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

A. Rasheed¹, M. Ashfaq² and M. Sajjad²

¹Institute of Agricultural Sciences, University of the Punjab, Quaid-e-Azam Campus, Lahore, Pakistan; ²Department of Biosciences, COMSATS University Islamabad, Park Road, Tarlai Kalan, Islamabad 45550, Pakistan

Corresponding author: ashfaq.iags@pu.edu.pk; ashfaq_qs@yahoo.com

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/P), 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.

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 indispensable 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 (Bhatty 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 F₁ 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 F1 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 F1+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 cm². 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/10m²), 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 F1 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
Grifﬁn’s approach (1956). Heterosis was calculated by
using following formulas described by (Dan et al., 2014).

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

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

**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 ef fects 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 combining 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/PI):** 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/10m²):** 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/PI | PL    | G/P  | FG/P | SSR  | TGW  | GY/plot | GY/ha |
|-------------|-----|------|-------|-------|-------|-------|------|------|------|------|---------|-------|
| Rep.        | 2   | 1.41 | 1.09  | 20.70 | 0.55  | 1.27  | 110.06 | 33.80 | 9.76 | 0.13 | 0.03      | 35349.33 |
| Genotype    | 14  | 10.96 | 118.55 | 872.14 | 17.35 | 18.09 | 836.70 | 313.29 | 57.60 | 9.97 | 1.43      | 1395715.0 |
| GCA         | 4   | 0.62 | 55.09 | 122.34 | 2.19  | 7.91  | 53.80  | 14.34 | 13.46 | 4.58 | 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/PI = 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/10m²), Y/H = Grain Yield/hectare (Kg/ha)

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

| Parents     | DF50% | GD    | PH    | EP/PI | 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  | 0.47NS| -2.26 | -3.18 | 0.22NS| -0.50NS| 0.08NS| 1.52NS| 0.95  | 0.35  | 0.03NS  | -33.87NS |
| CB-15       | -0.30NS| 1.22  | 5.72  | -0.30NS| -0.83  | -1.21NS| 0.43NS| 0.80NS| -0.42NS| 0.30**  | 296.87** |
| CB-40       | -0.20NS| 2.08  | -3.80 | -0.45NS| 1.08NS| 1.79NS| -2.33**| -2.02**| 0.12**| 0.10*** | 95.51*** |
| CB-42       | -0.06NS| 2.65 | 3.06  | -0.35NS| -0.97 | 3.27**| 0.48NS| 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/PI = 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/10m²), Y/H = Grain Yield/hectare (Kg/ha)

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

| Crosses      | DF50% | GD    | PH    | EP/PI | PL    | G/P  | FG/P | SSR  | TGW  | GY/plot | GY/ha |
|--------------|-------|-------|-------|-------|-------|------|------|------|------|---------|-------|
| L-203 × Jasmine-85 | -1.62**| 1.03NS| 5.49**| 1.98**| 0.48NS| 23.05**| 12.57**| -5.14**| -2.03**| 0.23**  | 222.69** |
| L-203 × CB-15   | 0.86NS| -0.78NS| -6.75**| -1.16**| 0.14NS| -16.00**| -12.33**| 1.77**| -0.03NS| -0.67**  | -664.63** |
| L-203 × CB-40   | -1.29*| -1.30NS| -14.89**| -0.02NS| -0.43NS| -11.00**| -2.90NS| 4.07**| 0.89**| -0.43**  | -420.45** |
| L-203 × CB-42   | 4.24**| -4.54**| 39.92**| 1.22**| -0.38NS| -8.81**| -9.05**| -0.90NS| 2.48**| 0.52**  | 517.68** |
| Jasmine-85 × CB-15| -1.24*| -0.21NS| 7.97**| 1.84**| 1.86**| 23.67**| 16.05**| -3.14**| -0.97**| 0.08NS  | 80.61NS |
| Jasmine-85 × CB-40| 0.67NS| -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**| -2.14NS| -5.67**| -2.55**| -2.39**| 0.87**  | 857.84** |
| CB-15 × CB-40   | 3.10**| -5.21NS| -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**| -0.86NS| -2.90NS| 1.44**| 0.81**| 0.72**  | 711.52** |
| CB-40 × CB-42   | -2.48**| -6.97**| 5.25**| -0.11NS| 2.76**| 1.14NS| 1.52NS| -0.15NS| -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/PI = 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/10m²), Y/H = Grain Yield/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 |
|--------|-------|----|----|------|----|-----|
|        | 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* | 12.23 NS | -12.85 NS | 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 NS | -11.60 NS | 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 NS | 50.75 NS | 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 NS | -3.50** | 63.27 NS | 53.85 NS | 11.41* | 9.21 NS | 16.95 NS | 13.47 NS |
| Jasmine-85 × CB-40 | -0.20 NS | -1.96 NS | -6.21** | -11.70** | 20.84 NS | 11.33** | 49.02 NS | 35.71 NS | -9.52* | -17.39** | -25.62** | -33.58 NS |
| Jasmine-85 × CB-42 | -1.80 NS | -3.92 NS | -6.70** | -13.02** | 32.16 NS | 29.06 NS | 100.00 NS | 95.65 NS | 16.31 NS | 7.89 NS | -0.88 NS | -6.64 NS |
| CB-15 × CB-40 | 4.51* | 3.66 NS | -9.73** | -11.17 NS | -7.09 NS | -14.25 NS | 37.04 NS | 32.14 NS | -10.30* | -19.57 NS | -19.60 NS | -26.20 NS |
| CB-15 × CB-42 | 2.88 NS | 2.46 NS | -10.16** | -12.50 NS | 6.95 NS | -6.54 NS | 66.67 NS | 53.85 NS | 23.19 NS | 16.44 NS | -3.74 NS | -6.64 NS |
| CB-40 × CB-42 | -2.45 NS | -2.85 NS | -12.37** | -13.28 NS | 15.84 NS | 9.12 NS | 28.00 NS | 14.29 NS | 14.65 NS | -2.17 NS | -9.18 NS | -14.21 NS |

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 |
|--------|------|-----|------|---------|-------|
|        | Ht%   | Hbt% | Ht%   | Hbt% | Ht% | Hbt% | Ht%   | Hbt% | Ht% | Hbt% |
| L-203 × Jasmine-85 | 8.39** | 6.13 NS | -6.68** | -9.69* | -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 NS | -5.30* | -7.02 NS | -7.70 NS |
| L-203 × CB-40 | -9.31** | -10.50 NS | 8.60 NS | -0.21 NS | 7.07 NS | 1.72 NS | -4.85 NS | -7.00 NS | -7.85 NS | -10.00 NS |
| L-203 × CB-42 | -11.62** | -12.68 NS | -2.47 NS | -5.42* | 11.25 NS | 0.32 NS | 5.11 NS | 4.65 NS | 16.11 NS | 5.28 NS |
| Jasmine-85 × CB-15 | 11.53** | 9.34* | -4.67 NS | -5.65* | -8.15 NS | -13.57 NS | 6.62 NS | 3.22 NS | 11.62 NS | 7.42 NS |
| Jasmine-85 × CB-40 | -16.54 NS | -19.33 NS | 11.09 NS | 2.36 NS | 10.42 NS | 5.25 NS | 0.35 NS | -2.29 NS | 0.75 NS | -4.57 NS |
| Jasmine-85 × CB-42 | -6.06 NS | -9.09 NS | -5.33* | -7.92* | -15.46 NS | -16.10 NS | 8.52 NS | 7.81 NS | 29.62 NS | 21.63 NS |
| CB-15 × CB-40 | -13.80 NS | -15.04 NS | 6.36 NS | -1.06 NS | -0.62 NS | -1.95 NS | 7.20 NS | 10.11 NS | 27.29 NS | 25.22 NS |
| CB-15 × CB-42 | -6.67* | -7.89* | -3.23 NS | -4.92* | 1.13 NS | -5.52 NS | 6.35 NS | 6.75 NS | 27.71 NS | 15.62 NS |
| CB-40 × CB-42 | -6.81 NS | -6.92* | 2.28 NS | -3.26 NS | 14.16 NS | -18.77 NS | 0.55 NS | -4.23 NS | 0.70 NS | -10.16 NS |

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/10m²), GY/ha= Grain Yield/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 agronomical 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 F1 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 midparent 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 additive 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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