*Plant Archives* Vol. 19 No. 1, 2019 pp. 1135-1140 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

# COMBINING ABILITY AND GENE ACTION FOR GRAIN YIELD USING LINE × TESTER TECHNIQUE IN AEROBIC RICE

**Yashlok Singh, P.K. Singh, V.N. Pathak[1], Varucha Misra and A.K. Mall***

ND University of Agriculture & Technology, Kumarganj, Faizabad-224 221 (U.P.)
[1]SMMT Post Graduate College, Ballia-277 001 (UP)
*ICAR-Indian Institute of Sugarcane Research, Lucknow-226 002 (U.P.)

## Abstract

The little role of additive gene effects of fixable nature for grain yield and most of other yield components in the present study suggested that these traits are not amenable to improvement through selection even in early generations. This indicated that considerable improvement in status of grain yield and important yield attributes in aerobic rice cannot be achieved by conventional breeding procedures normally used in autogamous crops leading to development of pure line varieties. The predominance of non-additive gene effects representing non-fixable dominance and epistatic components of genetic variance indicated that maintenance of heterozygocity would be highly fruitful for improving the characters. In present study, none of the crosses showed significant sca effects in desirable direction for all the characters. Several crosses exhibited significant and desirable sca effects for one or more characters but none of them emerged as good specific combination for more than nine characters. The significant and positive gca effects for grain yield per plant were exhibited by seven testers, R-RF-65, IR 81057-B-132-U-4-4, IR 83614-315-B-AROBIC-E-7, IR 80416-B-152-4, IR 83614-61-B, LALIT and IR 79966-B-53-3.

***Key words:*** Combining ability, sca, gca, gene action, line × tester, Aerobic rice

## Introduction

The understanding of inheritance of various characters and identification of superior parents are important pre-requisites for launching an effective and efficient breeding programme (Akter *et al.,* 2010). It is not always necessary that parents with high mean performance for yield and other traits would produce desirable $F_1$'s and/or sergeants. The selection of a few parents having high genetic potential as per breeding objectives is essential because analyzing and handling of very large number of crosses resulting from numerous parents available in germplasm collections of a crop would be an impractical and perhaps impossible task. Combining ability analysis is useful technique for understanding of genetic worth of parents and their crosses for further exploitation in breeding programmes. In addition, it also provides the idea about gene effects involved in inheritance of different characters which is essential for deciding suitable breeding strategy. Among the various techniques of combining ability analysis, line × tester analysis (Kempthorne, 1957) has been widely utilized for screening of germplasm to identify valuable donor parents and promising crosses in many crops including rice (Saidaiah *et al.,* 2011; Varpe *et al.,* 2011; Asfaliza *et al*., 2012**;** Gopikannan and Ganesh 2013; Kolom *et al.,* 2014). The present study, therefore, aims to study the combining ability of parents and crosses and gene action for grain yield and its components using line × tester technique.

***Author for correspondence :** E-mail : Ashutosh.Mall@icar.gov.in

## Materials and methods

The present investigation was carried out at the Research Farm of Crop Research Centre, Masodha, N.D. University of Agriculture & Technology, Narendra Nagar (Kumarganj), Faizabad. The crosses were made during *Kharif*, 2012 and the germplasm lines, hybrids along with parental lines and check varieties were evaluated during *Kharif*, 2013.

### Experimental details

Four cytoplasmic male sterile (CMS) lines *viz*., IR 58025 A, IR-68888 A, IR-68897A and IR-79156A were crossed with sixteen genetically diverse aerobic rice pollen parents in a line × tester mating fashion. The eighteen testers were IR 83614-673-B, IR 84899-B-185-CRA-1-1, IR 83614-61-B, R-RF-45, R-84856-159-CRA-12-1, IR 78875-207-B-1-B, IR 64, LALIT, R-RF-65, IR 81057-B-132-U-4-4, IR 80416-B-152-4, IR 79906-B-5-3-3, IR 84887-B-153-CRA-2-5-1, IR 78537-B-4-B-B-B, IR 79956-B-60-2-3, IR 81039-B-137-U-3-3, IR 84614-203-B, and IR 83614-315-B-AROBIC-E-7. The seeds of CMS lines were treated with 0.02 per cent mercuric chloride solution followed by subsequent washing with sterilized distilled water and then placed in petri-dishes holding a moist towel paper for proper germination at room temperature. The 7-10 days old seedlings of CMS lines were transplanted in earthen pots for their normal growth, while male lines were direct seeded in fully prepared nursery beds at three different dates to coincide the flowering dates with CMS lines for crossing purpose. A total of 72 $F_1$'s were produced during *Kharif,* 2012. The resulting set of 72 $F_1$'s along with their 22 parents and standard 2 check varieties (Baranideep and MTU-1010) were evaluated in randomized complete block design with three replications during *Kharif,* 2013. The seeds of each entry were sown on 21$^{th}$ June, 2013 in separate pots and 33 days (24$^{th}$ July, 2013) old seedlings were transplanted single seedling per hill in single row plots of 3 m length with inter- and intra- row spacing of 20 cm and 15 cm, respectively. All the recommended cultural practices were followed to raise a good crop. The fertilizers were applied @ 120 kg nitrogen, 60 kg phosphorus and 60 kg potash per hectare through urea, DAP and murate of potash, respectively. The full dose of phosphorus and potash and half dose of nitrogen were applied as basal and rest of nitrogen was applied in two split doses as top dressing at tillering and panicle initiation stage of crop growth.

**Observations recorded**

The observations were recorded on five randomly selected competitive plants of a genotype in a plot in each replication for twelve characters in both experiments. The mean values of observations recorded on five plants of each plot were used for analysis. The observations for different characters were recorded for Days to 50 per cent flowering (DFF), Days to maturity (DM), Flag leaf area in cm$^2$ (FLA), Plant height in cm (PH), Panicle bearing tillers per plant (PBT/P), Panicle length in cm (PL), Spikelet per panicle (S/P), Spikelet fertility (SF), 1000-grain weight in g (TW), Biological yield per plant in g (BY/P), Harvest-index (HI) and Grain yield per plant (GY/P).

**Statistical analyses**

The experimental data collected on all the twelve characters in respect of two experiments of the present study were compiled by taking the mean values over five randomly selected plants in each plot in each replication. The combining ability analysis was carried out following line × tester mating design outlined by Kempthorne (1957) and further elaborated by Arunachalam (1974). Line × tester analysis was used to estimate general combining ability (gca) and specific combining ability (sca) variances and their effects using the observations taken on $F_1$ generation of the line × tester set of crosses. In this mating system, a random sample of 'l' lines is taken and each line is mated to each of the 't' testers (Singh and Chaudhary, 1977). Heritability in narrow sense ($h^2n$) was calculated as suggested by Kempthorne (1957).

**Combining ability analysis**

The understanding of inheritance of various characters and identification of superior parents are important pre-requisites for launching an effective and efficient breeding programme. The present study, therefore, aims to study the combining ability of parents and crosses and gene action for grain yield and its components using line × tester technique. The important findings of the analysis are discussed below:

**Gene action and components of genetic variance:**

The estimates of components of genetic variance and other genetic parameters are given in Table 1. The mean squares due to replications appeared non-significant for all the traits. The mean squares due to testers emerged significant for plant height. The variance due to lines was found to be non- significant for all the characters. The mean squares due to line × tester interactions, representing importance of specific combining ability and non-additive gene effects, was found to be highly significant for all the twelve characters under study. The above discussion suggests predominant role of non-additive gene effects represented by specific combining ability variances for all the characters.

The estimates of heritability in narrow sense ($h^2n$) showed high estimates of narrow sense heritability. Plant height (23.57%), DM (21.64%), GY/P (18.36%), HI (18.36%), SF (17.58%), FLA (16.88%), PBT/P (11.95%), PL (11.49%) and DFF (11.10%) exhibited moderate narrow sense heritability while remaining three traits had low narrow sense heritability. This indicated that little role of additive gene effects and predominant role of non-additive gene effects with predominance of non-additive gene effects in inheritance of grain yield and yield components of rice has also been reported earlier (Asfaliza *et al*., 2012**;** Gopikannan and Ganesh 2014; Kolom *et al.,* 2014).

**Table 1:** Components of genetic variance, average degree of dominance, predictability ratio and heritability in narrow sense for 12 characters in aerobic rice

| Characters | gca variance ($\sigma^2$g) | sca variance ($\sigma^2$s) | Average degree of dominance | Predictability ration | ó²A | ó²D | Heritability (h²n %) | Genetic advance (%) |
|---|---|---|---|---|---|---|---|---|
| **DFF** | 1.60 | 24.66 | 2.77 | 0.12 | 3.21 | 24.66 | 11.10 | 1.23 |
| **PH (cm)** | 19.44 | 125.04 | 1.79 | 0.24 | 38.88 | 125.04 | 23.57 | 6.24 |
| **FLA (cm²)** | 0.85 | 7.63 | 2.11 | 0.18 | 1.70 | 7.63 | 16.88 | 1.11 |
| **PBT/P** | 0.06 | 0.70 | 2.34 | 0.15 | 0.12 | 0.70 | 11.95 | 0.25 |
| **PL (cm)** | 0.10 | 1.00 | 2.18 | 0.17 | 0.21 | 1.00 | 11.49 | 0.32 |
| **S/P** | 11.15 | 490.92 | 4.69 | 0.04 | 22.30 | 490.92 | 4.29 | 2.02 |
| **SF (%)** | 0.90 | 7.62 | 2.05 | 0.19 | 1.80 | 7.62 | 17.58 | 1.16 |
| **TW (g)** | 2.36 | 46.31 | 3.13 | 0.09 | 4.71 | 46.31 | 8.97 | 1.34 |
| **BY/P (g)** | 0.26 | 7.23 | 3.72 | 0.07 | 0.52 | 7.23 | 6.32 | 0.37 |
| **GY/P (g)** | 0.33 | 2.86 | 2.06 | 0.19 | 0.66 | 2.86 | 18.36 | 0.72 |
| **HI (%)** | 5.07 | 44.67 | 2.09 | 0.19 | 10.15 | 44.67 | 18.02 | 2.79 |
| **DM** | 2.50 | 16.22 | 1.80 | 0.24 | 5.00 | 16.22 | 21.64 | 2.14 |

**Table 2:** Summary of general combining ability effects of parents for 12 characters in aerobic rice

| Testers | DFF | PH | FLA | PBT/P | PL | S/P | SF | TW | BY/P | GY/P | HI | DM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IR 83614-673-B | + | + | 0 | 0 | 0 | + | 0 | - | 0 | 0 | 0 | + |
| IR 84899-B-185-CRA-1-1 | + | + | + | 0 | 0 | - | - | 0 | 0 | - | - | - |
| IR 83614-61-B | + | + | 0 | 0 | 0 | - | 0 | - | 0 | + | + | - |
| R-RF-45 | - | + | + | - | - | - | + | + | + | 0 | - | - |
| IR 84856-159-CRA-12-1 | + | - | + | 0 | 0 | - | + | + | 0 | - | - | 0 |
| IR 78875-207-B-1-B | 0 | - | + | - | + | - | + | + | - | - | - | + |
| IR 64 | + | + | - | - | + | + | - | - | 0 | 0 | + | + |
| LALIT | + | 0 | 0 | 0 | 0 | + | 0 | _ | + | + | + | - |
| R-RF-65 | - | - | 0 | 0 | 0 | 0 | - | 0 | + | + | + | + |
| IR 81057-B-132-U-4-4 | - | - | - | 0 | - | - | 0 | 0 | 0 | + | + | + |
| IR 80416-B-152-4 | 0 | - | 0 | 0 | 0 | + | 0 | 0 | + | + | + | - |
| IR 79906-B-5-3-3 | - | + | 0 | 0 | - | + | 0 | - | 0 | + | + | - |
| IR 84887-B-153-CRA-2-5-1 | + | + | 0 | + | 0 | + | 0 | - | 0 | - | - | + |
| IR 78537-B-4-B-B-B | - | + | 0 | 0 | + | - | 0 | 0 | - | - | - | 0 |
| IR 79956-B-60-2-3 | 0 | + | 0 | - | 0 | - | + | + | + | - | - | 0 |
| IR 81039-B-137-U-3-3 | - | - | 0 | - | 0 | - | + | + | 0 | 0 | 0 | 0 |
| IR 84614-203-B | 0 | - | 0 | + | 0 | + | 0 | - | - | 0 | + | - |
| IR 83614-315-B-AROBIC-E-7 | - | - | 0 | 0 | 0 | - | 0 | + | 0 | + | 0 | - |
| IR 58025 A | + | + | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IR 68888 A | + | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IR 68897 A | - | + | - | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IR 79156 A | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

+= Good combiner, -= Poor combiner, 0 =Average combiner

## General combining ability:

For illustrating genetic worth of parents for hybridization programme, the general combining ability (gca) effects of 22 parents (3 lines + 18 testers) for twelve characters are consolidated in Table 2. The significant and positive gca effects for grain yield per plant were exhibited by seven testers, R-RF-65 (1.56), IR 81057-B-132-U-4-4 (1.48), IR 83614-315-B-AROBIC-E-7 (1.34), IR 80416-B-152-4 (1.28), IR 83614-61-B (0.95), LALIT (0.72) and IR 79966-B-53-3 (0.40). The parent with highest gca effects for grain yield, R-RF-65, also showed significant gca effects in desirable direction for days to maturity, plant height, biological yield per plant and harvest-index. LALIT recorded significant and desirable gca

**Table 3:** Summary of sca effects for 12 characters of crosses with desirable sca effects for grain yield per plant

| Characters / Crosses | GY/P | DFF | PH | FLA | PBT/P | PL | S/P | SF | TW | BY/P | HI | DM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IR 68888 A × IR 83614-673 | 3.89 | + | 0 | + | + | 0 | - | 0 | + | + | + | + |
| IR 68897 A × IR 83614-3 | 3.85 | - | + | - | 0 | 0 | + | - | - | + | + | 0 |
| IR 58025 A × IR 80416-B | 3.16 | - | 0 | 0 | 0 | 0 | - | 0 | + | + | + | + |
| IR 58025 A × IR 79906-B | 3.03 | + | - | 0 | 0 | 0 | - | 0 | + | + | + | 0 |
| IR 68888 A × R-RF-45 | 2.92 | + | - | + | + | 0 | 0 | + | 0 | 0 | + | 0 |
| IR 79156 A × IR 83614-61 | 2.44 | 0 | - | 0 | + | 0 | 0 | 0 | 0 | 0 | + | + |
| IR 79156 A × IR 84887 B | 2.22 | + | - | 0 | - | 0 | 0 | 0 | 0 | + | + | + |
| IR 68888 A × IR 84614-2 | 1.45 | _ | + | - | 0 | 0 | 0 | - | - | 0 | + | - |

*, ** significant at 5 and 1 per cent probability levels, respectively.

**Table 4:** Most promising cross combinations for different characters along with their mean performance and gca effects of parents

| Characters | Crosses with significant effects | Mean performance of crosses | gca effects of parents |
|---|---|---|---|
| **Days to 50% flowering** | IR 68897 A × LALIT | -7.29 | A × H |
| | IR 68897 A × IR 64 | -6.29 | A × H |
| | IR 68888 A × IR 79906-B | -5.93 | H × L |
| | IR 58025 A × IR 84614-2 | -5.79 | H × A |
| | IR 58025 A × IR 81039-B | -5.54 | H × L |
| **Plant height** | IR 68897 A × IR 84856-1 | -29.09 | H × L |
| | IR 58025 A × IR 81039-B | -23.77 | H × L |
| | IR 79156 A × IR 80416-B | -16.46 | L × L |
| | IR 79156 A × IR 83614-3 | -15.98 | L × L |
| | IR 58025 A × R-RF-45 | -15.83 | H × H |
| **Flag leaf area** | IR 68888 A × IR 83614-61 | 4.85 | L × H |
| | IR 68897 A × IR 78537-B | 4.81 | L × A |
| | IR 58025 A × IR 64 | 3.22 | H × L |
| | IR 68888 A × IR 81057-B | 3.13 | L × A |
| | IR 68897 A × IR 79906-B | 3.11 | L × A |
| **Panicle bearing tillers per plant** | IR 68888 A × IR 83614 | 1.78 | A × A |
| | IR 68888 A × R-RF-45 | 1.76 | A × L |
| | IR 68888 A × IR 80416-B | 1.58 | A × A |
| | IR 68897 A × IR 84899-B | 1.57 | H × A |
| | IR 68897 A × IR 79956-B | 1.47 | H × A |
| **Panicle length** | IR 68897 A × IR 81039 | 3.12 | A × A |
| | IR 58025 A × IR 84614-2 | 2.19 | A × A |
| | B IR 68888 A × IR 79956-B | 2.01 | A × L |
| | IR 68897 A × IR 81057-B | 1.81 | A × L |
| | IR 79156 A × IR 80416-B | 1.66 | A × A |
| **Spikelets per panicle** | IR 79156 A × IR 80416-B | 51.13 | A × H |
| | IR 68897A × R 83614-673 | 47.57 | A × H |
| | IR 68888 A × IR 79906-B | 43.25 | A × H |
| | IR 58025 A × IR 78875-2 | 39.61 | A × L |
| | IR 68888 A × IR 84856-1 | 31.42 | A × L |

***contined ... table 4***

*contined ... table 4*

| | | | |
|---|---|---|---|
| **Spikelet fertility** | IR 68897 A × IR 78537-B | 5.01 | A × A |
| | IR 68888 A × IR 83614-61 | 4.74 | A × A |
| | IR 68897 A × IR 79906-B | 3.39 | A × A |
| | IR 58025 A × R-RF-65 | 3.34 | A × H |
| | IR 58025 A × IR 64 | 3.31 | A × L |
| **1000-grain weight** | IR 68888 A × IR 83614-3 | 20.41 | A × H |
| | IR 79156 A × IR 81057-B | 13.39 | A × A |
| | IR 79156 A × IR 78875-2 | 10.34 | A × H |
| | IR 68897 A × R-RF-65 | 9.46 | A × H |
| | IR 68897 A × IR 84856-1 | 8.06 | A × H |
| **Biological yield per plant** | IR 68888 A × IR 81039-B | 4.50 | A × A |
| | IR 79156 A × IR 84887-B | 4.14 | A × A |
| | IR 68897 A × IR 83614-61 | 3.77 | A × A |
| | IR 58025 A × IR 79906-B | 3.46 | A × A |
| | IR 58025 A × IR 84899-B | 3.35 | A × A |
| **Grain yield per plant** | IR 68888 A × IR 83614-673 | 3.89 | A × A |
| | IR 68897 A × IR 83614-3 | 3.85 | A × H |
| | IR 58025 A × IR 80416-B | 3.16 | A × H |
| | IR 58025 A × IR 79906-B | 3.03 | A × H |
| | IR 68888 A × R-RF-45 | 2.92 | A × A |
| **Harvest-index** | IR 58025 A × IR 84856-1 | 12.58 | A × L |
| | IR 68888 A × R-RF-45 | 12.47 | A × L |
| | IR 68888 A × IR 83614-673 | 11.56 | A × A |
| | IR 68897 A × IR 78875-2 | 10.95 | A × L |
| | IR 68897 A × IR 83614-3 | 10.71 | A × A |
| **Days to maturity** | IR 79156 A × R-RF-65 | -10.18 | A × L |
| | IR 79156 A × IR 78537-B | -7.51 | A × A |
| | IR 68897 A × IR 84614-2 | -7.16 | A × L |
| | IR 58025 A × IR 84899-B | -4.96 | A × L |
| | IR 68888 A × IR 83614-673 | -4.85 | A × A |

H = High (significant and positive), L= Low (significant and negative) A= Average (non-significant)

effects for DFF, S/P, BY/P and HI. Seven testers emerged as good general combiner for GY/P along with other traits also. None lines showed good general combiner for GY/P. Among the four CMS lines, IR 58025 A was good general combiner for short stature, DFF, PH and FLA. IR 58025 A needs special attention because it may be valuable for developing fine grain in aerobic rice hybrids. The other line, IR 68888 A was good general combiner for DFF besides being average and poor combiner for remaining traits. IR 68897 A was good general combiner for PH and PBT/P and IR 79156 A was average and poor combiner for traits. The seven parents showing positive and significant gca effects for grain yield and other important traits as mentioned above may serve as valuable parents for hybridization programme or multiple crossing programme for obtaining high yielding hybrid varieties or transgressive sergeants for developing pure line varieties of aerobic rice.

**Specific combining ability effects (sca)**

The sca effects, which are supposed to be manifestation of non-additive components of genetic variance, are highly valuable for discrimination of crosses for their genetic worth as breeding materials. The most promising specific cross combinations for different characters along with their mean performance and gca effects of parents are listed in table 3. Twenty out of seventy-two crosses emerged with positive and significant sca effects for grain yield per plant. The top five crosses, were IR 68888 A × IR 83614-673, IR 68897 A × IR 83614-3, IR 58025 A × IR 80416-B, IR 58025 A × IR 79906-B and IR 68888 A × R-RF-45 showed significant and positive sca effects for GY/P as well as some other yield components. The cross having highest positive and significant sca effects for GY/P (IR 68888 A × IR 83614-673 also recorded significant sca effects in desirable direction for BY/P, HI, SF and short stature. The second ranking cross for higher positive and significant sca effect for GY/P, IR 68897 A × IR 83614-3 showed significant and desirable sca effects for BY/P, HI, TW and PBT/P. The third ranking cross for significant and positive sca effects for GY/P, IR 58025 A × IR 80416-B, exhibited significant and desirable sca effects for BY/P, TW and FLA. The fourth ranking cross, IR 58025 A × IR 79906-B, possessed significant and desirable sca effects for BY/P and HI. The fifth ranking cross in this context, IR 68888 A × R-RF-45 recorded significant sca effects in desirable direction for BY/P, HI and TW besides GY/P. Similarly, remaining 15 crosses having significant and positive sca effects for GY/P also possessed significant sca effects in desirable direction for some other characters also. The twenty crosses having positive and desirable sca effects for GY/P and some of its component traits merit attention in breeding programme for exploitation of hybrid cultivars. In general, the crosses showing significant and desirable sca effects were associated with better *per se* performance for respective traits. However, the crosses having high sca effects in desirable direction did not always have high mean performance for the character in question. Thus, the sca effect of the crosses may not be directly related to their *per se* performance. This may be attributed to the fact that *per se* performance is a realized value whereas sca effect is an estimate of $F_1$ performance over parental one. Therefore, both *per se* performance along with sca effects should be considered for evaluating the superiority of a cross although the former may be more important if development of $F_1$ hybrids is the ultimate objective. The most promising five crosses having significant and desirable sca effects for different characters are listed along with their mean performance and gca effects their parents in table 3. The crosses listed in Table 3 may be considered for further utilization owing to their higher genetic worth.

The critical examination of Table 4 would reveal that the crosses exhibiting high order significant and desirable sca effects for different characters involved parents having all types of combinations of gca effects such as high × high (H × H), high × average (H × A), high × low (H × L), average × average (A × A), average × low (A × L) and low × low (L × L) general combiner parents. The foregoing observation clearly indicated that there was no particular relationship between positive and significant sca effects of crosses with gca effects of their parents for the characters under study. Singh and Kumar (2004) have also found that crosses having high order positive sca effects for grain yield resulted from parents having high × high as well as high × low gca effects for grain yield. Varpe *et al.,* (2011) and Dadilakshmi and Upendra (2014) observed that all crosses identified as superior specific combinations for grain yield per plant on the basis of sca effects emerged either through average × poor and average × average general combiner parents for grain yield per plant.

## References


Akter, A., M.J. Hasan, H. Begum, M.U. Kulsum and M.K. Hossain (2010). Combining ability analysis in rice. Bangladesh. *J. Pl. Breed. Genet*., **23(2)**:7-13.

Arunachalam, V. (1974). The fallacy behind the use of modified line × tester design. *Indian J. Genet*, **34 (2)**:200-207.

Asfaliza, R., M.Y. Rafii, G. Saleh, O. Omar and A. Puteh (2012). Combining ability and heritability of selected rice varieties for grain quality traits. *Australian Journal of Crop Science,* **6(12)**:1718-1723.

Dadilakshmi and A. Upendra (2014). Combining ability analysis for quality and nutritional traits in rice. *International Journal of Farm Sciences,* **4(2):**15-23.

Gopikannan, M. and S. K. Ganesh (2014). Investigation on combining ability and heterosis for sodicity tolerance in rice (*Oryza sativa* L.). *African Journal of Agricultural Research*, **8(32)**:4326-4333.

Kempthorne, O. (1957). An Introduction to Genetical Statistics. John Wiley and Sons Inc. New York, pp. 468-471.

Kolom, R., S. Changkija and M.B. Sharma (2014). Combining ability analysis for yield and yield components in some important upland rice germplasm of Nagaland**.** *Indian Journal of Hill Farming,* **27**(1): 118-125.

Saidaiah, P., M.S. Ramesha and S.S. Kumar (2011). Combining ability analysis for yield and yield component traits in rice (*Oryza sativa* L.). *Progressive Agriculture*, **11(2):** 293-297.

Singh, R. K. and Chaudhary, B. D. (1977). Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publ., New Delhi, India.

Varpe, P.G., R.D. Vashi, P.P. Patil, V.A. Lodam and M.V. Patil (2011). Studies on gene action and combining ability for yield and its component traits in rice (*Oryza sativa* L.). *International Journal of Agricultural Sciences*, **7(2)**: 407-411.