Combining ability analysis of three line hybrids in rice (Oryza sativa L.) under aerobic condition

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SUMMARY

Information on the availability of genetic variability and mode of gene action are critically important for choosing effective breeding methods that result in appreciable improvement in performance under drought stress. An investigation in rice (Oryza sativa L.) was carried out subjecting six ‘lines’ and 15 ‘testers’ crossed in a line × tester mating design and the 90 hybrids along with 21 parents were tested for gene action, combining ability for 19 traits under aerobic condition. Three ‘lines’ viz., IR79128A (L1), IR79156A (L2) and IR70369A (L4) and three ‘testers’ viz., IR7925A-428-2-1-1R (T4), KMP-148 (T12) and BI-33 (T15) were identified as the best general combiners. The genotype IR70369A is suggested for conversion to cytoplasmic male sterility with suitable male sterile source. The parents MAS-26, IR 7925A-428-2-1-1R and KMP-105 are recommended for testing their restorability with suitable CMS source.

Key Words : Additive genetic variance (σ²A), Dominance genetic variance (σ²D), General combining ability variance/effects, Specific combining ability variance/effects, Aerobic rice


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Rice is the staple food for over 70 per cent of Asians, the majority of whom are living below the poverty line. More than 90 per cent of the world’s rice is produced and consumed in Asia (Barker et al., 1999) and rice production must be increased by an estimated 56 per cent over the next 30 years to keep up with population growth and income-induced demand for food in most Asian countries where about 75 per cent of total rice production comes from irrigated lowlands (Maclean et al., 2002). Almost 25 per cent of the world’s rice is grown under rainfed lowlands and frequently affected by uneven rainfall distribution. Another 13 per cent of the rice area under cultivation is always subjected to water stress during the growing season (Bouman et al., 2007). Food security in Asia and the increasing scarcity of fresh water resources for agriculture in many areas are stimulating the development of aerobic rice production system (Tuong et al., 2005).

Aerobic rice is high-yielding rice grown under
nonflooded conditions in nonpuddled and unsaturated (aerobic) soil. It is responsive to high inputs, can be rainfed or irrigated and tolerates occasional flooding (Maclean et al., 2002). The water use of aerobic rice was about 60 per cent less than that of flooded rice and total water productivity was 1.6 to 1.9 times higher (Vijayakumar et al., 2006).

To formulate an efficient breeding program for developing drought tolerant varieties, it is essential to understand the mode of inheritance, the magnitude of gene effects and their mode of action (Farshadfar et al., 2008). Due to their quantitative nature, drought related traits cannot be studied in simpler way. Specialized biometrical techniques are required to work out the type of genetic variability associated with the traits. These biometrical techniques are dependent on different mating designs such as diallel, line × tester, North Carolina design and generation mean analysis for the estimation of type of genetic variability. In breeding high yielding varieties of crop plants, the breeders often face with the problems of selecting parents and crosses. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis. The line × tester analysis provides information about general combining ability (gca) of parents and specific combining ability (sca) effects of crosses and is helpful in estimating various types of gene actions. Zhang et al. (2002) studied the heterosis and combining ability of hybrid rice. The genetic improvement of rice for aerobic environments has not been understood well and major efforts in this front are lacking.

Significant yield advantage gained through the adoption and spread of hybrid rice technology had helped China to add about 350 million tonnes of extra rice to its food basket during 1976-1998 and enabled it to divert some of their rice areas to other commercial crops. Hybrid rice technology had also shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce and aerobic conditions. Development of rice hybrids with high yield potential for aerobic conditions would be one of the exciting researches to be carried out to overcome the existing water crisis in India. Breeding strategies based on selection of hybrids require expected level of heterosis as well as the specific combining ability.

**MATERIAL AND METHODS**

**Site description :**

The present investigation was carried out in the Research Farm of the Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Madurai, Tamil Nadu, India during 2009-2011.

**Hybridization programme :**

The 21 parental seed materials [six Lines and 15 Testers (Testers = eight R lines and seven aerobic rice varieties)] were sown in a raised nursery bed during the month of June, 2009. Recommended package of practices and need based plant protection measures were adopted. Crosses were effected in a ‘line × tester’ mating design (Kempthorne, 1957). The hybrid seeds of 90 cross combinations and selfed seeds from all the 21 parents were collected after maturity. The seeds were dried at 12 per cent moisture and preserved at room temperature (28±1°C).

**Evaluation of F₁ hybrids and parents for yield traits under aerobic condition :**

Ninety hybrids along with six lines, 15 testers and one check were raised in a Randomized Block Design (RBD) with three replications under non-puddled and non-flooded aerobic soil, during Rabi, 2010. The hybrids along with their parents were maintained under irrigated condition upto 55 days. From the 56th day onwards the treatment plot was maintained under aerobic condition. Five plants were selected at random and tagged. Data were recorded at panicle initiation (75 – 80 days), flowering and maturity stages for physiological and quantitative traits. Observations of B lines were recorded for the corresponding A lines.

**Characters studied :**

Observations were recorded for the drought tolerant, yield and its component traits viz., days to 50 per cent flowering (DF), plant height (PH), number of productive tillers per plant (PT), number of panicles per plant (PP), panicle length (PL), filled grains per panicle (FG), spikelet fertility (SF), hundred grain weight (HGW), proline content (PC), SPAD chlorophyll meter reading (SCMR), chlorophyll stability index (CSI), relative water content (RWC), biomass yield (BMY), dry shoot weight (DSW), dry root weight (DRW), root / shoot ratio (RS), root length (RL), harvest index (HI), single plant yield (YLD) under water stress and fully
irrigated (control) conditions as per the Standard Evaluation System (1996).

Statistical analysis:
The mean values of all the above observations recorded on five randomly selected plants were utilized for statistical analysis. Lines, testers and hybrids were tested for their significance based on their respective means.

Line × tester analysis:
Analysis of variance:
The analysis of variance of Randomized Block Design and their significance for all the characters were worked out as suggested by Panse and Sukhatme (1967).

Analysis of combining ability and gene action:
Line × tester analysis was carried out to test parents and hybrids with respect to their general and specific combining ability, respectively. The line × tester analysis of combining ability gives useful information regarding the choice of parents and elucidates the nature and magnitude of various types of gene action for the expression of yield and yield attributing characters.

The data on the hybrids and parents were subjected to L × T analysis. The assumption of Null hypothesis was tested for differences among the genotypes as detailed by Panse and Sukhatme (1967). The general combining ability effects of the parents and specific combining ability effects of the crosses were worked out as suggested by Kempthorne (1957).

Estimation of combining ability effects:
General combining ability effects (gca) of parents and specific combining ability effects (sca) of hybrids of ijkth observation were arrived at using the mathematical model given below:

\[ X_{ij} = \mu + \hat{g}_i + \hat{g}_j + \hat{s}_{ij} + \hat{e}_{ijk} \]

where,
\[ X_{ij} = \text{value of ijkth observation} \]
\[ \mu = \text{population mean} \]
\[ \hat{g}_i = \text{gca of ith line} \]
\[ \hat{g}_j = \text{gca of jth tester} \]
\[ \hat{s}_{ij} = \text{sca of ijth hybrid} \]
\[ \hat{e}_{ijk} = \text{error associated with ijkth observation} \]
\[ i = \text{number of lines} \]
\[ j = \text{number of testers} \]
\[ k = \text{number of replications} \]

Mean ( ) = \[ \frac{X...}{rlt} \]

where,
\[ X... = \text{total of all hybrids} \]
\[ r = \text{number of replications} \]
\[ l = \text{number of lines} \]
\[ t = \text{number of testers} \]

General combining ability effects:
The individual gca effects were estimated as follows:

\[ \text{gca effect of lines (g)}} = X_{ij} \times \frac{X...}{rlt} \]
\[ \text{gca effect of testers (g)}} = X_{j} \times \frac{X...}{rlt} \]

where,
\[ X_{i} = \text{Total of i th line over ‘t’ testers and ‘r’ replications} \]
\[ X_{j} = \text{Total of j th tester over ‘l’ lines and ‘r’ replications} \]
\[ X... = \text{Total of all hybrids} \]

Specific combining ability effects:
The individual sca effects were estimated as follows:

\[ \text{sca effects of hybrid (s)}} = X_{ij} \times \frac{X...}{rlt} \]

where,
\[ X_{ij} = \text{Total of the hybrid between ith line and jth tester over ‘r’ replications} \]

Test of significance of combining ability effects:
The standard error pertaining to gca effects of lines and testers and sca effects of hybrids were calculated as follows:

S.E. of gca of lines = \[ \sqrt{\frac{EMS}{rt}} \]

S.E. of gca of testers = \[ \sqrt{\frac{EMS}{rl}} \]

S.E. of sca of hybrids = \[ \sqrt{\frac{EMS}{r}} \]

where,
\[ S.E. = \text{Standard error} \]
\[ EMS = \text{Error mean square} \]
\[ ‘t’ = \text{Parameter} \]
\[ \text{S.E.} = \frac{S.E.}{S.E.} \]
The calculated ‘t’ value was compared with table ‘t’ value at error degrees of freedom to test the significance.

The significance of gca effect of lines, gca effect of testers and sca effects of hybrids was tested against twice the standard error at five per cent level and one per cent level.

The ratio of $\sigma^2_A/\sigma^2_D$ was worked out for each character to find out predominance of additive or non-additive gene action, assuming the simple additive dominance model.

**Estimation of heterosis :**

The term heterosis was coined by Shull in 1914. It refers to the superiority of $F_1$ hybrid over its parents. In other words, heterosis refers to increase in fitness and vigour of $F_1$ over the parental values. While heterosis refers to the phenomenon (cause), hybrid vigour is the phenotypic expression (effect) of the genetical phenomenon.

The mean values of hybrids and their respective parents were used for estimation of heterosis per cent under three categories. The magnitude of heterosis in hybrids was expressed as percentage of increase or decrease of a character over mid parent ($d_1$), better parent ($d_{ii}$) and standard hybrid ($d_{iii}$) and was estimated by following the formula of Fonseca and Patterson (1968).

**Heterobeltiosis ($d_{ii}$) :**

The superiority of $F_1$ over better parent was estimated as follows:

$$d_{ii} = \frac{F_1 - BP}{BP} \times 100$$

where,

$F_1 =$ Mean value of hybrid

$BP =$ Mean value of better parent

**Standard heterosis ($d_{iii}$) :**

The superiority of $F_1$ hybrid over the standard commercial variety or hybrid is known as standard heterosis. The term useful heterosis was used by Meredith and Bridge (1972). It is also called as economical heterosis. This type of heterosis is of direct practical value in plant breeding. It is estimated as follows:

$$d_{ii} = \frac{F_1 - SV}{SV} \times 100$$

where,

$F_1 =$ Mean value of hybrid

$SV =$ Mean value of standard variety

The variety IR 6888 was used as standard variety for yield components and drought tolerant traits in the present study.

**Test of significance :**

The significance of magnitude of heterobeltiosis and standard heterosis was tested at error degrees of freedom by the formula as suggested by Turner (1953):

$$t' for\ heterobeltiosis = \frac{F_1 - BP}{\sqrt{2\text{EMS}}}$$

$$t' for\ standard\ heterosis = \frac{F_1 - SV}{\sqrt{2\text{EMS}}}$$

where,

EMS = Error mean square

$r =$ Number of replication

**RESULTS AND DISCUSSION**

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads:

**Variability studies :**

Progress in any crop improvement venture depends mainly on the variability existing in the metric traits of the base population. Genetic variability studies provide basic information regarding the genetic properties of the population based on which breeding methods are formulated for further improvement of the crop. The variability for 19 traits was estimated on the basis of phenotypic and genotypic co-efficient of variations. The PCV value was found to be higher in all the 19 characters studied than the GCV. The differences between PCV and GCV for the 19 characters were very less indicating less environmental influence on those characters (Table 1). Similar findings were reported by Muhammad Rashid et al. (2007).

**Selection of biometrical techniques :**

The analysis of variance for combining ability indicated that the lines and testers differed significantly among themselves for all the traits under aerobic condition. Further, the analysis of GCA/SCA variances indicated that the nature of gene action was non-additive due to dominance with non-fixable genetic variation for
all the characters studied. The results are in accordance with the earlier reports of Babu et al. (2001).

The presence of greater magnitude of non-additive gene action offers scope for exploiting hybrid vigour through heterosis breeding and hence, these parents can be exploited for production of commercial hybrids. Similar results were also reported by Banumathy (2001). The proportional contribution to total genetic variance by the lines was found to be higher for 100 grain weight. For other characters contribution from line x tester interaction was higher. These results indicate the predominance of non-additive gene action. This is in accordance with the earlier reports of Muhammad Yussouf Saleem et al. (2010) and Malathi (2010).

**Evaluation of parents based on mean performance:**

As said by Gilbert (1958) and Nadarajan (1986) that the parents with high mean performance would result in good performing offspring, the lines IR79128A (L₁), IR79156A (L₂), COMS14A (L₃) and COMS24A (L₄) and the testers, IR 80286-22-3-6-1R (T₁), IR7925A-428-2-1-1R (T₂) and KMP -148 (T₁₂) were adjudged as the best parents as it had significantly desirable mean values for drought and yield traits (Fig. 1).

**Evaluation of parents based on general combining ability:**

Since the combining ability effect is one of the most important parameters commonly used by plant breeders to evaluate the genetic potential of the materials handled, IR79128A (L₁), IR70369A (L₄) and IR79156A (L₂) among lines and BI-33 (T₁₅), IR79582-21-2-2-1R (T₇), KMP-105 (T₁₁), T₁ (IR 69726-29-1-2-2R) and MAS-946-1 (T₉) (Fig. 2) among testers were found to be the best general combiners as earlier reported by Simmonds (1979) emphasizing that \(gca\) effect gives the intrinsic

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### Table 1: Details of parents

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Symbol</th>
<th>Genotypes</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lines</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>L₁</td>
<td>IR 79128A</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>2.</td>
<td>L₂</td>
<td>IR79156A</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>3.</td>
<td>L₃</td>
<td>IR73328A</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>4.</td>
<td>L₄</td>
<td>IR70369A</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>5.</td>
<td>L₅</td>
<td>CO MS-14A</td>
<td>TNAU, Coimbatore</td>
</tr>
<tr>
<td>6.</td>
<td>L₆</td>
<td>CO MS 24A</td>
<td>TNAU, Coimbatore</td>
</tr>
<tr>
<td><strong>Testers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>T₁</td>
<td>IR 69726-29-1-2-2R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>2.</td>
<td>T₂</td>
<td>IR 81178-2T-2-2-3R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>3.</td>
<td>T₃</td>
<td>IR 80286-22-3-6-1R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>4.</td>
<td>T₄</td>
<td>IR 7925A-428-2-1-1R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>5.</td>
<td>T₅</td>
<td>IR 79582-21-2-2-1R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>6.</td>
<td>T₆</td>
<td>IR 79200-45-2-2-1R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>7.</td>
<td>T₇</td>
<td>IR 80402-88-3-1-3R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>8.</td>
<td>T₈</td>
<td>IR05 N496R</td>
<td>IRRI, Phillipines</td>
</tr>
<tr>
<td>9.</td>
<td>T₉</td>
<td>MAS-946-1</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>10.</td>
<td>T₁₀</td>
<td>MAS-26</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>11.</td>
<td>T₁₁</td>
<td>KMP-105</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>12.</td>
<td>T₁₂</td>
<td>KMP-148</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>13.</td>
<td>T₁₃</td>
<td>KMP-149</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>14.</td>
<td>T₁₄</td>
<td>BR-2655</td>
<td>UAS, Bangalore</td>
</tr>
<tr>
<td>15.</td>
<td>T₁₅</td>
<td>BI-33</td>
<td>UAS, Bangalore</td>
</tr>
</tbody>
</table>
genetic value of the parent for a trait. High gca effects show presence of favourable genes with additive type of gene action. Therefore, a multiple crossing programme involving good general combiners isolated in the present study is recommended to identify superior genotypes as suggested by Nadarajan and Gunasekaran (2005).

Evaluation of hybrids based on sca effects:
The second important criterion for the evaluation of hybrids is the specific combining ability effects which could be related with hybrid vigour. The sca effects signify the role of non-additive gene action in character expression (Sprague and Tatum, 1942). The hybrids IR70369A / IR 7925A-428-2-1-1R (L₄ × T₄), IR 79128A / BR -2655 (L₄ × T₁₁) and IR70369A / KMP-105 (L₄ × T₁₁) expressed superior sca effects for majority of drought tolerant and yield attributing characters including single plant yield.

Evaluation of hybrids based on heterosis:
Significant standard heterosis over check IR6888 was observed in IR79156A / IR 79582-21-2-2-1R (L₂ × T₅) for 16 traits except plant height, 100 grain weight and root: shoot ratio. Similar results have been reported by Khoyumthem et al. (2005) and Soni et al. (2005).}

Evaluation of hybrids:
Hybridization is the most important method of crop improvement. The basic idea of hybridization is to combine favourable genes present in different parents into a single genotype.

Evaluation of hybrids based on mean performance:
The hybrids IR79156A / KMP-105 (L₄ × T₁₁), IR70369A / MAS -26 (L₄ × T₁₀), IR79156A / IR05 N496 (L₄ × T₉), IR79156A / BI-33 (L₄ × T₁₃) and CO MS- 14A / BR -2655 (L₄ × T₁₄) exhibited significantly desirable mean performance for most of the characters which included drought tolerant, yield and yield components under aerobic condition. These results are in conformity with the earlier findings of Sabesan et al. (2009) and Saravanan et al. (2006).

Selection of best parents and hybrids for utilization in plant breeding programme:
The utilization of hybrids directly for commercial seed production mainly depends on the genetic constitution of hybrids. The genetic constitution from the parameter like mean performance, sca effects and extent of heterosis. The hybrids IR70369A / IR 7925A-428-2-1-1R (L₄ × T₄) and IR70369A / KMP-105 are suitable for heterosis breeding (Plate 1) under aerobic condition (Fig. 3). This is in accordance with the reports of Malarvizhi et al. (2010).
Considering the hybrids showing non-significant sca effects with significantly favourable gca effects of parents for more than one character, the hybrid IR70369A / MAS -26 ($L_4 \times T_{10}$) is suitable for recombination breeding to get desirable segregants in early segregating generations for drought tolerant and yield attributes (Plate 2). These results are supported by the findings of Utharasu (2007) and Sheeba et al. (2010).

**Plate 2: Hybrid recommended for recombination breeding**

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