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# Combining Ability Studies in Rice (*Oryza sativa* L.) under Coastal Saline Soil Conditions

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**Combining ability study of yield contributing and salt tolerance related physiological parameters from the diallel analysis of eight well adopted and salt tolerant varieties under saline soil conditions revealed higher *sca* variance than *gca* variance for all the characters studied except for yield reduction per cent, suggesting the significant role of non-additive gene action for majority of the parameters. The genotypes CSRC(S)5-2-2-5, SR26B and CSRC(S)7-1-4 were the good combiners for yield and its attributing as well as salt tolerance related traits . The hybrids SR26-B x CST-7-1, RPBio-226 x CSR-30 and CSR-27 x CSRC(S)5-2-2-5 were adjudged as potential hybrids for yield coupled with salt tolerance.**

**Key words:** Rice, combining ability, coastal saline conditions.

Rice (*Oryza sativa L.*) is the most important food crop in the world, which accounts for more than 21 per cent of the calorific needs of the world's population and up to 76 per cent of the calorific intake of the population of South East Asia (Ma *et al.*, 2007 and Melissa *et al.,* 2009). Though significant improvement in productivity has been achieved over the years, a series of biotic and abiotic stresses limit its productivity worldwide. Abiotic stresses alone contribute to 50 per cent of the total yield losses. High salt concentration in soil is the major constraint to rice production in Bangladesh and India (Mohammadi-Nejad *et al*., 2008). The loss of farm land due to salinisation is directly in conflict with the needs of the world population. Nearly 20 per cent of the world`s cultivated area (800 M ha) and nearly half of the world's irrigated lands are affected by salinity (Zhu *et al*., 2001 and Maser *et al.*, 2002). The area is still increasing as a result of secondary salinization and land clearing (FAO, 2003& 2005 and Metterhichi and Zinck, 2003). This is either due to the direct result of over irrigation, where a raised water table brings the underground salt, particularly sodium chloride, to the surface or reclaimed from the sea or have developed due to sea water intrusion.

In India, nearly 8.5 M ha are salt affected. Out of which 2.19 M. ha are coastal saline and the yield reduction is estimated to the tune of 30 – 50 per cent (Babu *et al.*, 2005). Salinity and sodicity are gradually becoming constraints to rice production in coastal region of Andhra Pradesh. The salt affected soils in Andhra Pradesh are estimated to be 2.74 lakh ha (NRSC, 2010). Investigation of the effects of salinity on rice have been underway for more than 50 years (McWilliam, 1966 ) and attempts to enhance the salt tolerance in rice through breeding started from the early 1970s (Akbar *et al.,* 1972). Several workers reviewed the concept of breeding for salt tolerance and opined that rice being sensitive to salt stress (Grover and Pental, 2003) and its sensitivity is found to vary with its growth stages. Therefore, increasing the yield of rice in poor soils and in less productive saline land is essential for feeding the world.

Success in any breeding programme is dependent on the knowledge and understanding of the inheritance of the trait of interest. Improvement of salt tolerance in high yielding genotypes could be brought about only through the incorporation of such morphological and physiological mechanisms of salt tolerance (Yeo *et al.,* 1990). Genetic information about the combining ability of parents and hybrids and nature of gene action involved in the inheritance of a trait would be of immense value to plant breeders in the choice of parents and to identify potential crosses of practical use.

## Materials and Methods

A pilot experiment was taken up during 2009 at Directorate of Rice Research, Rajendranagar, Hyderabad, with an objective to classify the 24 rice genotypes for salt tolerance based on differential reaction to salinity stress and to utilize them in the crossing programme to study the gene action. Fifty seeds of each cultivar for each treatment were allowed to germinate on a filter paper in 9 cm diameter petridishes. Each filter paper was moistened with salt solution (NaCl) at three concentrations of salinity (4, 8 and 12 dS $m^{-1}$ of electrical conductivity and distilled water as control) created by mixing 2.57 g, 5.14 g and 7.70 g of sodium chloride per litre of water.

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Observations were recorded on ten random plants in each replication for parameters on 15 days old seedlings. The salt injury score was recorded based on Standard Evaluation Score (IRRI, 1986) and the varieties were classified accordingly. The results are summarized in Table 1.

**Table 1. Grouping of rice cultivars based on salt injury score and its relation with $Na^+$ / $K^+$ ratio at 4 $dSm^{-1}$ of salinity**

| Genotype | Salt injury score | $Na^+$ in shoot | $K^+$ in shoot | $Na^+/K^+$ in shoot | Reaction to salinity |
|---|---|---|---|---|---|
| RPBio-226 | 5.877 | 5.443 | 4.480 | 1.214 | Susceptible |
| Swarna | 5.943 | 6.127 | 4.740 | 1.075 | Susceptible |
| CSR-27 | 3.780 | 1.107 | 3.660 | 0.300 | Moderately tolerant |
| CSR-30 | 3.227 | 2.137 | 4.127 | 0.517 | Moderately tolerant |
| SR26-B | 1.910 | 2.163 | 4.313 | 0.500 | Tolerant |
| CST-7-1 | 3.197 | 3.007 | 5.427 | 0.550 | Moderately tolerant |
| CSRC(S)5-2-2-5 | 2.300 | 2.030 | 3.957 | 0.510 | Tolerant |
| CSRC(S)2-1-7 | 4.187 | 2.110 | 4.900 | 0.430 | Moderately tolerant |
| CSR-4 | 2.853 | 3.477 | 5.147 | 0.677 | Tolerant |
| Krishna Hamsa | 5.230 | 3.160 | 6.073 | 0.520 | Susceptible |
| Santhi | 4.403 | 4.997 | 7.230 | 0.690 | Moderately tolerant |
| Sampada | 5.160 | 13.473 | 8.070 | 1.667 | Susceptible |
| NLR-3042 | 5.037 | 3.920 | 4.670 | 0.843 | Susceptible |
| NLR-145 | 5.643 | 2.883 | 4.970 | 0.580 | Susceptible |
| BPT-5204 | 5.040 | 6.027 | 5.977 | 1.007 | Susceptible |
| NLR-33359 | 3.567 | 6.267 | 7.673 | 0.817 | Moderately tolerant |
| Varadan | 4.893 | 7.883 | 6.653 | 1.187 | Moderately tolerant |
| CSRC(S)7-1-4 | 2.583 | 0.913 | 2.543 | 0.353 | Tolerant |
| BPT-2231 | 5.820 | 8.363 | 8.003 | 1.050 | Susceptible |
| BPT-2270 | 6.480 | 7.763 | 6.510 | 1.193 | Susceptible |
| NLR-3041 | 4.060 | 6.583 | 6.200 | 1.060 | Moderately tolerant |
| Dhanarasi | 6.007 | 4.027 | 6.967 | 0.803 | Susceptible |
| NLR-33892 | 4.873 | 4.600 | 7.183 | 0.643 | Moderately tolerant |
| NLR-34449 | 3.097 | 6.477 | 6.267 | 1.030 | Moderately tolerant |

Based on salt injury score, the 24 rice genotypes were categorized into three classes. The cultivars *viz.*, RPBio-226, Swarna, Krishna Hamsa, Sampada, NLR-3042, NLR-145, BPT-5204, BPT-2231, BPT-2270 and Dhanarasi were graded as susceptible as they showed salt injury score of more than 5, while the genotypes, CSR-27, CSR-30, CST7-1, CSRC(S)2-1-7, Santhi, NLR-33359, Varadan, NLR-3041, NLR-33892 and NLR-34449 were moderately tolerant by virtue of their salt injury score being less than five. Similarly, the cultivars SR26B, CSRC(S)5-2-2-5, CSR-4 and SCRC(S) 7-1-4 were identified to be tolerant to salinity as they showed salt injury score of less than three.

Eight genotypes *viz.,* RPBio-226, Swarna, CSR-27, CSR-30, CSRC(S)7-1-4, SR26-B, CST-7-1 and CSRC(S)5-2-2-5 were selected based on their reaction to salinity tolerance and were crossed in diallel fashion (without reciprocals) and the resulting 28 hybrids along with parents were evaluated during *kharif,* 2010 under salt affected soils of Agricultural Research Station, Machilipatnam .

A site with appropriate chemical properties was selected after intensive sampling from a salt affected field. Seedlings (30 days old) were transplanted in the main field following randomized block design with three replications. The saline soils were of sandy loam in texture with an average electrical conductivity of 6.3 dS $m^{-1}$ and pH of 7.9. The parents and $F_1$s were transplanted in 3 rows of 1.5 metre length with a spacing of 20 x 15 cm. The recommended agronomic practices were adopted in conducting the experiment. The results obtained on gene effects governing the inheritance of physiological parameters and yield components through diallel analysis following model I and method II of Griffing (1956) and discussed trait wise for 10 yield parameters and six physiological traits in eight parents and 28 $F_1$ hybrids under saline soil.

## Results and Discussion

Mean squares due to *gca* for yield components and salt tolerance related physiological components were significant, indicating that all the parents differed significantly for their general combining ability for all the traits studied (Table 2 and 3). Similarly, the mean squares due to *sca* were significant for all characters except SPAD chlorophyll metre readings, which indicated that there was a variance among the hybrids for the characters under study.

**Table 2. ANOVA for combining ability for yield and its components**

| Genotype | df | PHT (cm) | | DFF | | TT | | PT | | PL (cm) | | PW (g) | | NFG/P | | SF (%) | | TW (g) | | GY (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N |
| GCA | 7 | 150.89** | 69.03** | 75.74** | 66.11** | 8.34** | 12.33** | 4.84** | 13.54** | 19.31** | 4.94** | 1.56** | 1.06** | 1447.20** | 2286.41** | 93.05** | 27.83** | 13.75** | 10.20** | 72.76** | 30.36** |
| SCA | 28 | 94.06** | 33.19** | 31.39** | 26.48** | 2.05** | 12.85** | 2.26** | 13.78** | 6.73** | 4.37** | 0.75** | 0.50** | 693.37** | 582.81** | 59.86** | 44.32** | 5.14** | 2.77** | 19.55** | 14.52** |
| Error | 70 | 5.10 | 7.12 | 1.93 | 5.11 | 0.46 | 0.55 | 0.25 | 0.50 | 0.74 | 0.96 | 0.04 | 0.03 | 40.49 | 86.96 | 8.53 | 5.89 | 0.25 | 0.59 | 1.78 | 2.27 |
| $\sigma^2 gca$ | | 14.58 | 6.19 | 7.38 | 6.10 | 0.79 | 1.18 | 0.46 | 1.30 | 1.86 | 0.40 | 0.15 | 0.10 | 140.67 | 219.95 | 8.45 | 2.19 | 1.35 | 0.96 | 7.10 | 2.81 |
| $\sigma^2 sca$ | | 88.96 | 26.07 | 29.46 | 21.37 | 1.59 | 12.29 | 2.01 | 13.28 | 5.99 | 3.42 | 0.71 | 0.46 | 652.87 | 495.85 | 51.33 | 38.43 | 4.89 | 2.18 | 17.78 | 12.25 |
| $\sigma^2 gca / \sigma^2 sca$ | | 0.16 | 0.24 | 0.25 | 0.29 | 0.49 | 0.10 | 0.23 | 0.10 | 0.31 | 0.12 | 0.21 | 0.22 | 0.22 | 0.44 | 0.16 | 0.06 | 0.28 | 0.44 | 0.40 | 0.23 |

* Significant at p=0.05; ** Significant at p=0.01; S (Saline soils); N (Normal soils)

PHT (cm): Plant height; DFF: Days to 50% flowering; TT: Number of tillers per plant; PT: Number of productive tillers plant-1; PL (cm): Panicle length; PW(g): Panicle weight;NFGP-1: Number of filled grains per panicle; SF (%): Spikelet fertility per cent; TW (g): 1000-grain weight; GY (g): Grain yield (g plant-1).

The comparative estimates of variances due to *gca* and *sca* revealed the importance of *sca* variance. The *sca* variances were higher than *gca* variances for all the characters except for yield reduction per cent suggesting the significant role of non-additive gene

**Table 3. ANOVA for combining ability for physiological parameters**

| Genotype | df | Salt injury score | | Root/ Shoot ratio | | Harvest Index (%) | | $Na^+/K^+$ ratio | | SPAD chlorophyll metre reading | | Yield reduction (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | N | S | N | S | N | S | N | S | N | S |
| GCA | 7 | 1.13** | 0.10** | 0.01** | 0.02** | 32.96* | 7.36* | 1.46** | 0.03** | 43.07** | 22.32** | 1055.26** |
| SCA | 28 | 1.18** | 0.15** | 0.01** | 0.01** | 20.46 | 12.23** | 0.55** | 0.05** | 16.86** | 2.67 | 157.30** |
| $\sigma^2 gca$ | | 0.11 | 0.01 | 0.01 | 0.00 | 2.03 | 0.48 | 0.15 | 0.00 | 4.10 | 1.90 | 97.83 |
| $\sigma^2 sca$ | | 1.13 | 0.13 | 0.07 | 0.01 | 7.80 | 9.65 | 0.55 | 0.05 | 14.75 | -0.70 | 80.34 |
| $\sigma^2 gca / \sigma^2 sca$ | | 0.10 | 0.06 | 0.07 | 0.13 | 0.26 | 0.05 | 0.27 | 0.06 | 0.28 | -2.72 | 1.22 |

*Significant at p=0.05; **Significant at p=0.01; S (Saline soils); N (Normal soils)

**Table 4. General Combining Ability effects of parents for yield and its components**

| Genotype | PHT (cm) | | DFF | | TT | | PT | | PL (cm) | | PW (g) | | NFG/P | | SF (%) | | TW (g) | | GY (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N |
| RPBio-226 | -2.08** | -1.81* | -2.95** | -1.70* | -1.32** | -0.23 | -0.76** | -0.59** | -1.91** | -1.07** | -0.09 | 0.01 | -11.90** | -1.22 | -0.11 | 2.67** | -2.17** | -1.94** | -2.72** | 0.80 |
| Swarna | -5.65** | -2.91** | 3.72** | 3.57** | 0.08 | -0.17 | 0.07 | 0.11 | -0.45 | -0.13 | -0.43** | -0.23** | -3.57 | 2.98 | -5.18** | 0.10 | -0.99** | -0.71** | -1.84** | 1.07* |
| CSR-27 | -1.12 | -1.00 | -1.02* | -1.87** | -0.59** | -0.30 | -0.26 | -0.36 | -0.31 | 0.68* | -0.04 | -0.02 | 1.13 | -9.18** | -0.66 | 0.63 | 0.76** | 0.31 | -2.47** | -1.23** |
| CSR-30 | -4.56** | -0.25 | -3.98** | -4.07** | -1.06** | -2.17** | -1.16** | -2.13** | -1.37** | -0.83** | -0.65** | -0.61** | -20.50** | -32.22** | -2.96** | -3.17** | -0.35* | -0.36 | -2.31** | -3.61** |
| CSRC(S)7-1-4 | 3.22** | 4.42** | 2.12** | 1.77* | 0.97** | -0.27 | 0.64** | -0.46* | 0.34 | 0.22 | 0.43** | 0.52** | 6.77** | 11.25** | 0.10 | -0.70 | 0.76** | 0.80** | 2.37** | 0.07 |
| SR26-B | 4.51** | 3.66** | 0.58 | 1.30 | 1.04** | 1.57** | 0.81** | 1.57** | 1.53** | 0.11 | 0.41** | 0.14** | 11.90** | 4.62 | 1.62 | -0.64 | 1.01** | 0.71** | 3.82** | 2.00** |
| CST-7-1 | 2.40** | -1.51 | -1.18** | -1.13 | 0.14 | 0.70** | 0.07 | 0.74** | -0.12 | -0.03 | 0.01 | 0.02 | 0.37 | 7.55** | 3.00** | 0.12 | -0.27 | -0.05 | 0.23 | -0.05 |
| CSRC(S)5-2-2-5 | 3.29** | -0.59 | 2.72** | 2.13** | 0.74** | 0.87** | 0.57** | 1.11** | 2.29** | 1.05 | 0.35** | 0.16** | 15.80** | 16.22** | 4.18** | 1.00 | 1.26** | 1.23** | 2.91** | 0.94* |

* Significant atp=0.05; ** Significant at p=0.01; S (Saline soils); N (Normal soils)

PHT (cm): Plant height; DFF: Days to 50% flowering; TT: Number of tillers plant-1; PT: Number of productive tillers per plant; PL (cm): Panicle length; PW(g): Panicle weight;NFGP-1: Number of filled grains panicle-1; SF (%): Spikelet fertility per cent; TW (g): 1000-grain weight; GY (g): Grain yield (g plant-1).

action for majority of the parameters (Table 2 and 3). These findings are in agreement for days to 50 per cent flowering, plant height, number of productive tillers plant$^{-1}$ and panicle length with the earlier reports of Karthikeyan and Anbuselvam (2006), Sanjeevkumar *et al.*(2007) Senguttuvel (2008), Salgotra *et al.* (2009) and Kumar Babu *et al.*(2010).

The non-additive gene effects for test weight were reported by earlier researchers *viz.,* Rogbell and Subbaraman (1997), Sarma *et al.*(2007), Venkatesan *et al.* (2007), Shukla and Pandey (2008) and Kumar Babu *et al.* (2010). Similar reports for number of filled grains panicle$^{-1}$ were also noticed by Thirumeni *et al*. (2003), Raju *et al*. (2006), Sharma and Mani (2008), Senguttuvel (2008), Sanjay Singh *et al.* (2008), Saidaiah *et al.* (2010). For spikelet fertility, Mahmood *et al.* (2002), Thirumeni *et al*. (2003) and Senguttuvel (2008) observed similar results and for grain yield plant, Rogbell and Subbaraman (1997a), Mishra *et al.* (1998), Mohmood *et al.* (2002), Karthikeyan and Anbuselvam (2006), Shukla and Pandey (2008), Salgotra *et al*. (2009) and Kumar Babu *et al.* (2010) reported the same gene action as in case of present study. Likewise, Karthikeyan and Anbuselvam (2006) reported similar results for panicle weight; Mahmood *et al*. (2002) for salt injury score, Raju *et al.* (2006) for harvest index; Mahmood *et al.* (2002), Mishra *et al.* (2003 ) and Senguttuvel (2008) for $Na^+/K^+$ ratio; Malarvizhi (2004) and Senguttuvel (2008) for SPAD chlorophyll metre readings.

***General combining ability***

Under saline soils, SR26B was adjudged the best combiner coupled with high *per se* for12 traits *viz.,* total tillers plant$^{-1}$ and productive tillers plant$^{-1}$, panicle length, panicle weight, number of filled grains panicle$^{-1}$,1000-grain weight, grain yield, visual salt injury, harvest index, low $Na^+/K^+$ ratio, SPAD readings and low yield reduction, while CSRC(S)7-1-4 was the next good general combiner which showed high *gca* and *per se* for six traits *viz.,* number of tillers plant$^{-1}$, panicle weight, number of filled grains panicle$^{-1}$, test weight, root/shoot ratio and $Na^+/K^+$ ratio (Table 4 and 5).

***Specific combining ability***

In the present investigation, significantly higher *sca* effects were recorded by several cross combinations for every trait. Several hybrids also recorded high *sca* effects for many of the characters. Among them, the hybrid Swarna x CSRC(S)7-1-4 was considered to be the best for 13 traits including yield and physiological attributes under saline soils *viz*., days to 50 per cent flowering, panicle length, panicle weight, number of filled grains per panicle, spikelet fertility, 1000-grain weight, grain yield per plant, SES for visual salt injury, root/shoot ratio, harvest index, $Na^+/K^+$ ratio, SPAD value and yield reduction per cent (Table 6 and 7).

The other hybrids SR26-B x CST-7-1, RPBio-226 x CSRC(S)7-1-4 and RPBio-226 x CSR-30 were also good specific combiners for majority of the traits.

**Table 5. General combining ability effects of parents for physiological parameters**

| Genotype | Salt injury score | | Root/ Shoot ratio | | Harvest Index (%) | | $Na^+/K^+$ ratio | | SPAD chlorophyll meter reading | | Yield reduction (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | N | S | N | S | N | S | N | S | N | S |
| RPBio-226 | 0.46** | 0.02 | -0.02** | -0.02** | -1.03 | 0.04 | 0.35** | -0.08 | -0.97* | -1.09* | 13.42 |
| Swarna | -0.21** | 0.10* | -0.02** | 0.03** | 0.41 | -0.58 | 0.27** | 0.02 | 1.78** | 3.22** | 11.47** |
| CSR-27 | 0.12 | 0.09* | -0.02** | -0.01 | 0.20 | 0.72 | 0.17** | 0.10** | -0.61 | -0.07 | 9.35** |
| CSR-30 | 0.47** | -0.08 | -0.01* | 0.01 | -3.67** | -1.65** | 0.44** | 0.04** | -3.47** | -1.77** | -1.27 |
| CSRC(S)7-1-4 | 0.07 | -0.03 | 0.04** | 0.04** | 0.35 | -0.01 | -0.06* | -0.05** | -0.33 | -0.34 | -10.32** |
| SR26-B | -0.26** | -0.15** | 0.01 | -0.08** | 2.50** | 1.21* | -0.57** | -0.03 | 3.43** | 0.77 | -10.62** |
| CST-7-1 | -0.27** | 0.12** | -0.01 | 0.03** | -0.16 | 0.32 | -0.07* | 0.04* | -0.83 | -0.39 | -1.19 |
| CSRC(S)5-2-2-5 | -0.39** | -0.07 | 0.03** | 0.02** | 1.40 | -0.06 | -0.53** | -0.04* | 1.01* | -0.33 | -10.84** |

*Significant at p=0.05; **Significant at p=0.01; S (Saline soils); N (Normal soils)

There was no relation to predict that parents with significant positive *gca* effects combine to give rise hybrids of significant positive *sca* effects, as most of the cross combinations that recorded significant positive *sca* effects were combined by parents having high x low combining ability as seen in case of CSR-30 x CSRC(S)7-1-4 for plant height; CST-7-1 x CSRC(S)5-2-2-5 for days to 50 per cent flowering; Swarna x CSRC(S)5-2-2-5 for number of total as well as productive tillers per plant; SR26B x CST7-1 for panicle length, number of filled grains per panicle, test weight, grain yield per plant and root shoot ratio;

**Table 6 . Specific combining ability effects for yield and its components**

| Hybrid | Plant height (cm) | | Days to 50%flowering | | No.total of tillersplant$^{-1}$ | | No. of productive tillers plant$^{-1}$ | | Panicle length (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal |
| RPBio-226 × Swarna | 1.05 | -4.52* | -4.34** | -3.76* | -0.37 | 3.88** | -0.05 | 2.27** | -1.39* | -1.70* |
| RPBio-226 × CSR-27 | -2.21 | -7.50** | 7.73** | 6.01** | 0.96 | 0.31 | 0.29 | 1.74** | -0.37 | -0.60 |
| RPBio-226 × CSR-30 | 11.96** | 5.79* | -2.64* | -4.79* | 1.76** | 1.84** | 1.85** | 1.17* | 3.83** | 1.34 |
| RPBio-226 × CSRC(S)7-1-4 | 18.34** | 5.92* | -5.41** | -4.29* | 2.06** | 2.28** | 2.05** | 2.50** | -0.42 | -1.84* |
| RPBio-226 × SR26-B | 6.56** | -3.46 | 3.46** | 1.84 | 0.33 | 0.11 | -0.45 | 1.80** | -1.87* | -2.26** |
| RPBio-226 × CST-7-1 | 4.42* | -0.35 | -4.11** | -8.39** | -0.77 | 0.64 | -0.72 | 0.64 | -1.46* | 0.47 |
| RPBio-226 × CSRC(S)5-2-2-5 | -2.53 | 3.83 | 1.33 | 0.99 | -1.37* | -2.86** | -1.22** | -4.06** | -0.79 | -0.04 |
| Swarna × CSR-27 | -11.88** | -1.90 | -5.94** | -2.92 | 0.23 | 2.58** | 0.12 | 3.04** | -1.86* | -1.30 |
| Swarna × CSR-30 | 3.33 | 3.35 | -3.97** | -6.06** | 0.03 | -4.22** | 0.35 | -2.53** | 0.77 | -0.54 |
| Swarna × CSRC(S)7-1-4 | 14.78** | 3.72 | -8.74** | -4.56* | 0.33 | -1.46* | -0.12 | -1.20** | 1.53* | -0.58 |
| Swarna × SR26-B | 8.83** | 3.48 | -5.21** | -4.76* | -1.07 | 1.04 | -0.95* | 1.77** | -0.63 | 0.20 |
| Swarna × CST-7-1 | -2.41 | 1.12 | 1.23 | 1.01 | -0.17 | 3.24** | -0.22 | 4.94** | -2.38** | 0.40 |
| Swarna × CSRC(S)5-2-2-5 | -5.19** | 3.13 | 1.66 | -0.26 | 3.23** | 1.41* | 2.62** | 0.57 | 0.61 | 1.99* |
| CSR-27 × CSR-30 | -2.03 | 0.65 | -6.91** | -3.62 | -0.30 | 6.91** | 1.02* | 7.60** | -1.01 | 2.13* |
| CSR-27 × CSRC(S)7-1-4 | -13.88** | -8.59** | -0.34 | 0.21 | -0.67 | -1.99** | -0.45 | -2.73** | -3.61** | -2.38** |
| CSR-27 × SR26-B | 5.27** | 6.47** | 5.19** | 6.01** | -1.74** | -0.49 | -2.28** | -0.43 | 0.00 | 1.86* |
| CSR-27 × CST-7-1 | 6.37** | 4.98* | 9.96** | 3.44 | 1.50* | 3.04** | 1.79** | 1.40* | 1.01 | 1.10 |
| CSR-27 × CSRC(S)5-2-2-5 | 2.78 | -1.24 | -5.27** | -4.82* | 0.23 | 2.21** | -1.38** | 3.04** | 1.03 | 0.52 |
| CSR-30 × CSRC(S)7-1-4 | -21.85** | 8.23** | -1.37 | -0.59 | -0.20 | 2.54** | -1.88** | 1.70** | -0.96 | 1.56 |
| CSR-30 × SR26-B | -14.20** | -0.18 | 2.16 | -2.46 | 1.06 | 3.04** | -1.72** | 4.34** | -4.31** | -4.47** |
| CSR-30 × CST-7-1 | 5.67** | 1.26 | 3.59** | 8.64** | 0.96 | -1.09 | 1.02* | -0.83 | -0.90 | 0.84 |
| CSR-30 × CSRC(S)5-2-2-5 | 9.25** | 1.97 | -2.31* | -1.62 | -0.30 | 1.41* | 0.19 | 0.47 | 1.13 | 0.32 |
| CSRC(S)7-1-4 × SR26-B | -1.95 | -1.15 | 3.73** | 3.38 | 0.36 | -1.86** | 1.15** | -1.66** | 0.95 | 4.42** |
| CSRC(S)7-1-4 × CST-7-1 | 2.12 | 12.39** | 1.16 | 2.14 | -2.74** | 1.01 | -2.78** | 2.17** | -7.14** | -5.18** |
| CSRC(S)7-1-4 × CSRC(S)5-2-2-5 | 0.64 | -1.53 | 1.26 | -2.79 | 2.00** | 3.51** | 1.39** | 2.47** | 1.79* | 1.71* |
| SR26-B × CST-7-1 | 0.54 | 0.85 | -2.64 | -3.39 | 2.20** | 3.84** | 2.05** | -0.53 | 4.31** | 1.60* |
| SR26-B × CSRC(S)5-2-2-5 | -3.05 | -1.84 | 2.13 | 5.01** | -1.74** | 2.34** | -1.12** | 2.77** | -0.53 | -1.01 |
| CST-7-1 × CSRC(S)5-2-2-5 | 1.25 | -6.76** | -7.44* | -4.22* | -1.17* | 1.21* | -2.05** | 2.94** | 1.21 | -0.18 |
| SE±($S_{ij}$) | 2.05 | 2.40 | 1.26 | 2.05 | 0.61 | 0.67 | 0.45 | 0.64 | 0.78 | 0.89 |

*Significant at p=0.05; **Significant at p=0.01

| Hybrid | Panicle weight (g) | | No. of filled grains panicle$^{-1}$ | | Spikelet fertility (%) | | 1000-grain weight (g) | | Grain yield (g plant$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal |
| RPBio-226 × Swarna | -0.26 | 0.39* | 3.43 | 8.47 | -10.18** | 8.13** | -3.90** | -2.47** | -1.88 | -2.31 |
| RPBio-226 × CSR-27 | 0.44** | 0.14 | -3.27 | -7.36 | 3.47 | 2.23 | -2.17** | 0.68 | -2.19* | 3.00* |
| RPBio-226 × CSR-30 | 1.24** | 0.75** | 28.36** | 8.67 | 1.24 | -13.47** | 1.69** | 0.62 | 4.02** | 2.36 |
| RPBio-226 × CSRC(S)7-1-4 | 0.89** | -0.29 | 3.43 | -37.79** | 8.57** | 5.70** | 1.20** | 1.62* | 1.98 | -0.72 |
| RPBio-226 × SR26-B | -0.90** | -0.29* | -9.04 | -14.16 | -9.21** | -4.97* | -0.97* | -1.00 | -6.05** | -4.02** |
| RPBio-226 × CST-7-1 | 0.37* | -0.01 | -3.50 | -11.09 | 1.84 | 1.78 | 2.90** | 2.53** | 1.31 | 0.73 |
| RPBio-226 × CSRC(S)5-2-2-5 | 0.37* | -0.29 | -4.27 | -2.09 | 4.23 | 3.09 | 4.29** | 1.07 | 1.74 | -0.88 |
| Swarna × CSR-27 | -1.08** | -0.32* | 17.40** | -11.23 | -5.12* | 5.56** | -1.55** | -1.19 | -4.36** | -5.77** |
| Swarna × CSR-30 | 0.03 | 0.01 | 2.36 | 0.81 | 2.41 | 3.36 | 1.14** | 1.21 | 1.01 | -2.52* |
| Swarna × CSRC(S)7-1-4 | 0.93** | 0.68** | 53.43** | 8.01 | 11.21** | 1.40 | 3.73** | 1.05 | 9.47** | 5.61** |
| Swarna × SR26-B | -0.20 | -0.17 | 2.63 | 3.31 | 1.13 | -4.93* | -0.17 | 0.15 | 1.10 | -1.26 |
| Swarna × CST-7-1 | -0.47** | -0.76** | -27.17** | -5.63 | -3.45 | -15.95** | -2.67** | -1.39* | -3.85** | -0.14 |
| Swarna × CSRC(S)5-2-2-5 | -1.02** | -0.30 | -14.27** | 7.71 | -10.77** | -10.04** | -1.22** | -0.21 | -2.51* | -1.73 |
| CSR-27 × CSR-30 | -1.14** | -540.00** | 1.00 | 13.64 | -6.07* | -1.90 | 0.39 | 0.87 | 0.52 | -0.33 |
| CSR-27 × CSRC(S)7-1-4 | -0.94** | -1.36** | -7.60 | 30.84** | -11.50** | -5.27* | 1.56** | 1.84** | -7.80** | -6.50** |
| CSR-27 × SR26-B | 0.37* | 0.01 | -44.40** | -42.53** | 1.61 | 0.80 | 0.82* | 0.20 | -2.69* | -0.30 |
| CSR-27 × CST-7-1 | 0.41** | -0.01 | 10.80* | 18.21* | 3.73 | 0.95 | -0.11 | -0.71 | 3.81** | 4.27** |
| CSR-27 × CSRC(S)5-2-2-5 | 0.56** | 0.81** | 20.70** | 6.54 | 4.15 | -0.30 | -1.75** | -0.35 | 7.52** | 5.54** |
| CSR-30 × CSRC(S)7-1-4 | -1.13** | -1.21** | -27.97** | -4.13 | -9.20** | -3.90 | -2.71** | 0.26 | -1.19 | 0.38 |
| CSR-30 × SR26-B | -1.24** | -1.27** | -37.10** | -20.16* | 13.15** | -8.50** | -0.34 | -1.88** | -3.08** | -2.35 |
| CSR-30 × CST-7-1 | 0.16 | -0.72** | -5.90 | -1.43 | 5.37* | 5.91** | -0.12 | 0.05 | -3.35** | 0.13 |
| CSR-30 × CSRC(S)5-2-2-5 | -0.08 | -0.25 | -2.00 | -13.43 | 1.62 | 4.36* | -0.47 | 0.39 | -3.29** | -0.49 |
| CSRC(S)7-1-4 × SR26-B | 0.51** | 0.39* | 14.63** | 7.04 | 4.65 | 4.10* | -2.33** | 0.58 | 3.23** | 2.68* |
| CSRC(S)7-1-4 × CST-7-1 | -1.48** | 1.02** | -62.50** | 4.77 | -15.83** | -9.88** | -4.28** | -3.44 | -7.30** | -7.94** |
| CSRC(S)7-1-4 × CSRC(S)5-2-2-5 | 0.72** | 0.32* | -5.60 | 43.11** | -2.28 | 0.63 | 0.90* | 0.88 | -0.92 | 1.40 |
| SR26-B × CST-7-1 | 0.81** | 0.68** | 57.03** | 61.74** | 8.25** | 8.82** | 2.77** | 2.69** | 7.92** | 8.07** |
| SR26-B × CSRC(S)5-2-2-5 | -0.43** | -0.08 | -13.40* | -3.26 | -2.46 | 0.20 | -2.51** | -0.21** | -1.47 | -0.49 |
| CST-7-1 × CSRC(S)5-2-2-5 | 0.35* | 0.20 | 25.46** | 17.14* | 3.76 | 0.05 | 0.62 | 3.02** | 4.28** | 2.64* |

*Significant at p=0.05; **Significant at p=0.01

**Table 7. Specific combining ability effects for physiological traits**

| Hybrid | Salt injury score | | Root/ shoot ratio | | Harvest Index(%) | | $Na^+/K^+$ ratio | | SPAD value | | Yield reduction (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal | Saline | Normal | |
| RPBio-226 × Swarna | -1.82** | -0.16 | 0.01** | 0.02 | 4.03 | 2.75 | -0.09 | -0.01 | -0.05 | -1.49 | 3.88 |
| RPBio-226 × CSR-27 | -0.66** | -0.11 | 0.03* | 0.10** | 3.24 | 1.35 | 0.53** | -0.19** | 0.85 | 0.87 | 17.01* |
| RPBio-226 × CSR-30 | -0.04 | -0.37** | -0.02 | -0.06** | -5.62 | -1.21 | -0.67** | -0.31** | 6.41** | 0.46 | -14.82* |
| RPBio-226 × CSRC(S)7-1-4 | -0.74** | 0.18 | -0.02 | -0.03 | 3.33 | 4.02** | -0.39** | -0.32** | 4.47** | 3.24* | -13.78 |
| RPBio-226 × SR26-B | 0.49** | -0.31* | -0.15** | -0.08** | -0.56 | -1.90 | -0.61** | 0.14** | 0.07 | -0.30 | 17.37* |
| RPBio-226 × CST-7-1 | -0.73** | -0.61** | 0.04** | 0.00 | -2.00 | -0.21 | 0.27** | -0.16** | 2.47* | 1.65 | -2.66 |
| RPBio-226 × CSRC(S)5-2-2-5 | -0.70** | -0.33** | 0.08** | 0.04* | 3.78 | 0.60 | -0.27** | 0.44** | -0.50 | -2.07 | -9.39 |
| Swarna × CSR-27 | -0.52** | 0.19 | 0.01 | 0.10** | 0.40 | -0.66 | 0.49** | 0.13* | 3.90** | 0.46 | 10.55 |
| Swarna × CSR-30 | -1.85** | -0.37** | 0.11** | 0.15** | 7.07* | 5.47** | 0.07 | -0.12** | 3.79** | 1.59 | -14.25* |
| Swarna × CSRC(S)7-1-4 | -0.74** | -0.24* | 0.11** | 0.00 | 7.32* | -2.20 | -1.25** | -0.15** | 6.81** | 1.47 | -21.40** |
| Swarna × SR26-B | 0.16 | -0.04 | -0.02 | -0.09** | 0.57 | 2.05 | -0.27** | 0.13** | -1.40 | -0.17 | -11.21 |
| Swarna × CST-7-1 | -0.38* | 0.59** | -0.11** | 0.02 | -1.28 | 0.70 | 0.30** | 0.18** | -3.73** | 1.12 | 17.38* |
| Swarna × CSRC(S)5-2-2-5 | 0.06 | 0.08 | -0.16** | -0.08** | -8.03** | -6.99** | 0.51** | -0.22** | 0.67 | 0.73 | 5.37 |
| CSR-27 × CSR-30 | 0.60** | -0.35** | -0.10** | -0.05** | 2.61 | 0.24 | 0.13 | 0.18** | -3.85** | -0.05 | -4.75 |
| CSR-27 × CSRC(S)7-1-4 | 0.94** | 0.00 | -0.12** | -0.06** | -3.81 | 0.74 | 1.12** | 0.14** | 0.01 | 1.42 | 20.37** |
| CSR-27 × SR26-B | -0.44* | 0.94** | 0.03* | 0.01 | 2.61 | 3.31* | 0.27** | 0.41** | -2.00 | -1.82 | 9.20 |
| CSR-27 × CST-7-1 | 0.24 | -0.16 | -0.12** | -0.23** | 0.30 | 4.14** | -0.46** | 0.11* | 2.58* | 1.40 | -7.64 |
| CSR-27 × CSRC(S)5-2-2-5 | -0.52** | -0.11 | 0.08** | 0.03 | 5.91* | 2.55 | -0.62** | -0.18** | 4.94** | 1.08 | -15.59* |
| CSR-30 × CSRC(S)7-1-4 | 1.29** | 0.02 | -0.09** | -0.07** | -3.67 | 2.57 | 0.79** | -0.13** | -6.14** | -0.35 | 3.37 |
| CSR-30 × SR26-B | 1.21** | -0.14 | -0.12** | -0.09** | -5.79* | -0.92 | 1.42** | 0.30** | -1.96 | 1.74 | 2.97 |
| CSR-30 × CST-7-1 | -1.71** | -0.18 | 0.03* | -0.05** | 2.97 | 4.11** | 0.02 | 0.10* | 1.37 | -0.47 | 19.82** |
| CSR-30 × CSRC(S)5-2-2-5 | 0.11 | 0.42** | -0.02 | 0.02 | -0.59 | 0.85 | 0.36** | 0.07 | 0.56 | 0.24 | 13.89 |
| CSRC(S)7-1-4 × SR26-B | -0.59** | -0.17 | 0.03* | 0.05** | -1.57 | 1.85 | -0.17* | 0.02 | 3.93** | 0.92 | -4.44 |
| CSRC(S)7-1-4 × CST-7-1 | 1.40** | 0.25* | 0.04** | 0.25** | -5.88* | -3.06* | 1.86** | 0.21** | -4.34** | -1.79 | 5.21 |
| CSRC(S)7-1-4 × CSRC(S)5-2-2-5 | 0.04 | 0.04 | -0.02 | 0.20** | 4.86 | 3.35* | -0.14 | 0.14** | 2.35* | 1.15 | 8.02 |
| SR26-B × CST-7-1 | -0.65** | -0.29* | 0.08** | 0.06** | 5.40 | 0.81 | -0.54** | -0.36** | 1.43 | -0.03 | -5.04 |
| SR26-B × CSRC(S)5-2-2-5 | 0.05 | 0.46** | 0.03* | -0.05* | 3.31 | 3.36* | 0.11 | -0.07 | 0.39 | 0.51 | 5.69 |
| CST-7-1 × CSRC(S)5-2-2-5 | 0.19 | 0.07 | 0.07** | 0.14** | 0.07 | 1.25 | -0.49** | -0.25** | 5.29** | 1.87 | -9.15 |

*Significant at p=0.05; **Significant at p=0.01

Swarna x CSRC(S)7-1-4 for panicle weight, number of filled grains per panicle, test weight, grain yield per plant, SPAD readings and yield reduction per cent; Swarna x CSR30 for SES for visual salt injury; CSR27 x CSRC(S)5-2-2-5 for $Na^+/K^+$ ratio. The desirable performance of these combinations may be attributed to the interaction of dominant alleles from good combiners and recessive alleles from poor combiners (Saidaiah *et al*., 2010).

Involvement of parents having poor combining ability also produced superior specific combining hybrids as evidenced from the combinations *viz.,* CSR-27 x CSRC(S)7-1-4 for dwarfness; Swarna x CSRC(S)7-1-4 for earliness, spikelet fertility per cent and harvest index; RPBio226 x CSR-30 for panicle length, panicle weight, number of filled grains per panicle, $Na^+/K^+$ ratio, SPAD readings and for lesser yield reduction per cent. This may be ascribed to over dominance and epistatic interaction, which has been suggested by Dalvi and Patel (2009).

In majority of the hybrids, high *sca* was either due to high x low or low x low combing parents, which further substantiate the operation of non-additive gene action (additive x dominance and dominance x dominance epistatic interaction). An ideal combination to be explored in one, where high magnitude of *sca* is present, in addition to high *gca* in both or at least one of the parents.

Combining ability analysis revealed that SR26B, CSRC(S)7-1-4 and CSRC(S) 5-2-2-5 were the good general combiners for yield and majority of yield attributes and salt tolerance related physiological parameters. The hybrids namely, SR26-B x CST-7-1, RPBio-226 x CSR-30 and CSR-27 x CSRC(S)5-2-2-5 were adjudged as the most promising hybrids for yield and its attributes as well as salt tolerant traits based on *sca* effects, better *per se* and one of the parents with high *gca* and could be exploited for higher yield coupled with salt tolerance .

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