# COMBINING ABILITY AND HETEROSIS ANALYSIS OF DIVERSE CMS LINES IN HYBRID RICE

**BY**

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## ABSTRACT

Line x tester analysis using four diverse cytoplasmic male sterile lines (CMS) and three Egyptian restorers (testers) was carried out to study the combining ability, gene action, heterosis and recombination breeding for yield and its contributing characters in rice. The results indicated that important additive gene action was present for the inheritance of heading date, plant height, panicle length, productive tillers plant$^{-1}$, spikelets panicle$^{-1}$ and 1000-grain weight. On the other hand, the greater role of non-additive gene action was noticed for panicle weight, spikelet fertility % and grain yield. Among the parents, IR 58025 A, G 46 A and Giza 178 R were found to have favourable genes for one or more characters along with grain yield. Hence, it is suggested that they could be used in hybrid rice programme. Among the 12 hybrid combinations, G 46 A/Giza 182 followed by IR 58025 A/Giza 181 R and IR 68885 A/Giza 181 R for heterosis breeding and IR 68885 A/Giza 178 R, IR 68885 A/Giza 181, Large Stigma A/ Giza 182 R and IR 58025 A/Giza 178 R for recombination breeding were found to be the best ones.

## INTRODUCTION

Cultivation of semi-dwarf high yielding pure line varieties of rice remarkably increased rice production in many countries during the past three decades. However, yield of these varieties is now considered to have reached a plateau because research efforts to further improve their yield potential have been unsuccessful. Therefore, to meet the demand of ever increasing population, development of high yielding hybrid varieties for commercial exploitation of heterosis is a major rice breeding objective in several countries. In China, hybrid rice varieties have already been developed by using Wild Abortive (WA) cytoplasmic male sterility. These varieties are being cultivated in large areas in China and yield about 20 percent more than pure line varieties (Lin & Yuan, 1980 and Yuan & Virmani, 1988).

The success of a plant breeding programme greatly depends on the correct choice of parents for hybridization and the gene action of different economic traits. Combining ability analysis provides such information so as to frame the breeding programme effectively. The line x tester analysis gives reliable information about the nature and magnitude of gene action and combining ability effects present in the genetic material. Dhillon (1975) pointed out that the combining ability gives useful information on the choice of parents in terms of expected performance of the hybrids and their progenies. Hence, the present investigation was carried out involving promising cytoplasmic male sterile lines (CMS) and restorers.

The utilization of hybrids in any crop can be used either one of two ways: (i) utilizing the $F_1$ hybrids commercially with a view to exploit heterosis and (ii) selecting superior segregants of the hybrid in the subsequent generations and releasing the best performing recombinants after attaining homozygosity .

The parameters viz., performance of hybrids per se, percent heterosis of crosses, GCA effect of parents and SCA effect of hybrids are helpful in evaluating the usefulness of hybrids in either heterosis breeding to select best hybrid combinations for production directly or recombination breeding to develop new parental lines of maintainers or restorers with desirable traits (Devaraj and Nadarajan, 1996).

## MATERIALS AND METHODS

Four diverse cytoplasmic male sterile lines (CMS) Viz., IR 58025 A from wild rice with abortive pollen cytoplasmic source (WA), G 46 A from Gambiaca cytoplasmic source, Large Stigma A from Kalinga cytoplasmic source IR 68885 A from Mutant, and three Egyptian restorers namely Giza 178 R, Giza 181 R and Giza 182 R constituted the materials of the present study. The $F_1$ generation of 12 cross combinations produced by crossing 4 CMS lines and three restorers in a line x tester fashion, maintainers of the corresponding 4 CMS lines and three restorers were raised in a randomized complete block design and replicated four times during the summer season of 2002 at Rice Research and Training Center (RRTC), Sakha, Kafr El-Sheikh, Egypt. Thirty days-old seedlings were transplanted with one seedling $hill^{-1}$, adopting a spacing of 20 cm between rows and 20 cm between plants. Each genotype was grown in seven rows of 5 m length. Ten competitive plants were selected randomly from each genotype and in each replication to measure the biometrical traits viz., heading date, plant height, panicle length, productive tillers plant$^{-1}$, panicle weight, spikelets panicle$^{-1}$, spikelet fertility % and 1000-grain weight. Five rows (5 $m^2$) were harvested from each genotype in each replication to estimate grain yield T/ha. Combining ability analysis was done following the method suggested by Kempthorne (1957) and heterosis was worked out over mid-parent, better-parent and over the best local check variety (Giza 178).

## RESULTS AND DISCUSSION

**Mean performance :**

Mean performance of the seven parental lines (CMS and restorers) and their hybrid combinationsd of line x tester for the nine studied characters i.e. heading date, plant height, panicle length, productive tillers plant$^{-1}$, panicle weight, spikelets panicle$^{-1}$, spikelet fertility, 1000-grain weight and grain yield (t/ha) are presented in Table (1).

All the twelve hybrid combinations for heading date, six for plant height, eight for productive tillers plant$^{-1}$, two for panicle weight, five for spikelets panicle$^{-1}$, two for sikelet fertility % and six for 1000-grain weight and two hybrids for grain yield (T/ha) showed intermediate mean values between the two parents involved. While, the mean values of all hybrids for panicle length, four for productive tillers plant$^{-1}$, nine for panicle weight, four for spikelets panicle$^{-1}$, one for spikelet fertility, six for 1000-grain weight were more than the highest parent.

The highest mean values for grain yield (T/ha) were obtained from the hybrid combinations G 46 A/Giza 182 R, IR 58025 A/Giza 181 R, G 46 A/Giza 178 R and IR 58025 A/Giza 178 R and ranged between 13.550 to 12.893 T/ha. The lowest value was estimated for the hybrid Large Stigma A/Giza 181 R. The parental lines Giza 181 R, Giza 182 R and Giza 178 R manifested highest mean performance 10.940, 10.675 and 10.600 T/ha, respectively for the grain yield.

**Analysis of variance :**

The analysis of variance given in Table (2) revealed highly significant differences among the 19 genotypes (12 hybrids, 4 CMS lines and 3 restorers) tested for all characters studied. The parents, hybrids and interaction between the parents and the hybrids showed highly significant differences for all characters. The analysis of variance for combining ability (Table 1) also showed highly significant differences among the lines for

**Table (1). Mean performance of parental lines (CMS and restorers lines) and hybrid combinations for the studied characters**

| Genotypes | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| <u>CMS lines</u> : | | | | | | | | | |
| IR 58025 A | 113.5 | 109.0 | 24.40 | 14.25 | 3.84 | 235.9 | 86.05 | 22.88 | 9.800 |
| IR 68885 A | 102.3 | 94.8 | 23.00 | 20.50 | 3.05 | 140.7 | 90.90 | 22.33 | 9.300 |
| G 46 A | 86.5 | 104.8 | 22.25 | 16.25 | 4.71 | 173.9 | 91.13 | 28.73 | 8.150 |
| Large Stigma A | 80.8 | 93.0 | 20.18 | 14.00 | 3.07 | 115.0 | 91.13 | 30.10 | 5.100 |
| <u>Restorer lines</u> : | | | | | | | | | |
| Giza 178 R | 105.0 | 102.8 | 22.60 | 19.00 | 3.58 | 165.6 | 86.45 | 22.38 | 10.600 |
| Giza 181 R | 116.5 | 107.8 | 23.25 | 19.25 | 3.87 | 166.4 | 87.63 | 27.75 | 10.950 |
| Giza 182 R | 101.5 | 99.3 | 23.98 | 19.50 | 3.70 | 152.6 | 93.73 | 27.05 | 10.675 |
| <u>Hybrid combinations</u> : | | | | | | | | | |
| IR 58025 A/Giza 178 R | 102.0 | 103.3 | 25.73 | 18.25 | 4.99 | 218.9 | 85.93 | 25.18 | 12.893 |
| IR 58025 A/Giza 181 R | 111.3 | 109.0 | 28.45 | 18.25 | 5.15 | 204.8 | 90.80 | 28.80 | 13.450 |
| IR 58025 A/Giza 182 R | 103.3 | 105.8 | 26.50 | 19.00 | 4.92 | 161.6 | 87.43 | 26.98 | 9.250 |
| IR 68885 A/Giza 178 R | 94.3 | 98.5 | 25.13 | 21.50 | 3.74 | 133.9 | 87.03 | 24.15 | 11.950 |
| IR 68885 A/Giza 181 R | 105.3 | 99.3 | 26.78 | 22.50 | 3.77 | 136.8 | 83.18 | 26.13 | 12.750 |
| IR 68885 A/Giza 182 R | 100.3 | 99.3 | 25.90 | 23.25 | 4.34 | 149.4 | 85.75 | 26.20 | 8.350 |
| G 46 A / Giza 178 R | 102.0 | 114.3 | 25.50 | 17.25 | 5.62 | 173.5 | 94.80 | 28.18 | 13.325 |
| G 46 A / Giza 181 R | 102.5 | 108.8 | 25.23 | 19.75 | 3.43 | 165.9 | 83.68 | 28.95 | 11.325 |
| G 46 A / Giza 182 R | 100.5 | 119.0 | 25.43 | 18.25 | 5.69 | 183.3 | 88.15 | 30.43 | 13.550 |
| Large Stigma A/Giza 178 R | 101.3 | 106.0 | 25.00 | 17.00 | 5.05 | 198.3 | 84.95 | 29.43 | 10.600 |
| Large Stigma A/Giza 181 R | 102.0 | 108.3 | 25.83 | 17.50 | 4.13 | 194.9 | 76.60 | 30.05 | 7.775 |
| Large Stigma A/Giza 182 R | 98.0 | 109.8 | 26.40 | 15.23 | 4.24 | 210.7 | 83.38 | 30.68 | 9.460 |
| LSD 0.05 | 1.58 | 2.39 | 1.28 | 1.82 | 0.68 | 24.2 | 4.93 | 0.37 | 0.884 |
| 0.01 | 2.10 | 3.19 | 1.71 | 2.43 | 0.91 | 32.3 | 6.56 | 0.49 | 1.177 |

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Table (2). Mean square estimates of ordinary analysis and combining ability analysis for the studied characters

| S.O.V. | d.f | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| Replications | 3 | 0.33 | 2.19 | 0.03 | 1.07 | 0.21 | 399.56 | 4.18 | 0.04 | 0.09 |
| Genotypes | 18 | 270.83** | 170.70** | 14.71** | 25.35** | 2.60** | 4048.70** | 72.24** | 29.89** | 20.25** |
| Parents | 6 | 681.37** | 153.49** | 7.61** | 28.45** | 1.25** | 5567.59** | 33.18* | 43.15** | 16.98** |
| Hybrids | 11 | 65.34** | 153.09** | 3.66** | 23.41** | 2.26** | 3300.85** | 79.36** | 18.69** | 17.45** |
| Parents Vs hybrids (heterosis) | 1 | 68.04** | 467.73** | 178.87** | 28.08** | 14.38** | 3161.66** | 228.22** | 73.69** | 70.60** |
| GCA of lines (CMS) | 3 | 76.58 | 459.00** | 4.98 | 74.72** | 2.85 | 9158.37** | 128.29 | 51.63** | 26.07 |
| GCA of testers (Restorers) | 2 | 138.25* | 36.81 | 6.12 | 4.00 | 2.64 | 148.88 | 85.56 | 17.19** | 16.76 |
| Lines x Testers (SCA) | 6 | 35.42** | 38.90** | 2.18* | 4.22* | 1.84** | 1422.76** | 52.83** | 2.71** | 13.37** |
| Error | 54 | 1.24 | 2.86 | 0.82 | 1.65 | 0.23 | 292.09 | 12.09 | 0.07 | 0.39 |
| $\sigma^2$ GCA/$\sigma^2$ SCA | | 1.15 | 3.87 | 1.41 | 9.16 | 0.38 | 2.07 | 0.82 | 7.55 | 0.39 |

*, ** : Significant at P= 0.05 and 0.01, respectively

plant height, productive tillers plant$^{-1}$, spikelets panicle$^{-1}$, and 1000-grain weight and insignificant for heading date, panicle length, panicle weight, spikelet fertility % and grain yield T/ha. While the testers exhibited significant differences for heading date and 1000-grain weight and insignificant for all the rest of characters. The mean squares due to line x tester interactions (SCA) were significant for all the nine biometrical traits, indicating that they interacted and produced markedly different combining ability effects and it might be due to the wide genetic diversity of lines and testers. The ratio of GCA:SCA variances are presented in Table (2). The estimate of variance due to GCA was more than that due to SCA for all characters, except panicle weight, spikelet fertility % and grain yield T/ha, revealing the importance of the additive gene action for the inheritance of heading date, plant height, panicle length, productive tillers, spikelets panicle$^{-1}$ and 1000-grain weight and the importance of the non-additive gene action for the inheritance of panicle weight, spikelet fertility % and grain yield T/ha.

## Genetic parameters :

The estimates of genetic parameters viz., additive variance ($\sigma^2$ A), dominance variance ($\sigma^2$ D), environmental variance ($\sigma^2$ E), genotypic variance ($\sigma^2$ G) and phenotypic variance ($\sigma^2$ P), broadsense heritability ($h^2_b$ %), narrow sense heritability ($h^2_n$ %), relative importance of GCA % and relative importance of SCA % for all nine studied characters are presented in Table (3). It is clear that the estimates of the additive variance ($\sigma^2$ A) and relative importance of GCA % for heading date, plant height, panicle length, productive tillers plant$^{-1}$, spikelets panicle$^{-1}$ and 1000-grain weight were higher than dominance variance ($\sigma^2$ D) and relative importance of SCA % for these characters. These results indicate that the former characters were largely governed by additive gene action. The importance of the additive gene action for the inheritance of these traits was in agreement with the findings of Wilfred Manual and Palanisamy (1989), Lokaprakash *et al.* (1991), El-Mowafi (1994), Sharma and Koranne (1995) and El-Mowafi (2001). On the other hand, high estimates of dominance genetic variance and its relative magnitude of SCA % were found to be more than that of the additive variances for the rest of characters, panicle weight, spikelet fertility % and grain yield T/ha. These results indicated that dominance variance played a major role in the inheritance of these characters which were in general agreement with the results reported by Bobby and Nadarjan (1993), Ramalingam *et al.* (1993), Sharma and Koranne (1995) and Ramalingam *et al.* (1997).

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**Table (3). Genetic parameters for the studied characters of hybrid rice**

| S.O.V. | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Additive variance ($\sigma^2$ A) | 9.86 | 34.88 | 0.48 | 5.86 | 0.15 | 585.0 | 8.33 | 4.98 | 1.27 |
| Dominance variance ($\sigma^2$ D) | 8.54 | 9.01 | 0.34 | 0.64 | 0.40 | 282.7 | 10.19 | 0.66 | 3.24 |
| Environmental variance ($\sigma^2$ E) | 1.24 | 2.85 | 0.82 | 1.65 | 0.23 | 292.1 | 12.09 | 0.07 | 0.39 |
| Genotypic variance ($\sigma^2$ G) | 18.40 | 43.89 | 0.82 | 6.50 | 0.55 | 867.7 | 18.52 | 5.64 | 4.52 |
| Phenotypic variance ($\sigma^2$ P) | 19.64 | 46.74 | 1.64 | 8.15 | 0.78 | 1159.8 | 30.61 | 5.71 | 4.90 |
| Broad sense heritability ($h^2_b$) % | 93.68 | 93.89 | 49.98 | 79.73 | 70.90 | 74.8 | 60.50 | 98.81 | 92.08 |
| Narrow sense heritability ($h^2_n$) % | 50.19 | 74.61 | 28.21 | 71.86 | 19.30 | 50.4 | 27.22 | 87.23 | 25.90 |
| Relative importance of GCA %* | 53.57 | 79.47 | 58.44 | 90.13 | 27.22 | 67.4 | 45.00 | 88.27 | 28.13 |
| Relative importance of SCA %** | 46.43 | 20.53 | 41.56 | 9.87 | 72.78 | 32.6 | 55.00 | 11.73 | 71.87 |

* Relative importance of GCA = $\sigma^2$ A / $\sigma^2$ G x 100

** Relative importance of SCA = $\sigma^2$ D / $\sigma^2$ G x 100

High values of environmental component ($\sigma^2$ E) were estimated for panicle length and spikelet fertility %, while the other estimates for the rest characters were normal but differ in magnitudes indicating that, the characters were affected by the environmental component with different degrees.

Heritability estimates in broad sense were high for all characters under study as given in Table (3) except panicle length and spikelet fertility % which were relatively low. This further suggested that a major part of the total phenotypic variance is due to environmental effect for panicle length and spikelet fertility %. However, heritability estimates in the narrows sense were high for plant height (74.61%), productive tillers plant$^{-1}$ (71.86%) and 1000-grain weight (87.23%) and moderate for heading date (50.19%) and spikelets panicle$^{-1}$ (50.4%) indicating that a major part of the total genotypic is additive. While heritability estimates in the narrow sense for panicle length, panicle weight, spikelet fertility and grain yield T/ha were low.

**Estimation of general combining ability effects (GCA) :**

Among the nine characters of cytoplasmic genetic male sterile lines (CMS), the GCA of panicle length, panicle weight, spikelets panicle$^{-1}$ in IR 58025 A line was higher than the other female lines (Table 4). The IR 68885 A line had the highest GCA of heading date, plant height and productive tillers plant$^{-1}$, which illustrated that it is worthwhile transfer its male sterility into genetic background of elite lines having good GCA for yield and its components. The G 46 A line had the highest GCA for spikelet fertility % and grain yield characters. While, Large Stigma A had the highest GCA for 1000-grain weight character. Among four CMS lines tested, G 46 A and IR 58025 A were the best combiners for grain yield character.

Among the nine economic studied characters of the restorer lines, the GCA of heading date, plant height, panicle weight, spikelets panicle$^{-1}$, spikelet fertility % and grain yield in Giza 178 R was the highest compared with other restorer lines (Table 5). Giza 181 R line had the best GCA of panicle length and productive tillers plant$^{-1}$. While, the GCA of Giza 182 R line was better than the other restorer lines in 1000-grain weight.

The results of combining method proposed by Wang (1981) are shown in Table (6). The data in Table (6) are from the ranking numbers of GCA and according to the total marks, the evaluation of the parents was

Table (4). Estimates of GCA effects of the CMS lines for 9 studied characters

| CMS lines | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| IR 58025 A | 3.62** | -0.75* | 0.90** | -0.50* | 0.432** | 17.42** | 2.08* | -0.94** | 0.64** |
| IR 68885 A | -1.96** | -7.75** | -0.05 | 3.50** | -0.638** | -37.63** | -0.65 | -2.44** | -0.21* |
| G 46 A | -0.20 | 7.25** | -0.60* | -0.58* | 0.324* | -3.42 | 2.91** | 1.26** | 1.51** |
| Large Stigma A | -1.46** | 1.25* | -0.25 | -2.42** | -0.118 | 23.63** | -4.34** | 2.12** | -1.94** |
| S.E. (gca for line) | 0.32 | 0.49 | 0.26 | 0.37 | 0.138 | 4.93 | 1.00 | 0.08 | 0.18 |
| S.E. ($g_i$-$g_j$) line | 0.45 | 0.69 | 0.37 | 0.52 | 0.195 | 6.98 | 1.42 | 0.11 | 0.25 |
| LSD 0.05 | 0.33 | 0.49 | 0.26 | 0.37 | 0.139 | 4.98 | 1.01 | 0.20 | 0.18 |
| 0.01 | 0.87 | 1.31 | 0.70 | 0.99 | 0.369 | 13.22 | 2.69 | 0.08 | 0.48 |

*, ** Significant at P= 0.05 and 0.01, respectively.

Table (5). Estimates of GCA effects of the restorer lines (testers) for 9 studied characters

| Restorer lines | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Giza 178 R | -2.00** | -1.25** | -0.65** | -0.50* | 0.259* | 3.50 | 2.21* | -1.19** | 0.97** |
| Giza 181 R | 3.37** | -0.44* | 0.58* | 0.50* | -0.468** | -2.09 | -2.40** | 0.55** | 0.10 |
| Giza 182 R | -1.37** | 1.69** | 0.07 | 0.00 | 0.209* | -1.41 | 0.19 | 0.64** | -1.07** |
| S.E. (gca for tester) | 0.28 | 0.42 | 0.23 | 0.32 | 0.119 | 4.27 | 0.87 | 0.06 | 0.16 |
| S.E. ($g_i$-$g_j$) tester | 0.39 | 0.60 | 0.32 | 0.45 | 0.169 | 6.04 | 1.22 | 0.09 | 0.22 |
| LSD 0.05 | 0.28 | 0.43 | 0.23 | 0.32 | 0.120 | 4.32 | 0.88 | 0.07 | 0.16 |
| 0.01 | 0.74 | 1.13 | 0.61 | 0.86 | 0.319 | 11.45 | 2.33 | 0.17 | 0.42 |

*, ** Significant at P= 0.05 and 0.01, respectively.

Table (6). Comparison of general combining ability effects for the parents

| Genotypes | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) | Total | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CMS lines : | | | | | | | | | | | |
| IR 58025 A | 4 | 2 | 1 | 2 | 1 | 1 | 2 | 3 | 2 | 18 | 1 |
| IR 68885 A | 1 | 1 | 2 | 1 | 4 | 4 | 3 | 4 | 3 | 23 | 3 |
| G 46 A | 3 | 4 | 4 | 3 | 2 | 3 | 1 | 2 | 1 | 23 | 2 |
| Large Stigma A | 2 | 3 | 3 | 4 | 3 | 2 | 4 | 1 | 4 | 26 | 4 |
| Restorer lines : | | | | | | | | | | | |
| Giza 178 R | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 3 | 1 | 15 | 1 |
| Giza 181 R | 3 | 2 | 1 | 1 | 3 | 3 | 3 | 2 | 2 | 20 | 3 |
| Giza 182 R | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 19 | 2 |

made. As the results showed in this table, among the female lines (CMS), IR 58025 A line was the best general combiner followed by G 46 A line. On the other hand, among the male lines, Giza 178 R had the better GCA.

**Estimation of specific combining ability (SCA) :**

The SCA expresses the non-additive effect of genes. The results presented in Table (7), indicated that the characters depend not only on the GCA but also on the SCA. The SCA effects revealed that the cross combinations IR 58025 A/Giza 181 R for panicle length, panicle weight, spikelet fertility and 1000-grain weight, IR 68885 A/Giza 182 R for productive tillers plant$^{-1}$, IR 58025 A/Giza 178 R for spikelets panicle$^{-1}$ and G 46 A/Giza 182 R for grain yield character were the superior specific combinations as they showed high positive significant SCA effects. As far as the heading date and plant height are concerned, the negative estimates of SCA effects are desirable for reduced days to flowering and plant height and the good specific combinations were IR 68885 A/Giza 178 for heading date and G 46 A/Giza 181 for plant height that had the highest negative significant of SCA effect values.

The data in Table (8) are from ranking numbers of SCA effects for hybrid combinations, and according to the total ranks, the evaluation of the hybrids was made. Among the 12 hybrid combinations, IR 58025 A/ Giza 181 R was the best specific combination followed by G 46 A/ Giza 182 R for grain yield and most of desirable characters.

**Standard heterosis :**

The magnitude of heterosis in $F_1$ hybrids is related not only to the performance of parents per se but also to genetic diversity between two parents. Positive as well as negative standard heterosis were observed for all characters, except for panicle length, and 1000-grain weight, which showed positive standard heterosis for all the twelve hybrid combinations (Table 9). The most promising hybrids identified in this study were, G 46 A/Giza 182 R with significant standard heterosis % for heading date, panicle length, 1000-grain weight and had the highest standard heterosis for panicle weight and grain yield followed by the hybrid IR 58025 A/ Giza 181 R with significant standard heterosis for panicle length, panicle weight, spikelets panicle$^{-1}$, 1000-grain weight and grain yield then, the hybrid combination G 46 A/Giza 178 R with significant standard heterosis for heading date, panicle length, panicle weight, spikelet fertility, 1000-grain weight and grain yield T/ha.

**Table (7). Estimates of specific combining ability of the nine studied characters**

| Hybrid combination | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| IR 58025 A/Giza 178 R | -1.50** | 1.50* | -0.52* | 0.25 | -0.291* | 20.29* | -4.33* | -0.61** | 0.06 |
| IR 58025 A/Giza 181 R | 2.38** | 3.44** | 0.98* | -0.75* | 0.599* | 11.79* | 5.15** | 1.26** | 1.48** |
| IR 58025 A/Giza 182 R | -0.88* | -1.94* | -0.46* | 0.50 | -0.308* | -32.08** | -0.82 | -0.65** | -1.54** |
| IR 68885 A/Giza 178 R | -3.67** | 0.75 | -0.16 | -0.50 | -0.473* | -9.59* | -0.50 | -0.15* | -0.04 |
| IR 68885 A/Giza 181 R | 1.96** | 0.69 | 0.26 | -0.50 | 0.290* | -1.18 | 0.26 | 0.08 | 1.63** |
| IR 68885 A/Giza 182 R | 1.71** | -1.44* | -0.10 | 1.00* | 0.183 | 10.77* | 0.24 | 0.07 | -1.59** |
| G 46 A / Giza 178 R | 2.33** | 1.50* | 0.77* | -0.67* | 0.450* | -4.22 | 3.71* | 0.19* | -0.38* |
| G 46 A / Giza 181 R | -2.54** | -4.81** | -0.74* | 0.83* | -1.020** | -6.28 | -2.79* | -0.79** | -1.51** |
| G 46 A / Giza 182 R | 0.21 | 3.31** | -0.03 | -0.16 | 0.570* | 10.50* | -0.92 | 0.60** | 1.89** |
| Large Stigma A/Giza 178 R | 2.83** | -0.75 | -0.09 | 0.92* | 0.314* | -6.47 | 1.12 | 0.57** | 0.35* |
| Large Stigma A/Giza 181 R | -1.79** | 0.69 | -0.50* | 0.41 | 0.130 | -4.34 | -2.62* | -0.55** | -1.60** |
| Large Stigma A/Giza 182 R | -1.04* | 0.06 | 0.59* | -1.33* | -0.444* | 10.81* | 1.50 | -0.02 | 1.25** |
| S.E. (sca effects) | 0.56 | 0.84 | 0.45 | 0.64 | 0.238 | 8.55 | 1.74 | 0.13 | 0.31 |
| S.E. ($S_{ij} - S_{kl}$) | 0.79 | 1.19 | 0.64 | 0.90 | 0.337 | 12.08 | 2.46 | 0.18 | 0.44 |
| LSD 0.05 | 0.56 | 0.85 | 0.46 | 0.65 | 0.241 | 8.63 | 1.76 | 0.13 | 0.31 |
| 0.01 | 1.49 | 2.27 | 1.21 | 1.72 | 0.639 | 22.90 | 4.66 | 0.35 | 0.83 |

*, ** Significant at P= 0.05 and 0.01, respectively.

Table (8). Comparison of specific combining ability effects for the hybrid combinations

| Hybrid combination | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) | Total | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IR 58025 A/Giza 178 R | 4 | 3 | 11 | 6 | 8 | 1 | 12 | 10 | 6 | 61 | 8 |
| IR 58025 A/Giza 181 R | 11 | 12 | 1 | 11 | 1 | 2 | 1 | 1 | 3 | 43 | 1 |
| IR 58025 A/Giza 182 R | 6 | 2 | 9 | 4 | 9 | 12 | 8 | 11 | 10 | 71 | 10 |
| IR 68885 A/Giza 178 R | 1 | 9 | 8 | 8 | 11 | 11 | 7 | 8 | 7 | 70 | 9 |
| IR 68885 A/Giza 181 R | 9 | 8 | 4 | 9 | 5 | 6 | 5 | 5 | 2 | 53 | 4 |
| IR 68885 A/Giza 182 R | 8 | 4 | 7 | 1 | 6 | 4 | 6 | 6 | 11 | 53 | 5 |
| G 46 A/Giza 178 R | 10 | 10 | 2 | 10 | 3 | 7 | 2 | 4 | 8 | 56 | 7 |
| G 46 A/Giza 181 R | 2 | 1 | 12 | 3 | 12 | 9 | 11 | 12 | 9 | 71 | 11 |
| G 46 A/Giza 182 R | 7 | 11 | 5 | 7 | 2 | 5 | 9 | 2 | 1 | 49 | 2 |
| Large Stigma A/Giza 178 R | 12 | 5 | 6 | 2 | 4 | 10 | 4 | 3 | 5 | 51 | 3 |
| Large Stigma A/Giza 181 R | 3 | 7 | 10 | 5 | 7 | 8 | 10 | 9 | 12 | 71 | 12 |
| Large Stigma A/Giza 182 R | 5 | 6 | 3 | 12 | 10 | 3 | 3 | 7 | 4 | 53 | 6 |

Table (9). Standard heterosis % of $F_1$ hybrids of the nine studied characters for 12 hybrid rice combinations

| Hybrid combination | Heading date (days) | Plant height (cm) | Panicle length (cm) | Productive tillers plant$^{-1}$ | Panicle weight (g) | Spikelets panicle$^{-1}$ | Spikelet fertility % | 1000-grain weight (g) | Grain yield (T/ha) |
|---|---|---|---|---|---|---|---|---|---|
| IR 58025 A/Giza 178 R | -2.86** | 0.49 | 13.83** | -3.95 | 39.30** | 32.18** | -0.60 | 12.51** | 21.63** |
| IR 58025 A/Giza 181 R | 5.95** | 6.08** | 25.88** | -3.95 | 43.82** | 23.69** | 5.03 | 28.72** | 26.89** |
| IR 58025 A/Giza 182 R | -1.67** | 2.92* | 17.26** | 0.00 | 37.40** | -2.40 | 1.13 | 20.56** | -12.73** |
| IR 68885 A/Giza 178 R | -10.23** | -4.14** | 11.17** | 13.16** | 4.33 | -19.10* | 0.67 | 7.93** | 12.74** |
| IR 68885 A/Giza 181 R | 0.24 | -3.41** | 21.02** | 18.42** | 5.30 | -17.39* | -3.79 | 16.76** | 20.28** |
| IR 68885 A/Giza 182 R | -4.52** | -3.41** | 14.60** | 22.36** | 21.21* | -9.77 | -0.81 | 17.09** | -21.22** |
| G 46 A / Giza 178 R | -2.86** | 11.19** | 12.83** | -9.21 | 56.94** | 4.80 | 9.66** | 25.92** | 25.71** |
| G 46 A / Giza 181 R | -2.38** | 5.84** | 11.62** | 3.95 | -4.41 | 0.18 | -3.21 | 29.39** | 6.84 |
| G 46 A / Giza 182 R | -4.29** | 15.82** | 12.50** | -3.95 | 58.89** | 10.72 | 1.97 | 35.98** | 27.83** |
| Large Stigma A/Giza 178 R | -3.57** | 3.16** | 10.61** | -10.53* | 40.83** | 19.77** | -1.74 | 31.51** | 0.00 |
| Large Stigma A/Giza 181 R | -2.86** | 5.35** | 14.26** | -7.89 | 15.35 | 17.69* | -11.39** | 34.30** | -26.65** |
| Large Stigma A/Giza 182 R | -6.67** | 6.814** | 16.81** | -19.74 | 18.22 | 27.26** | -3.56 | 37.09 | -10.75 |
| LSD 0.05 | 1.58 | 2.40 | 1.28 | 1.82 | 0.68 | 24.23 | 4.93 | 0.37 | 0.88 |
| 0.01 | 2.10 | 2.10 | 1.71 | 2.43 | 0.90 | 32.26 | 6.57 | 0.49 | 1.17 |

*, ** Significant at P= 0.05 and 0.01, respectively.

The results exhibited the $F_1$ heterosis of the combinations that had late or early heading date, strong plant height and panicle length. Superior, heavier panicle, 1000-grain weight and higher grain yield comparing with best check inbred variety Giza 178 (Table 9).

Hybrids with a yield advantage of > 1.5 T/ha over the highest yielding check variety, Giza 178 were considered as promising. Among the 12 hybrid combinations evaluated, four of them were found promising in this study namely G 46 A/Giza 182 R, IR 58025 A/Giza 181 R, G 46 A/Giza 178 R and IR 58025 A/Giza 178 R with yield advantage of 2.950, 2.850, 2.725 and 2.293 T/ha, respectively.

Table (10) emphasized on estimates of heterosis revealed significant and positive heterobeltiosis for six hybrid combinations. The highest estimates of 26.93% was obtained for the hybrid G 46 A/Giza 182 R followed by G 46 A/Giza 178 R, IR 58025 A/Giza 181 R, IR 58025 A/ Giza 178 R, IR 68885 A/Giza 178 R and IR 68885 A/Giza 181 R with respective values of 2.571, 22.83, 21.63, 18.87 and 16.44% as many as nine combinations revealed significant and positive heterosis over mid-parent. The six combinations showing high heterobeltiosis exhibited mid-parent heterosis with increased magnitude of 43.96, 42.13, 29.64, 26 40, 20.10 and 25.93%, respectively. However, positive and significant standard heterosis was recorded in the same six former combinations with respective values of 27.83, 25.71, 26.89, 21.63, 12.74 and 20.28%. The same trend is exhibited by estimates of SCA effects as well showing high values for the hybrids G 46 A/Giza 182 R (1.89), IR 68885 A/Giza 181 R (1.63) and IR 58025 A/Giza 181 R (1.48).

Evaluation of hybrids for heterosis breeding based on five combinations, mean performance, heterobeltiosis (BP), mid-parent heterosis (MP), standard heterosis (SH) and SCA effects would be meaningful from this point of view. Out of 12 hybrid combinations, 3 hybrid combinations, namely, G 46 A/Giza 182 R, IR 68885 A/Giza 181 R and IR 58025 A/ Giza 181 R recorded significantly positive value and were most promising ones for all above mentioned five considerations.

Significant heterotic effects for grain yield have been reported by Davis and Rutger (1976), Anandakumar and Rangasamy (1985), Kaushik and Sharma (1986), El-Mowafi (1988), Devaraj and Nadarajan (1996), Mishra and Pandey (1998) and El-Mowafi (2001).

Table (10). Mean performance, yield advantage t/ha, MP, BP and standard heterosis % and GCA effects of female and male parents of $F_1$ hybrids for yield character

| Hybrid combination | Yield mean performance T/ha | Yield advantage T/ha | BP heterosis % | MP heterosis % | Standard heterosis % | SCA effects | GCA effect of female parent | GCA effect of male parent |
|---|---|---|---|---|---|---|---|---|
| IR 58025 A/Giza 178 R | 12.893 | 2.293 | 21.63** | 26.40** | 21.63** | 0.06 | 0.64** | 0.97** |
| IR 58025 A/Giza 181 R | 13.450 | 2.850 | 22.83** | 29.64** | 26.89** | 1.48** | 0.64** | 0.10 |
| IR 58025 A/Giza 182 R | 9.250 | -1.350 | -13.35** | -9.65* | -12.73** | -1.54** | 0.64** | -1.07** |
| IR 68885 A/Giza 178 R | 11.950 | 1.350 | 18.87** | 20.10** | 12.74** | -0.04 | -0.21* | 0.97** |
| IR 68885 A/Giza 181 R | 12.750 | 2.150 | 16.44** | 25.93** | 20.28** | 1.63** | -0.21* | 0.10 |
| IR 68885 A/Giza 182 R | 8.350 | -2.250 | -21.78** | -16.39** | -21.22** | -1.59** | -0.21* | -1.07** |
| G 46 A / Giza 178 R | 13.325 | 2.725 | 25.71** | 42.13** | 25.71** | -0.38* | 1.51** | 0.97** |
| G 46 A / Giza 181 R | 11.325 | 0.725 | 3.42 | 18.59** | 6.84 | -1.51** | 1.51** | 0.10 |
| G 46 A / Giza 182 R | 13.550 | 2.950 | 26.93** | 43.96** | 27.83** | 1.89** | 1.51** | -1.07** |
| Large Stigma A/Giza 178 R | 10.600 | 0.001 | 0.00 | 35.89** | 0.00 | 0.35* | -1.94** | 0.97** |
| Large Stigma A/Giza 181 R | 7.775 | -2.825 | -29.22** | -3.12 | -26.85** | -1.60** | -1.94** | 0.10 |
| Large Stigma A/Giza 182 R | 9.460 | -1.140 | -11.38** | 19.94** | -10.75* | 1.25** | -1.94** | -1.07** |
| Giza 178 (Local check) | 10.600 | - | - | - | - | - | - | - |

*, ** Significant at P= 0.05 and 0.01, respectively

The parents having higher GCA exhibited high standard heterosis in hybrids. Some crosses involving parents with lower SCA effects for grain yield, showed high negative standard heterosis.

The combinations involving CMS lines, IR 58025 A and G 46 A and restorer line, Giza 178 R revealed commercially exploitable heterosis. Superior hybrid vigor for grain yield was obtained more frequently at IRRI when at least one of the parents had high GCA effects (Peng and Virmani, 1990) although occasionally heterotic combinations were derived from combinations having both parents with low GCA effects (Kumar and Saini, 1981).

Table (11), demonstrates the correlation coefficients between the standard heterosis and mean performance, BP heterosis, MP heterosis, SCA effects and GCA effect of female and male parents. The results showed that there had significant positive correlation between the standard heterosis of the hybrids and each of mean performance, BP heterosis, MP heterosis, SCA effects and GCA of female parent for grain yield character.

**Table (11). Phenotypic correlation coefficients among standard heterosis (SH) and each of mean performance, BP heterosis, SCA effect, GCA of female parent and GCA of male parent for grain yield character**

| Parameters | Mean performance Yield T/ha | BP heterosis % | MP heterosis % | SCA | GCA female | GCA male |
|---|---|---|---|---|---|---|
| Standard heterosis SH % | 0.999** | 0.999** | 0.991** | 0.646* | 0.639* | 0.464 |

*, ** Significant at P= 0.05 and 0.01, respectively

## Hybrids for recombination breeding :

Recombination breeding makes use of fixable additive gene action. To get outstanding recombinants is segregating generations, the parents of hybrids must be good general combiners for the character to which improvement is sought. In addition, the SCA effect should not be significant because selection of superior recombinants will be hindered by significant SCA effect. Therefore, it will be useful to select only such of those hybrids with nonsignificant SCA effects and having parents with significant GCA effects (Nadarajan, 1986). The segregants of these hybrids are likely to throw recombinants possessing favourable additive genes from both the parents.

**Table (12). Hybrid combinations selected for recombination breeding of the studied characters**

| Character | Good combining line | GCA effects of line | Good combining tester | GCA effects of tester | Possible cross combinations | SCA effects of hybrids | Promising crosses for recombination breeding |
|---|---|---|---|---|---|---|---|
| Heading date (days) | IR 68885 A | -1.96** | Giza 178 R | -2.00** | IR 68885 A/Giza 178 R | -3.67** | - |
| | | | Giza 182 R | -1.37** | IR 68885 A/Giza 182 R | 1.96** | - |
| Plant height (cm) | IR 68885 A | -7.75** | Giza 178 R | -1.25** | IR 68885 A/Giza 178 R | 0.75ns | IR 68885 A/Giza 178 R |
| | | | Giza 181 R | -0.44* | IR 68885 A/Giza 181 R | 0.69ns | IR 68885 A/Giza 181 R |
| Panicle length (cm) | IR 58025 A | 0.90** | Giza 181 R | 0.58* | IR 58025 A/Giza 181 R | 0.98* | - |
| Productive tillers plant$^{-1}$ | IR 68885 A | 3.50** | Giza 181 R | 0.50* | IR 68885 A/Giza 181 R | -0.50ns | IR 68885 A/Giza 181 R |
| Panicle weight (g) | IR 58025 A | 0.43** | Giza 178 R | 0.26* | IR 58025 A/Giza 178 R | -0.29* | - |
| | | | Giza 181 R | 0.21* | IR 58025 A/Giza 181 R | 0.59* | - |
| Spikelets panicle$^{-1}$ | Large Stigma A | 23.63** | - | - | - | - | - |
| Spikelet fertility % | G 46 A | 2.91** | Giza 178 R | 2.21** | G 46 A / Giza 178 R | 3.71* | - |
| 1000-grain weight (g) | Large Stigma A | 2.12** | Giza 181 R | 0.55** | Large Stigma A/Giza 181 R | -0.55** | - |
| | | | Giza 182 R | 0.64** | Large Stigma A/Giza 182 R | -0.02ns | Large Stigma A/Giza 182 R |
| Grain yield T/ha | G 46 A | 1.51** | Giza 178 R | 0.97** | G 46 A / Giza 178 R | -0.38* | - |
| | IR 58025 A | 0.64** | Giza 178 R | 0.97** | IR 58025 A/Giza 178 R | 0.06 | IR 58025 A/Giza 178 R |

*, ** Significant at P= 0.05 and 0.01, respectively

ns Not significant

Based on the aforesaid considerations, the 12 hybrids were evaluated for recombination breeding. For each of the nine traits studied , the lines and testers with significant GCA effects, possible hybrids combinations and the promising crosses for recombination breeding are presented in Table (11). Overall, the crosses, IR 68885 A/Giza 178 R (for plant height), IR 68885 A/Giza 181 R (for plant height and productive tillers plant$^{-1}$), Large Stigma A/Giza 182 R (for 1000-grain weight) and IR 58025 A/ Giza 178 R (for grain yield) could be expected to throw superior recombinants. Devaraj and Nadarajan (1996) reported that the parameters viz., performance of hybrids per se, GCA effect of parents, SCA effect of hybrids and percent heterosis of crosses are helpful in evaluating the usefulness of hybrid in either heterosis breeding or recombination breeding.

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# تحليل القدرة على الإئتلاف وقوة الهجين من سلالات العقم الذكرى السيتوبلازمى المتنوعة فى الأرز الهجين

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## الملخص العربـــــــى

أجــرى هــذا البحــث بغــرض دراسة إمكانية الإستفادة من قوة الهجين باســتخدام نظــام العقم الذكرى السيتوبلازمى الوراثى الثلاثى ( السلالة العقيمة A والســلالة المحافظــة على صفة العقم B والسلالة المعيدة للخصوبة R والتى تنتج الهجــن) باســتخدام تحلــيل الســلالة × الكشاف لأربع سلالات ذات عقم ذكرى ســيتوبلازمى وراثى من أربع مصادر عقم مختلفة ومتنوعة إستُخدمت كآباء مؤنثة وثــلاث أصناف مصرية معيدة للخصوبة Restorers إستُخدمت كشافات. وقد تم دراسة القدرة على الإئتلاف ، فعل الجين ، قوة الهجين ومتابعة التربية والإنتخاب حــتى أجــيال متقدمة لتحسين السلالات الأبوية وذلك فى صفة محصول الحبوب والصــفات الهامة المرتبطة به . وقد أظهرت الدراسة أهمية الفعل المضيف للجين فــى وراثة صفات أيام التزهير ، طول النبات ، طول الدالية ، عدد الفروع الحاملة للداليات/نبات ، عدد السنيبلات فى الدالية ووزن الألف حبة بالجرام . على الجانب الأخــر إتضــح الدور الأهم للفعل الغير مضيف أو السيادى للجين فى وراثة صفة وزن الدالية بالجرام ، نسبة خصوبة السنيبلات وكذلك محصول الحبوب وكان لذلك

علاقـــة بقوة الهجين . وكانت أفضل الآباء فى قدرتها العامة على الإئتلاف السلالة العقيمة IR 58025 A واسعة الإنتشار عالمياً فى إنتاج الأرز الهجين تلاها السلالة الصينية العقيمة G 46 A وكذلك الصنف المصرى المعيد للخصوبة Giza 178 R وذلك فى صفة المحصول وصفة أو أكثر من الصفات المرغوبة مما يوضح إمكانية الإستفادة منها مباشرة فى برنامج الأرز الهجين .

أظهــرت الدراســة أنـــه مــن بيــن ١٢ هجيــن إســتُخدمت كان الهجين G 46 A/Giza 182 R والهجيــن IR 58025 A/Giza 181 R وكذلك الهجين IR 68885 A/Giza 181 R أفضــل الهُجــن التى يمكن إستغلالها مباشرة عند المــزارع وذلــك لــتفوقها على أفضل الأصناف المحلية التجارية المستخدمة فى الدراسة وهو الصنف جيزة ١٧٨ .

على الجانب الأخر يمكن استغلال الهُجن , IR 68885 A/Giza 178 R
IR 68885 A / Giza 181 R , Large Stigma A / Giza 182 R ,
IR 58025 A/Giza 178 R فى التربية بالإنتخاب حتى أجيال متقدمة لتحسين السلالات الأبوية فى الصفات المرغوبة وذلك لإعادة إستخدامها مرة أخرى كأباء مُحسنة فى برنامج إنتاج الهُجن بعد إدخال صفات مرغوبة إليها .