Filled Grains/Panicle, SSR= Seed Setting Rate (%), TGW= 1000 Grains weight (g), Grain Yield/plot= (kg/10m^2), GY/ha= GrainYield/hectare (Kg/ ha)

Table 3. Estimates of specific combining ability effects of hybrids.

Crosses	DF50%	GD	PH	EP/P	PL	G/P	FG/P	SSR	T GW	GY/plot	GY/ha
L-203 × Jasmine-85	-1.62**	1.03^{NS}	5.49**	1.98**	0.48^{NS}	23.05**	12.57**	-5.14**	-2.03**	0.23**	222.69**
L-203 × CB-15	0.86^{NS}	-0.78^{NS}	-6.75**	-1.16**	0.14^{NS}	-16.00**	-12.33**	1.77**	-0.03^{NS}	-0.67**	-664.63**
L-203 × CB-40	-1.29*	-1.30^{NS}	-14.89**	-0.02^{NS}	-0.43^{NS}	-11.00**	-2.90^{NS}	4.07**	0.89**	-0.43**	-420.45**
L-203 × CB-42	4.24**	-4.54**	39.92**	1.22**	-0.38^{NS}	-8.81**	-9.05**	-0.90^{NS}	2.48**	0.52**	517.68**
Jasmine-85 × CB-15	-1.24*	-0.21^{NS}	7.97**	1.84**	1.86**	23.67**	16.05**	-3.14**	-0.97**	0.08^{NS}	80.61^{NS}
Jasmine-85 ×CB-40	0.67^{NS}	-2.40**	14.16**	1.32**	-2.38**	-30.67**	-16.86**	7.04**	2.74**	-0.23**	-231.79**
Jasmine-85 × CB-42	-1.14*	-2.30**	10.63**	3.56**	1.67**	-2.14^{NS}	-5.67**	-2.55**	-2.39**	0.87**	857.84**
CB-15 × CB-40	3.10**	-5.21**	-6.75**	1.51**	-2.71**	-16.05**	-9.76**	2.19**	-0.19**	1.26**	1242.21**
CB-15 × CB-42	1.29*	-5.11**	-2.60**	2.41**	3.00**	-0.86^{NS}	-2.90^{NS}	-1.44*	0.81**	0.72**	711.52**
CB-40 × CB-42	-2.48**	-6.97**	5.25**	-0.11^{NS}	2.76**	1.14^{NS}	1.52^{NS}	-0.15^{NS}	-2.77**	-0.43**	-420.92**

Level of significance at 1% and 5%

DF50= Days to 50% Flowering, GD= Growth Duration (days), PH= Plant Height (cm), EP/P= Effective Panicles per Plant, PL= Panicle Length (cm), G/P= Grains per Panicle, FG/P= Filled Grains/Panicle, SSR= Seed Setting Rate (%), TGW= 1000 Grains weight (g), Grain Yield/plot= (kg/10m^2), GY/ha= GrainYield/hectare (Kg/ ha)

Table 4. Heterosis over mid parent and better parent for yield and yield related agronomic traits of rice

Traits	DF50%		GD		PH		EP/P		PL		G/P	
Crosses	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**
L-203 × Jasmine-85	-2.79 ^{NS}	-4.31^{NS}	-1.22^{NS}	-2.11 ^{NS}	19.69**	14.33**	46.67**	18.92^{NS}	3.03^{NS}	-4.49^{NS}	16.13**	14.03**
L-203 × CB-15	-0.20 ^{NS}	-1.21 ^{NS}	-4.35*	-9.34**	-2.23^{NS}	-12.85**	4.76^{NS}	-10.81^{NS}	2.47^{NS}	-6.74^{NS}	-14.41**	-15.45**
L-203 × CB-40	-1.42 ^{NS}	-1.62 ^{NS}	-5.70**	-11.97**	-8.18**	-11.60**	10.77^{NS}	-2.70^{NS}	-3.87^{NS}	-5.43^{NS}	-17.28**	-24.91**
L-203 × CB-42	5.91 **	5.26*	-9.01**	-15.89**	54.20**	50.75**	35.59**	8.11^{NS}	5.19^{NS}	-8.99*	-9.52**	-13.28**
Jasmine-85 × CB-15	-1.81 ^{NS}	-4.31 ^{NS}	-3.45*	-7.69**	12.69**	-3.50**	63.27**	53.85**	11.41*	9.21^{NS}	16.95**	13.47**
Jasmine-85 ×CB-40	-0.20 ^{NS}	-1.96 ^{NS}	-6.21**	-11.70**	20.84**	11.33**	49.02**	35.71**	-9.52*	-17.39**	-25.62**	-33.58**
Jasmine-85 × CB-42	-1.80 ^{NS}	-3.92 ^{NS}	-6.70**	-13.02**	32.16**	29.06**	100.00**	95.65**	16.31**	7.89^{NS}	-0.88^{NS}	-6.64**
CB-15 × CB-40	4.51 *	3.66 ^{NS}	-9.73**	-11.17**	-7.09**	-14.25**	37.04**	32.14*	-10.30*	-19.57**	-19.60**	-26.20**
CB-15 × CB-42	2.88 ^{NS}	2.46 ^{NS}	-10.16**	-12.50**	6.95**	-6.54**	66.67**	53.85**	23.19**	16.44**	-3.74^{NS}	-6.64**
CB-40 × CB-42	-2.45 ^{NS}	-2.85 ^{NS}	-12.37**	-13.28**	15.84**	9.12**	28.00*	14.29^{NS}	14.65**	-2.17^{NS}	-9.18**	-14.21**

Level of significance at 1% and 5%

Ht= mid parent heterosis, Hbt= better parent heterosis;

DF50= Days to 50% Flowering, GD= Growth Duration (days), PH= Plant Height (cm), EP/P= Effective Panicles per Plant, PL= Panicle Length (cm), G/P= Grains per Panicle,

Table 5. Heterosis over mid parent and better parent for yield and yield related agronomic traits of rice.

Traits	FG/P		SSR		TGW		GY/plot		GY/ha	
Crosses	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**	**Ht%**	**Hbt%**
L-203 × Jasmine-85	8.39**	6.13^{NS}	-6.68**	-6.96**	-11.54**	-19.69**	3.79*	2.51^{NS}	6.59*	3.31^{NS}
L-203 × CB-15	-12.88**	-12.99**	1.71^{NS}	0.36^{NS}	1.00^{NS}	-2.79*	-5.02**	-5.30*	-7.02**	-7.70*
L-203 × CB-40	-9.31**	-10.50**	8.60**	-0.21^{NS}	7.07**	1.72^{NS}	-4.85**	-7.00**	-7.85**	-10.00**
L-203 × CB-42	-11.62**	-12.68**	-2.47^{NS}	-5.42**	11.25**	0.32^{NS}	5.11**	4.65^{NS}	16.11**	5.82^{NS}
Jasmine-85 × CB-15	11.53**	9.34*	-4.67*	-5.65**	-8.15**	-13.57**	6.62**	3.22*	11.62**	7.42*
Jasmine-85 ×CB-40	-16.54**	-19.33**	11.09**	2.36^{NS}	10.42**	5.25**	0.35^{NS}	-2.29^{NS}	0.75^{NS}	-4.57^{NS}
Jasmine-85 × CB-42	-6.06^{NS}	-9.09*	-5.33**	-7.92**	-15.46**	-16.10**	8.52**	7.81**	29.62**	21.63**
CB-15 × CB-40	-13.80**	-15.04**	6.36**	-1.06^{NS}	-0.62^{NS}	-1.95^{NS}	7.20**	10.11**	27.29**	25.22**
CB-15 × CB-42	-6.67*	-7.89*	-3.23^{NS}	-4.92*	1.13^{NS}	-5.52**	6.35**	6.75**	27.71**	15.62**
CB-40 × CB-42	-6.81*	-6.92*	2.28^{NS}	-3.26^{NS}	-14.16**	-18.77**	0.55^{NS}	-4.23**	0.70^{NS}	-10.16**

Level of significance at 1% and 5%

Ht= mid parent heterosis, Hbt= better parent heterosis;

FG/P= Filled Grains/Panicle, SSR= Seed Setting Rate (%), TGW= 1000 Grains weight (g), Grain Yield/plot= (kg/10m^2), GY/ha= GrainYield/hectare (Kg/ ha)

DISCUSSION

In plant breeding diallel mating designs are very important tool for determination of the inheritance of various qualitative and quantitative traits. Crosses between different parent groups are very useful for the production of distinct plant population with desired characteristics and very helpful for breeder's interest. The evaluation of combining ability, different heterotic groups, pure lines and inbred lines in a series of cross combinations have widely used in plant breeding programme in a variety of diallel crosses for further screening and selection with respect to their desired characteristics. Half diallel crosses were used in the present research for the analysis of combining ability and heterosis for yield and yield related traits of various agro-morphological characters of parents and their hybrids (Rahimi *et al*., 2010; Mohammad *et al*., 2016; Kishor *et al*., 2017; Krishna *et al*., 2018).

We found that the numbers of potential hybrids with high yield characteristics were derived from the parents of high GCA value i.e. L-203, CB-15, CB-42 and such types of hybrids having high SCA values i.e. L-203 × CB-42 for PH, L-203 × Jasmine-85 for G/P, FG/P and CB-15 × CB-40 for GY/ha. On the basis of results GCA may be used as breeding elite hybrids combinations or may be used to predict heterosis for specific breeding target under the same environmental conditions. Hybrid and GCA breeding very useful for the prediction of various yield and yield parameters, disease resistance and drought resistance etc. (Gopal *et al*., 2008; Worku *et al*., 2008; Hasanalideh *et al.,* 2017; Vennila *et al*., 2017; Devi *et al*., 2018).

The SCA can also be used as for the prediction of heterosis on the basis of various specific hybrids (Torres and Geraldi 2007; Ahangar *et al*., 2008; Ni *et al*., 2009). Specific combining ability of a cross is the estimation of the effect of non-additive type of gene action for a trait that provides the basis for the selection of hybrid combination in breeding programme. Therefore, significant SCA effect is highly desirable for a successful hybrid breeding programme. In present study a strong association was observed between SCA and heterosis. SCA is a combining ability of specific crosses in series of hybrid combination while heterosis is increase or decrease of F_1 over its both parents. Usually, GCA is controlled by additive genes which are also different from SCA and describe the combining ability of the parents for a trait (Ganapati *et al*., 2020). Through inheritance GCA can easily be recombined and accumulated by gene flow in to next generation. Thus the sum of combining ability of the two parents constitutes the SCA by the crossing of two parents through hybridization. On the other hand, significant negative heterosis considered to be very beneficial in selection criteria for selection of specific traits (Haryanto, 2017; Shabbir *et al*., 2018; Kumar and Mudhalvan, 2018; Solanke *et al*., 2019).

Heterosis in rice breeding is of great importance for plant breeders for the estimation and development of new plant population on the basis their parentage along with the phenotypic and genotypic traits. In the present study a strong association was observed between mid-parent heterosis and better parent heterosis i.e. 'Jasmine-85 × CB-42', 'CB-15 × CB-42' and 'Jasmine-85 × CB-15' on the basis of various studied traits (Zha *et al*., 2008; Venkatesan *et al*., 2019; Zuxin *et al*., 2019). Such traits determine the hybrids which performs excellent and selected for further study for the development of new plant population and ultimately for the development of new variety. Additive gene action and additive x additive type of gene action which operates through conventional breeding approaches that is very important to breeder's interest for the selection of transgressive segregates, which may produce promising genotypes as commercial cultivars in self-pollinated crop species. Sometimes heterosis effect the morphological traits on the basis of day length and photoperiod that provides the significant information for the selection of new hybrids and their performance in the changing climatic condition (Yuan *et al*., 2015). Crop gene pools also widened through crop hybridization with land races, elite breeding with modern rice varieties, rice varieties with wild rice for the improvement and exploitation of combining ability/heterosis for the improvement of yield and yield related traits and control of many rice diseases (Pandey *et al*., 2010; Dan *et al*., 2015).

Conclusion: In the present study we found that, some of the traits i.e. effective numbers of panicles per plant, plant height, yield per hectare, panicle length and grains per panicle have significant positive mid parent and better parent heterosis along with their specific hybrids. These hybrids could be further used for the development of new distinct uniform homozygous plant population on the basis of the desired characteristics. Three parents i.e. L-203, CB-15 and CB-42 and three crosses Jasmine-85 × CB-42, L-203 × CB-42 and L-203 × Jasmine-85 showed very good results. Furthermore such types of hybrids could be very useful for the estimation and selection of good positive heterosis of yield and yield related traits. The study also provides the information of promising rice lines that could be very useful for the release of new rice varieties and start up new rice breeding programme and equally beneficial to the scientists and farmer's community.

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