Allocytoplasmic restorers and performance of hybrids in rice (*Oryza sativa* L.)

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Abstract

Combining ability analysis for yield and quality traits of 54 rice hybrids developed by crossing three CMS lines and eighteen restorers in L x T design were evaluated in RBD. The magnitude of additive genetic variance (\( \sigma^2A \)) was higher than dominance variance for days to 50% flowering, effective tillers, kernel length after cooking and volume expansion ratio indicating the predominance of additive gene action. However, for the rest of the characters non additive gene action was predominant. The relative contribution of testers were high for days to 50% flowering(79.6%), self fertility (72.8%) and flag leaf length (79.9%), indicating influence of parents and interaction contribution (L x T) was high for filled seeds/panicle, yield/plant (57.0%) and hulling percent (63.5%). Among the lines 68897A showed significant gca effects in the desirable direction and identified as best combiner for yield/plant, days to 50% flowering, effective tillers, panicle density, hulling percent, head rice recovery, kernel width after cooking, water uptake and volume expansion ratio, while 79156A for self fertility, filled seeds/panicle and panicle length. Among the male parents RR15 was found to be good combiner for panicle length, filled seeds/panicle, unfilled seeds/panicle, self fertility, test weight, yield/plant and RR 23 for effective tillers, panicle length and head rice recovery. The cross combinations 68897 A x RR 23, 68897 A x RR 32, 68897 A x RR55 and 79156 A x RR3 recorded significant sca effects for yield/plant and were relatively better performed for desired yield and quality traits based on sca effects, per se performance and gca effects of parents.

**Key words:** Rice, Combining ability, gca, sca, Quality, Hybrids

INTRODUCTION

Rice is the principal food crop and most extensively grown cereal crop in the tropical and subtropical regions of the world. Today rice has a special position and a source of providing more than 75% of the Asian population and more than three billion of world population meals which represents 50-80% of their daily calorie intake (Khush, 2005). There is an urgent need to increase rice production to meet the requirements of over growing population. The development of hybrids with a yield advantage of 30% over the existing hybrids is the best option for increasing production and productivity. Therefore performance of the hybrids depends on choice of the potential parents for exploitation of heterosis. Combining ability analysis is a powerful tool for estimating the value of a parent to produce superior hybrids, provides information about the nature and magnitude of gene effects governing various traits. Its role is important to decide parents, crosses and appropriate breeding procedures to be followed to select desirable segregants (Salgotra et al., 2009). Keeping this in view, the present investigation was undertaken to study the combining ability in rice to identify superior hybrid combinations for yield and quality traits.

MATERIALS AND METHODS

The present study was conducted between 2016 and 2017 in the research farm of Regional Agricultural Research Station, Warangal, Telangana state. The material for the study comprised of three Cytoplasmic Male Sterile lines 79156A, 79128A and 68897A and...
eighteen restorers RR3, RR15, RR17, RR23, RR32, RR50, RR55, RR65, WGL-347, WGL-616, WGL-674, WGL-676, WGL-705, WGL-739, WGL-810, WGL-1063, MTU1156 and MTU 11-320-20. The above first eight restorers were newly developed restorer lines through allocytoplasmic restorer (R x R) development programme through recombination breeding and other ten restorers were from advanced breeding lines. Staggered sowing of the parents was taken up to facilitate synchronization in flowering among female and male parents. Crossing block was raised during Rabi, 2016 and each line was crossed with 18 testers in Line x Tester mating design of Kempthorne, (1957) to develop hybrids. The F1 seed of 54 cross combinations was planted along with 21 parents (3 CMS lines and 18 restorers) with a spacing of 20 x 15 cm in randomized block design with two replications during kharif, 2017. Recommended package of practices was adopted. Twenty five days old seedlings were transplanted single plant per hill in two rows of 1.2 m length. The performance of F1 hybrid combination and their parents were evaluated by recording observations on ten randomly selected plants from each genotype on the following attributes as per the standard evaluation system i.e., plant height (cm), panicle length (cm), effective tillers/plant, flag leaf length (cm), flag leaf width (cm), panicle density (g), filled seeds/panicle, unfilled seeds/panicle, self fertility (%), test weight (g), grain yield/plant except days to 50% flowering which was computed on plot wise basis. Due to male sterility nature of the CMS lines or female lines their corresponding maintainer lines were used for studying yield and quality traits.

Data were also recorded on physical and chemical quality characters viz., hulling percent (%), milling percent (%), head rice recovery (%), kernel length (mm), kernel width (mm), length/breadth ratio, kernel length after cooking (mm), kernel width after cooking (mm), kernel elongation ratio, alkali spreading value, volume expansion ratio and water uptake (ml). Observations on hulling and milling were taken with the help of Satake company make laboratory huller (Type THU35A) and polisher (TypeTMO5). Data on head rice recovery was recorded. Kernel length and kernel width of 20 whole milled rice were measured by means of dial caliper and length and breadth ratio were computed as per Murthy and Govindaswamy (1967). Kernel elongation ratio was determined by soaking 5 g of whole milled rice in 12 ml distilled water for 10 minutes and later cooked for 15 minutes in the water bath. Observations on the length and breadth of cooked kernels and elongation ratio were recorded with the help of a graph sheet to quantify cooking traits, while water uptake, volume expansion ratio and alkali spreading value by following the standard procedures. Combining ability analysis for various yield and quality traits was accomplished by the method suggested by Kempthorne (1957) through windostat version 9.2 from indostat services Hyderabad (India). Character wise estimation of gca effects of parental lines and sca effects of cross combinations were evaluated by t-test.

RESULTS AND DISCUSSION

The analysis of variance showed significant variation due to genotypes for all the yield and quality traits studied (Table 1). The parents also exhibited significant differences for the characters under study. The lines differed significantly among themselves for most of the important characters. Testers also differed significantly for all the characters studied. Line x Tester interaction was significant for all the characters except effective tillers, unfilled seeds/panicle, hulling percent, kernel elongation ratio indicated presence of wide genetic variation among lines and testers. Female parents interacted significantly with the male parents provided a direct test indicating that non additive variance was important for many of the characters. These results are in conformity with the findings of Akter et al. (2010) and Thakare et al. (2013), Rukmini Devi et al. (2018) Ambikabathy et al. (2019) and Buelah et al. (2020) who also reported that female parents interacted significantly with the male parents. The parents Vs hybrids comparison was found to be significant for all the yield and quality traits except effective tillers, panicle density, filled seeds/panicle, hulling percent, kernel width, kernel elongation ratio and alkali spreading value indicating a substantial amount of heterosis in hybrids. The proportional contribution of female parents, male parents and their interaction towards total variance was also estimated (Table 1). Female parents played an important role towards volume expansion ratio and male parents were important for days to 50% flowering, plant height, flag leaf length, flag leaf width, panicle density, unfilled seeds/panicle, self fertility, test weight, kernel length, kernel width, length/breadth ratio, kernel length after cooking and alkali spreading value revealing the predominant influence for these traits. The contribution of paternal and maternal interaction (female x male) was observed to be best in proportion for the traits effective tillers, filled seeds/panicle, yield/plant, hulling percent, milling percent, head rice recovery, kernel width after cooking, kernel elongation ratio and water uptake indicating that these characters are influenced by non additive gene action. The high contribution of maternal and paternal interaction in rice for the traits yield/plant, effective tillers, head rice recovery, kernel width after cooking and alkali recovery recorded by Showkat et al. (2015). Combining ability variances in the present study (Table 2) revealed that magnitude of additive genetic variance (e2A) was higher than dominance variance (e2D) for the characters days to 50% flowering, effective tillers, flag leaf width, kernel length after cooking, kernel width after cooking and volume expansion ratio indicating predominance of additive gene action. Similar views were expressed by Srinivas et al. (2015) and Rukmini Devi et al. (2017) for kernel length after cooking and kernel width after cooking, Salgotra et al. (2009) and Showkat et al. (2015) for days to 50 % flowering and Asvin Kirubha et al. (2019) for kernel length after cooking. However, for rest of the traits viz., plant height, panicle length, flag leaf width, panicle density, filled seeds/panicle, self fertility, test weight, yield/plant, unfilled seeds/panicle,
Table 1a. Analysis of variance of combining ability for yield and yield components in rice

| Source of variation | D.F | Replications | Treatments | Parents | Parent(line) | Parent(tester) | Parent (line x tester) | Parents vs. Crosses | Crosses | Line effect | Tester effect | Line x tester effect | Error | Total | Contribution (%) |
|---------------------|-----|--------------|------------|---------|-------------|--------------|----------------------|---------------------|---------|-------------|---------------|---------------------|--------|-------|-----------------|
| Days to 50% flowering | 1 706 | 1.062 | 142.723** | 122.407** | 2.146 | 6.019 | 194.115** | 7.861** | 4.3718** | 0.201 | 0.053 | 0.009 | 0.012** | 0.366 | 29.92 | 4.678 | 2.2 | 1.38 |
| Effective tillers/m² | 1 706 | 0.022 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Plant height | 1 706 | 11.908 | 39.548 | 190.115** | 7.861** | 4.3718** | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Panicle length | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Flag leave length | 1 706 | 11.908 | 39.548 | 190.115** | 7.861** | 4.3718** | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Flag leave width | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Panicle density | 1 706 | 11.908 | 39.548 | 190.115** | 7.861** | 4.3718** | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Filled seeds/panicle | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Unfilled seeds/panicle | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Self fertility | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Test weight | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |
| Yield/plant weight | 1 706 | 0.026 | 19.44 | 2.574 | 0.201 | 0.053 | 0.009 | 0.366 | 4.678 | 2.2 | 1.38 |

* and ** significant at 5% and 1% level, respectively

Table 1b. Analysis of variance of combining ability for quality traits in rice

| Source of Variation | DF | Hulling recovery | Milling recovery | Head rice recovery | Kernel length | Kernel width | L/B ratio | Kernel length after cooking | Kernel breadth after cooking | Kernel elongation value | Alkali spreading value | Volume expansion ratio | Water uptake |
|---------------------|----|------------------|-----------------|-------------------|---------------|-------------|----------|---------------------------|---------------------------|-----------------------|---------------------|----------------------|-------------|
| Replications | 1 | 1.622 | 11.062 | 12.557 | 2E-05 | 0.02 | 0.06 | 0.026 | 0.00015 | 0.001 | 0.106 | 0.015 | 11.2 |
| Treatments | 1 | 7.179** | 64.713** | 255.455** | 0.350** | 0.035 | 0.160** | 0.543** | 0.098** | 0.011** | 1.124** | 2.255** | 10256.976** |
| Parents | 2 | 4.531 | 39.781** | 11.671** | 0.131 | 0.024 | 0.283 | 0.673** | 0.140** | 0.004 | 0.166 | 0.186 | 1754.166** |
| Parent(line) | 1 | 17.761** | 96.508** | 270.465** | 0.426** | 0.093** | 0.181 | 0.736** | 0.12159** | 0.009** | 0.797** | 0.267** | 8616.013** |
| Parent(tester) | 1 | 0.04 | 41.204** | 587.583** | 1.046 | 0.178 | 1.746** | 1.778** | 0.062** | 0.00009 | 7.862** | 0.600** | 85434.920** |
| Parent (line x tester) | 1 | 6.762 | 109.516** | 1610.613** | 2.735** | 0.00013 | 0.566** | 1.599** | 1.732** | 0.013 | 0.251 | 24.609** | 13410.326** |
| Parents vs. Crosses | 1 | 53.724** | 55.374** | 224.231** | 0.276** | 0.014 | 0.111 | 0.433** | 0.059** | 0.012** | 1.158** | 2.581** | 7178.499** |
| Crosses | 1 | 2.136 | 103.4 | 375.5 | 0.074 | 0.009 | 0.025 | 1.752** | 0.410** | 0.03 | 2.861* | 28.695** | 40028.481** |
| Line effect | 1 | 17.642 | 52.4 | 327.264** | 0.559** | 0.022 | 0.209 | 0.697** | 0.006 | 0.001 | 1.651* | 1.196 | 74288.323** |
| Tester effect | 1 | 34.177** | 54.036** | 163.638** | 0.146 | 0.011 | 0.067 | 0.224** | 0.049** | 0.014** | 0.812** | 1.737** | 5120.981** |
| Line X Tester effect | 1 | 7.401 | 6.346 | 3.589 | 0.032 | 0.005 | 0.009 | 0.018 | 0.003 | 0.047 | 0.179 | 0.076 | 52269.8 |
| Error | 1 | 149.457 | 35.36 | 12.667 | 0.19 | 0.02 | 0.094 | 0.318 | 0.058 | 0.007 | 0.766 | 1.158 | 52269.8 |
| Contribution (%) | 1 | 7.60 | 7.04 | 6.67 | 1.01 | 2.53 | 0.85 | 15.25 | 26.0 | 9.25 | 9.31 | 41.94 | 21.04 |
| Testers | 1 | 29.39 | 30.3 | 46.8 | 4.9 | 49.2 | 60.19 | 51.58 | 20.28 | 15.87 | 45.7 | 17.87 | 33.9 |
| L X T | 1 | 63.50 | 62.6 | 46.8 | 34.0 | 43.2 | 38.9 | 331.53 | 53.71 | 74.8 | 44.9 | 43.07 | 45.7 |

* and ** significant at 5% and 1% level, respectively

Rukmini Devi et al.,
hulling percent, milling percent, head rice recovery, kernel length, kernel width, length/breadth ratio, kernel elongation ratio, alkali spreading value and water uptake, the value of $e^2A$ is lower than $e^2D$ indicating the predominance of non additive gene action. The presence of non additive genetic variance offer scope for exploitation of heterosis. The predominance of non additive gene action for grain yield/plant and important yield and quality traits has been reported by Satyanarayana et al. (2000). The existence of both additive and non additive type of gene action for yield and quality traits has also been reported by Showkat et al. (2015) and Rukmini Devi et al. (2018).

Both $gca$ and $sca$ effects were estimated for yield and quality traits (Table 3, and 4). The estimates of combining ability effects aid in selecting desirable parents and crosses as well as suitable breeding procedures for further improvement of various yield and quality traits in rice. Regarding $gca$ effects, the negative effects for days to 50% flowering, plant height, flag leaf width, kernel width and kernel length after cooking are considered desirable whereas, positive effects are desirable for other yield and quality traits. The $gca$ attributed to additive gene effects and additive $x$ additive epistasis and theoretically fixable, on the other hand $sca$ attributable for non additive gene action may be due to dominance or epistasis or both and are non fixable. 'The presence of non additive genetic variance is the primary justification for initiating hybrid programme (Cockarham,1961; Pradhan et al., 2006).

Earliness being a desirable trait and helps to develop early hybrids. Significant negative $gca$ was exhibited by the line 68897A (-1.130) while, among testers RR32, RR3, RR17 and MTU 11-320-20 has showed good $gca$ in desired direction. The CMS lines 79156 A and restorers RR15, RR23, RR55, RR65, WGL676 and WGL 705 were recorded as poor combiners because they possessed significant positive $gca$ effect. (Table 3).The hybrids 79128 A x WGL-739, 68897 A x WGL 676, 79128 A x RR 3, 68897 A x MTU 1156 and 79156 A x MTU11-320-20 showed significant negative $sca$ effects (Table 4).Total number of productive tillers per plant generally associated with high productivity. The significant positive value of $gca$ effect for effective tillers amongst

### Table 2a. GCA and SCA variance for yield and yield components in rice

| Source of Variation | Days to 50% flowering | Plant height | Plant length | Effective tillers/ m² | Flag leaf length | Flag leaf width | Panicle density | Filled seeds / panicle | Unfilled Seeds/ panicle | Self fertility | Test weight | Yield/plant |
|---------------------|-----------------------|--------------|--------------|-----------------------|-----------------|----------------|------------------|-----------------------|------------------------|---------------|-------------|-------------|
| $\sigma^2$ GCA (Lines) | 1.1235                | 1.539        | 0.187        | 0.3232**              | 2.129           | 0.006         | 0.090           | 208.9                 | -1.79                  | 0.547         | 0.587*      | 9.445*      |
| $\sigma^2$ GCA (Testers) | 19.918**              | 27.37**      | 1.995**      | 0.3114                | 11.618*         | 0.0513*       | 1.216**         | 769.03                | 297.06**              | 39.77**       | 2.109**     | 10.948**    |
| $\sigma^2A$         | 7.61                  | 10.49        | 0.89         | 0.64                  | 6.96            | 0.0136        | 0.50            | 577.76                | 8.18                   | 12.3          | 1.60        | 19.32       |
| $\sigma^2D$         | 5.45                  | 29.75        | 1.22         | 0.45                  | 12.5            | 0.0017        | 0.75            | 1535.6                | 184.7                  | 16.9          | 2.96        | 34.3        |
| $\sigma^2GCA$       | 3.808                 | 5.247**      | 0.4456**     | 0.3215*               | 3.484*          | 0.0068*       | 0.251**         | 288.9*                | 40.90**                | 6.151**       | 0.804**     | 9.660**     |
| $\sigma^2SCA$       | 5.452                 | 29.75**      | 1.2208**     | 0.4456**              | 12.54**         | 0.0017        | 0.755**         | 1535.1**              | 184.78**               | 16.939**      | 2.963**     | 34.30**     |
| $\sigma^2GCA/ \sigma^2 SCA$ | 1.196                 | 0.176        | 0.730        | 0.760                 | 0.277           | 7.910         | 0.665           | 0.376                 | 0.442                  | 0.726         | 0.543       | 0.563       |

* and ** significant at 5% and 1% level, respectively

### Table 2b. GCA and SCA variance for quality traits in rice

| Source of Variation | Hulling recovery | Milling recovery | Head rice recovery | Kernel length | Kernel width | L/B ratio | Kernel length after cooking | Kernel breadth | Kernel elongation ratio | Alkali spreading value | Volume expansion ratio | Water uptake |
|---------------------|------------------|------------------|--------------------|---------------|--------------|-----------|----------------------------|-----------------|------------------------|-----------------------|----------------------|-------------|
| $\sigma^2$ GCA (Lines) | 0.3206           | 2.696            | 10415              | 0.0012        | 0.0001       | -0.0001   | 0.0460*                    | 0.0109**       | 0.0007                 | 0.0679*               | 1104.4*             | 0.7950**    |
| $\sigma^2$ GCA (Testers) | 0.7707           | 7.675            | 53.94*             | 0.0878**      | 0.0028*      | 0.0301**  | 0.1001**                   | 0.0037          | 0.00004                | 0.2057*               | 1193.57             | 0.1867*     |
| $\sigma^2A$         | 1.53              | 6.81             | 33.2               | 0.027         | 0.0001       | 0.008     | 0.107                       | 0.019           | 0.001                  | 0.175                 | 1.41                 | 2234        |
| $\sigma^2D$         | 10.3              | 23.8             | 80.02              | 0.057         | 0.0026       | 0.01      | 0.063                       | 0.156           | 0.005                 | 0.197                 | 0.830                | 2426        |
| $\sigma^2GCA$       | 0.3849*           | 3.407*           | 16.63**            | 0.0135**      | 0.0005**     | 0.0042**  | 0.0537**                   | 0.0098**       | 0.0007                 | 0.0876**               | 1117.020*            | 0.7081*     |
| $\sigma^2SCA$       | 2.579**           | 23.40**          | 80.02**            | 0.0570**      | 0.0026**     | 0.0196**  | 0.0636**                   | 0.0156**       | 0.0054                 | 0.1973*                | 2426.8*              | 0.8306**    |
| $\sigma^2GCA/ \sigma^2 SCA$ | 0.298             | 0.2858           | 0.4157             | 0.475         | 0.1905       | 0.4324    | 1.688                       | 1.249           | 0.2575                 | 0.8877                | 0.9207               | 1.705       |

* and ** significant at 5% and 1% level, respectively
the female and male parents was observed in 68897 A and RR 23, RR 50 and WGL 676 which could be utilized for evolving hybrids with more effective tillers/plant. Showkat et al. (2015) also reported 68897 A was good combiner for effective tillers (Table 3a). The crosses 79156 A x MTU 1156, 68897 A x RR 23 and 68897 A x RR 55 recorded significant desirable estimates of sca effects. Dwarf plant stature is desirable to develop semi dwarf high yielding hybrids which will be lodging resistant and fertilizer responsive. Among the females 68897A and among the testers RR 55, RR 32, RR 3, MTU 11-320, WGL 705 and WGL 676 recorded significant gca effects in desired direction. The hybrids 79128 A x RR 3 and 68897 A x RR 23, showed significant negative sca effects (Table 4a). Longer panicle length is associated with more number of spikelets per panicle resulting in higher productivity. Significant positive gca effect, among lines was exhibited by 79156 A and testers viz., RR 50, WGL 1063, RR 15, RR 23 and RR 65 (Table 3a). Only four hybrids 68897 A x WGL 616 and 68897 A x MTU-11-320 exhibited significant sca effect for panicle length. The number of filled seeds per panicle is one of the most important yield component in rice. Among the lines 79128 A, 79156 A and among male parents WGL 1063, RR 15, WGL 616 and WGL 347 and RR 65 exhibited significant positive gca effect which could be utilized for evolving more filled grains/panicle, whereas nine hybrids recorded significant sca effects viz., 68897 A x WGL 810, 68897 A x MTU 1156, 68897 A x MTU-11-320 and 79156 A x RR 23 (Table 4).

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Table 3b. Estimates of general combining ability effects for quality traits in rice

| Source of Variation | Hulling recovery | Milling recovery | Head rice recovery | Kernel length | Kernel width | L/B ratio | Kernel length after cooking | Kernel breadth after cooking | Kernel elongation ratio | Alkali spreading value | Volume expansion ratio | Water uptake |
|---------------------|------------------|------------------|--------------------|---------------|-------------|-----------|----------------------------|-----------------------------|-------------------------|------------------------|------------------------|---------------|
| Lines               |                  |                  |                    |               |             |           |                            |                             |                         |                        |                        |               |
| 79156A              | -0.684** -1.956*** -1.336** | 0.050             | 0.003              | 0.022         | 0.232**     | 0.100**   | 0.028**                    | 0.250*                      | -0.593** -36.130**       |
| 79128A              | 0.182            | 0.941* -2.361**  | -0.039 -0.018      | 0.008         | -0.025      | 0.012      | 0.003                       | -0.306**                    | -0.434** 29.593**        |
| 68897A              | 0.502* 1.016* 3.697** -0.011 0.015 | -0.030 -0.207** -0.112** -0.030** | 0.056 | 1.027** 6.537* |
| SE ±               | 0.236 0.419 0.317 0.03 0.092 | 0.028 0.051 0.022 0.01 | 0.107 | 0.04 2.72     |
| Testers            |                  |                  |                    |               |             |           |                            |                             |                         |                        |                        |               |
| RR3                 | -0.018 -3.390** -7.747** | 0.016             | -0.040            | 0.078         | -0.013      | -0.061    | -0.009                      | -0.381*                     | -0.326** 42.509**        |
| RR15                | -0.801 4.310** 10.719** -0.447** 0.070* -0.357** -0.338* 0.039 0.035 | -0.194 | -0.259* 49.157** |
| RR17                | 0.016 -5.173** -14.331** 0.059 0.081* -0.097 0.012 -0.044 -0.014 0.639* -0.759** 17.343* |
| RR23                | 0.432 0.327 2.653** -0.036 -0.029 | 0.031 -0.263* 0.006 -0.042 -0.194 | -0.259* 28.343* |
| RR32                | -2.218** -4.256** -9.214** -0.894** -0.045 -0.417** -0.971** 0.164* 0.021 | -0.361 -0.393** -40.824** |
| RR50                | 0.432 -1.306 4.019** 0.393** 0.078* | 0.074 0.346** 0.081 -0.020 0.139 | -0.576* 8.343 |
| RR55                | 0.416 0.260 -0.231 0.373** -0.012 0.219** 0.312* -0.061 -0.017 -0.528 | -0.459* -0.824 |
| RR65                | 0.149 0.577 -0.147 -0.167* 0.020 -0.124 -0.088 0.098 0.03 -0.694* -0.059 -19.157** |
| WGL347              | 0.316 -0.390 -2.064* -0.221** -0.034 | 0.071 -0.196 -0.011 0.01 -0.028 | 0.341** 9.176 |
| WGL616              | 1.699* 6.527** 11.753** 0.071 -0.042 0.103 | 0.171 0.081 0.015 0.139 | 0.257* 23.343* |
| WGL674              | -1.384* -0.490 -0.514 0.074 -0.064* 0.149* | -0.028 -0.144* -0.019 -0.361 | 0.391** -30.824** |
| WGL676              | 0.099 1.460 6.003** 0.029 -0.102** 0.194** 0.537** 0.106 0.086** 1.139** | 0.091 | 64.176** |
| WGL705              | 0.766 2.610* 3.053** 0.276** -0.029 0.198** 0.212 | -0.044 -0.019 | 0.806** | 0.291* | -13.324 |
| WGL739              | 0.749 -0.223 5.269** 0.333** 0.008 0.163* 0.312* -0.061 -0.014 -0.361 | 0.824** -5.824 |
| WGL810              | 1.732** 2.844** 8.853** 0.101 -0.005 0.059 | 0.096 -0.011 | 0.007 0.639* | 0.441** | -29.157** |
| WGL1063             | -0.318 0.510 -10.797** -0.011 0.143** -0.234** -0.304* -0.044 | 0.055 -0.694* -0.326** -62.491** |
| MTU1156             | -1.868* -3.410** -2.747** 0.016 -0.039 0.073 | 0.062 -0.077 | 0.006 0.139 | 0.107 | 54.176** |
| MTU II-320-20       | -0.201 -1.056 4.531** 0.008 0.036 -0.041 0.137 -0.019 0.015 0.139 | 0.674** 4.176 |
| SE ±                | 0.580 1.02 0.773 0.07 0.031 0.069 0.127 0.055 0.02 0.263 | 0.11 6.67     |

* and ** significant at 5% and 1% level, respectively.

Panicle density is also a very important yield contributing character in rice. The female parent 68897 A and male parents RR 32, RR 55, and RR 3 were good general combiners by recording significant positive gca effects indicating positive alleles for panicle density which could be fixed in subsequent generations (Table 3). Significant sca effects were exhibited by ten hybrids and 68897 A x RR 55, 79128A x MTU 1156, 68897 A x RR 65 and 68897 A x RR 32 recorded higher sca effects. Chaffy-ness is undesirable in case of hybrids to get more yield. For this trait, 79156 A among the lines and RR 3, RR 15, RR 17, WGL 616, WGL 1063, MTU 11-320-20, RR 50 and RR 23 recorded negative gca effects and the hybrids 68897 A x RR 55, 79156 A x WGL 674, 79156 A x WGL 676, 79156 A x MTU 1156 and 79156 A x MTU11-320 manifested significant negative sca effects in desirable direction (Table 4). Self fertility is generally associated with higher productivity. Interestingly the same lines, testers and hybrids which showed negative gca and sca effects for unfilled seeds per panicle and exhibited significant positive gca and sca effects for self fertility percentage.

Test weight is also a very important yield contributing trait in rice. The line 79128 A and male parents RR 50, MTU 1156, RR 17, WGL 810, RR 65 and MTU-11-320 were identified as good general combiners for this trait (Table 3). Among 54 hybrids, twelve hybrids 79128 A x MTU 1156, 79156 A x RR 23, 79156 A x RR 50 recorded significant sca effect (Table 4). For grain yield/plant significant gca effects was recorded by 68897 A among

https://doi.org/10.37992/2021.1204.194
| S.No. | Hybrids | Days to 50% flowering | Effective tillers/m² | Plant height | Panicle length | Flag leaf length | Flag leaf density | Filled seeds/panicle | Unfilled seeds/panicle | Self fertility | Test weight | Yield/ plant |
|-------|---------|------------------------|----------------------|-------------|---------------|----------------|------------------|----------------------|-----------------------|--------------|-------------|-------------|
| 1     | 79156AXRR3 | 4.139** | 0.694 | 11.657** | 1.450 | 5.436** | 0.188 | -1.343** | 28.083 | 12.556* | -4.679* | -0.760 | 6.138** |
| 2     | 79156AXRR15 | 0.639 | 0.194 | 1.274 | -0.234 | 0.653 | -0.079 | 0.792* | -28.750 | -0.278 | -1.256 | -0.360 | 2.871 |
| 3     | 79156AXRR17 | -0.361 | 0.528 | 1.774 | 0.666 | 0.253 | 0.205 | 0.888* | -14.250 | 3.556 | -2.759 | -0.060 | -6.556** |
| 4     | 79156AXRR23 | -1.361 | -1.472** | 2.374 | 0.000 | 4.419** | -0.079 | -1.075** | 48.083** | 7.556 | -1.256 | 3.506** | -8.529** |
| 5     | 79156AXRR32 | -0.528 | -1.139* | -1.859 | -0.167 | -2.214 | 0.055 | -0.472 | -26.083 | 27.389** | -1.333 | -0.277 | -9.979** |
| 6     | 79156AXRR50 | -1.694 | -0.639 | -3.693 | 1.033 | 4.353* | -0.132 | 0.862* | -1.447 | 5.511 | 2.319 | 3.914* | -2.629 |
| 7     | 79156AXRR55 | 0.639 | -0.472 | -1.443 | -1.109 | 1.419 | -0.359* | 1.422** | 29.583* | 34.389** | -4.894* | 0.956 | 0.071 |
| 8     | 79156AXRR65 | -0.028 | 0.028 | -2.226 | 0.000 | 2.119 | 0.088 | -0.185 | 1.250 | -0.944 | -3.899 | 1.340* | -0.162 |
| 9     | 79156AXWL347 | -0.528 | 0.528 | -3.259 | -0.034 | 0.786 | 0.038 | 0.175 | 34.583** | 4.056 | -0.788 | 0.106 | 5.738** |
| 10    | 79156AXWL616 | -1.861 | 0.694 | 1.959 | 0.900 | 0.153 | -0.012 | 0.448 | 35.639* | -5.611 | 4.146 | 0.923 | -2.995 |
| 11    | 79156AXWL674 | -0.916 | 0.194 | -3.053 | -0.200 | -3.547* | -0.079 | 0.907** | -13.083* | -23.444** | 5.882* | 0.390 | 5.221** |
| 12    | 79156AXWL676 | -1.028 | -0.472 | 2.207 | 0.666 | -3.321 | -0.016 | -0.932 | 5.128* | 0.306 | 5.355** |
| 13    | 79156AXWL678 | -0.861 | -0.636 | -1.939 | 0.333 | -2.381 | -0.162 | 0.106 | 6.417 | 9.556 | -3.442 | -0.094 | 2.438 |
| 14    | 79156AXWL739 | 1.306 | 0.361 | 5.574* | -0.200 | -0.314 | 0.188 | -0.348 | 14.083 | -9.944 | 4.516 | 1.123 | 6.055 |
| 15    | 79156AXWL810 | -1.194 | 0.528 | 1.174 | 0.133 | -1.814 | 0.021 | 0.277 | -80.583** | -6.611 | -3.707 | 0.156 | 2.171 |
| 16    | 79156AXWL1063 | 2.139* | -0.193 | -2.926 | 0.366 | -3.414 | -0.145 | -0.727 | -51.083* | -12.611* | -4.099 | -1.344* | -3.929* |
| 17    | 79156AXMTU1156 | 3.639** | 1.194** | -1.326 | -0.934 | -1.347 | 0.121 | -0.258 | 1.750 | -7.944 | 5.054* | -0.677 | 1.705 |
| 18    | 79156AXMTU1120-20 | -2.194* | 0.028 | 2.107 | 0.155 | 0.018 | 1.256 | 2.612* | -8.601** | -6.750 | 1.059 | 1.851** | -4.656** |

* and ** significant at 5% and 1% level, respectively

Rukmini Devi et al.,

Table 4a. Estimates of specific combining ability effects for yield and yield components in rice.
Table 4b. Estimates of specific combining ability effects for quality traits in rice.

| S.No. | Hybrids | Hulling recovery | Milling recovery | Head rice length | Kernel length | Kernel thickness | L/B ratio | Kernel length after cooking | Kernel breadth after cooking | Kernel elongation value | Alkali spreading value | Volume expansion ratio | Water uptake |
|-------|---------|------------------|------------------|------------------|---------------|-----------------|----------|----------------------------|----------------------------|------------------------|---------------------|----------------------|---------------------|
| 1     | 79156AXRR3 | 1.784 | 6.290** | 8.036** | 0.045 | -0.078 | 0.168 | -0.390 | -0.200** | -0.071 | 0.417 | -0.157 | 63.630** |
| 2     | 79156AXRR15 | 0.018 | 7.440** | 4.069** | -0.122 | -0.053 | 0.013 | 0.085 | 0.150 | 0.051 | 0.250 | 0.076 | 40.296** |
| 3     | 79156AXRR17 | -0.699 | -6.627* | -7.311** | 0.032 | 0.110** | -0.157 | -0.015 | 0.058 | -0.011 | -0.583 | 0.726** | -49.204** |
| 4     | 79156AXRR23 | -1.161 | -7.227* | -16.864** | 0.277* | -0.005 | 0.160 | 0.385 | 0.158 | 0.012 | 0.250 | -0.024 | -17.204 |
| 5     | 79156AXRR32 | -0.816 | -5.044** | -0.097 | 0.220 | -0.108 | 0.290* | -0.432 | 0.175 | -0.136** | -0.083 | 0.259 | -45.537** |
| 6     | 79156AXRR50 | 0.584 | 2.294 | 9.319** | 0.023 | 0.039 | -0.054 | 0.001 | -0.002 | -0.004 | 0.417 | 0.443* | 7.796 |
| 7     | 79156AXRR55 | -2.699* | -5.710** | -7.931** | -0.482** | -0.046 | -0.184 | 0.285 | -0.100 | 0.147** | -0.417 | 0.476* | -25.537* |
| 8     | 79156AXRR65 | -1.982 | -1.977 | -7.514** | 0.233 | -0.048 | 0.205 | -0.065 | 0.066 | -0.069 | 0.750 | 0.126 | 32.796** |
| 9     | 79156AXWGL347 | 1.151 | 1.040 | 5.653** | 0.152 | 0.030 | 0.031 | -0.082 | -0.025 | -0.004 | 0.583 | -0.624** | -10.537** |
| 10    | 79156AXWGL616 | -0.632 | 0.073 | 1.636 | -0.050 | -0.006 | 0.071 | 0.001 | 0.042 | 0.011 | -0.083 | 0.109 | 35.296** |
| 11    | 79156AXWGL674 | -0.199 | 2.540 | 9.603** | 0.172 | 0.025 | 0.056 | 0.105 | 0.033 | -0.016 | 0.417 | -0.224 | -55.537** |
| 12    | 79156AXWGL676 | 2.718** | 3.590* | -3.514* | -0.078 | 0.059 | -0.159 | 0.285 | 0.058 | 0.069 | 0.083 | 0.326 | 19.463 |
| 13    | 79156AXWGL705 | 2.701** | 4.190* | -0.414 | -0.080 | -0.055 | 0.633 | 0.335 | 0.008 | 0.074 | -0.750 | -0.024 | -65.537** |
| 14    | 79156AXWGL739 | 1.318 | 3.123 | 7.519** | -0.222 | 0.034 | -0.182 | 0.285 | 0.100 | 0.089* | -0.583 | -0.107 | -5.537** |
| 15    | 79156AXWGL810 | 0.384 | 4.856** | 0.836 | 0.240 | 0.117** | -0.074 | 0.051 | 0.000 | -0.038 | -0.083 | -0.424 | 62.796** |
| 16    | 79156AXWGL1063 | -2.065* | 3.340 | 0.236 | -0.093 | -0.101 | 0.100 | -0.749** | -0.267** | -0.109* | 0.750 | 0.357 | 3.630 |
| 17    | 79156AXMTU1156 | -1.016 | 5.460** | -0.114 | -0.045 | -0.017 | 0.235 | 0.184 | 0.084 | -0.583 | 0.259 | -0.537 | 6.463 |
| 18    | 79156AXMTU1150 | 1.068 | -4.144** | -8.331** | -0.080 | 0.134** | -0.254** | 0.315 | 0.108 | -0.039 | -0.583 | -0.857** | 9.463 |

* and ** significant at 5% and 1% level, respectively

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lines and among restorers RR23, WGL 1063, WGL 676, RR 15, WGL 705, RR 17, WGL 674. (Table 3) Eleven hybrids 68897 A x RR 23, 68897 A x RR 32, 79128 A x WGL 616, 79156 A x RR 3, 79128 A x RR 17, 68897 A x WGL 616, 79156 A x RR 3, 79156 A x WGL 347, 79156 A x WGL 674, 79128 A x WGL 810 exhibited significant sca effects (Table 4). Tiwari et al. (2011) observed that several hybrids had high sca effects for grain yield in rice.

In the present study, both general and specific combing ability effects were estimated for various quality attributes (Table 3 and 4). For hulling recovery, significant positive value of gca effects exhibited among female and male parents viz., 68897 A and WGL 616 and WGL 810. While, significant positive sca effect was recorded by six hybrids viz., 68897 A x RR 32 and 79156 A x WGL 676. For milling recovery 79128 A among lines and WGL 66, RR 15, WGL 810 and WGL 705 in testers exhibited significant positive gca effect implying their good general combining ability which may be utilized in breeding programmes for improvement of this trait (Table 3). Twelve hybrids registered significant sca effects in desired direction viz., 79128 A x MTU 1156, 79156 A x RR 15 and 79156 A x RR 3 for milling recovery.

In case of head rice recovery, significant positive value of gca effect among the female parents was exhibited by 68897A and among males WGL616, RR15, WGL810, WGL676, RR50, WGL739, WGL705 and RR23, respectively (Table 3). Significant positive sca effect was revealed by 21 hybrids viz., 68897 A x WGL676 (14.05), 68897 A x RR55(12.03), 79128A x MTU 1156(11.26), 79156A x WGL674 (9.60) and 68897 A x RR23(9.55) respectively (Table 4). Both positive and negative sca effects in various cross combinations of 68897A were also reported by Thakare et al. (2013) and Showkat et al. (2015).

Positive gca effect for kernel length among lines was exhibited by 79156 A, while pollen parents recorded significant positive gca effects viz., RR 50, RR 55, WGL 739 and WGL 705 (Table 3). Significant positive sca effect for kernel length was revealed by 79128 A x RR 65, 68897 A x RR 55, 68897 A x WGL 676, 68897 A x WGL 739 (Table 4). Priyanka et al. (2014) reported negative gca effect and poor combiner for kernel length. Kernel length after cooking showed significant gca effect by 79156 A and among the male parents viz., WGL 676, RR 50, WGL 739 and RR 55. Among the hybrids none of the hybrids recorded significant sca effects in desired direction for kernel width, length/breadth ratio and kernel length after cooking. Among the female parents 79156A, among male parents WGL 676 and hybrids 68897 A x RR 65, 68897 A x RR 32, 79156 A x RR 55 and 79156 A x WGL 739 recorded significant gca and sca effects, respectively for the character kernel elongation ratio.

Intermediate alkali spreading value indicated the medium disintegration and classified as intermediate gelatinization temperature which is highly desirable for quality grain (Shivani et al., 2009). For alkali spreading value 79156A among female and among males WGL 676, WGL 705, WGL 810 and RR 17 recorded significant positive gca effects. Among hybrids 79128 A x RR 23 and 68897 A x MTU 11-320-20 recorded high sca effect. In case of water uptake, 79128 A and 68897 A among lines and in male parents WGL 676, MTU 1156, RR 3, RR23, WGL 66 and RR 17 exhibited significant gca effect. Fourteen hybrids showed significant sca effect viz., 68897A x WGL 674 followed by 79128 A x RR 32, 68897 A x RR 55, respectively. For volume expansion ratio 68897 A and in testers WGL 676, MTU 1156, RR 3, RR 23, WGL 616 and RR 17 were good general combiners and hybrids 68897 A x MTU 11-320 and 68897A x RR32, were good specific combiners.

None of the parents showed significant desirable gca effects simultaneously in desired direction for all the traits studied. Among the lines 68897A showed significant gca effects in desired direction for days to 50% flowering, effective tillers, flag leaf length, flag leaf width, panicle density, yield/plant, hulling percent, head rice recovery, kernel width after cooking, water uptake and volume expansion ratio. Among the male parents, RR 15 was found to be good combiner for panicle length, filled seeds/panicle, unfulfilled seeds/panicle, self fertility, test weight, milling percent, yield/plant, Though different parents were found to be good general combiner for different characters, the results indicated that there was close relationship between mean performance of the parents and gca effect in most of the cases studied (Akanksha and Jaiswal, 2019). None of the crosses showed significant specific combining ability effects for all the traits in desired direction but some crosses showed good sca effects for important yield components and quality traits. The cross 68897 A x RR 23 showed highest significant sca effect for grain yield/plant and also recorded significant sca effect for component traits viz., effective tillers, plant height, flag leaf length, kernel length and head rice recovery, while 68897 A x RR 55 for grain yield/plant, effective tillers, plant height, unfulfilled seeds/panicle, self fertility, milling percent, head rice recovery, kernel length, milling percent, panicle length, panicle density in desired direction for yield and quality traits.

The present study revealed that, among the parents 68897A and RR15 recorded significant gca effect in desired direction for important yield and quality traits, while the cross combination 68897 A x RR 23 evinced the highest significant value of sca effect for grain yield/plant. The hybrids, 68897 A x RR55, 68897 A x RR 32, 68897 A x RR 15, 79156 A x RR 3 recorded desirable value of sca effects for most of the yield components and quality traits. The hybrids which recorded positive and significant sca effects in the present study needs to be further tested in observational/multi locational trials to exploit their heterotic potential at commercial level.

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Rukmini Devi et al.,
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