Studies on combining ability and heterosis for yield and drought tolerance traits in rice (*Oryza sativa* L.)

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Abstract
A research study was conducted involving four high yielding rice varieties viz., CO 51, MDU 6, ADT (R) 45 and ASD 16 as lines and five drought tolerant genotypes viz., CR Dhan 201, CR Dhan 203, DRR DHAN 42, Apo and GP 239 as testers to understand the nature of gene action, combining ability of parents and hybrids, the extent of heterosis for drought tolerance and yield traits. The ratio of GCA and SCA were less than unity revealed the predominance of dominance gene action for all the drought tolerant and yield traits. Based on both per se performance and gca, the lines viz., MDU 6, ADT (R) 45 and the tester viz., DRR DHAN 42 were identified as the best general combiners for yield and drought related traits. Hence, these parental genotypes could be used in developing cross combinations to produce desirable segregants with various mechanisms of drought tolerance and grain yield. Among the 20 hybrids, CO 51 x CR Dhan 203 and MDU 6 x CR Dhan 201 were good specific combiners, which had significant sca effects for many yield and drought tolerant traits. The crosses MDU 6 x DRR DHAN 42 and ADT (R) 45 x DRR DHAN 42 exhibited significantly positive heterosis for panicle length, productive tillers, chlorophyll stability index, relative water content, filled grains per panicle, grain yield, root length, dry root weight, root volume, root thickness and root/shoot ratio. Combining per se performance, sca and standard heterosis, the hybrids MDU 6 x DRR DHAN 42, ADT (R) 45 x DRR DHAN 42 and MDU 6 x CR Dhan 201 were identified as superior hybrids since they possessed good performance for many drought tolerant traits.

Key words: L × T analysis, Combining ability, Heterosis, Drought tolerance, Rice

INTRODUCTION
Rice (*Oryza sativa* L.) is the staple food for more than 50 per cent of the world population. It has a major role in food security and improving the livelihood of people. Worldwide rice is grown over an area of 162.76 million hectares with a total production of 495.87 million tonnes with a productivity of 4.55 tonnes/hectare (FAOSTAT, 2020). More than 90 per cent of rice is produced and consumed in Asian countries (Palanog et al., 2014). Among rice growing countries, India has the largest area under rice cultivation globally with 44.40 million hectares and it ranks second in rice production with 117.47 million tonnes next only to wheat (Ministry of Agriculture, Government of India, 2019-20). It plays a significant role in the Indian economy being the staple food for two third of
the population. The production of rice is limited by various biotic and abiotic factors. The most important abiotic stress is drought which limits rice production in a rainfed environment. Rainfed agriculture plays an important role in the Indian economy. In India 88 per cent of the total net sown area (136.8 m. ha) comes under rainfed lands spread over 177 districts. Rainfed crops account for 48 per cent area under food crops and 68 per cent of the area under non-food crops. The production of rice has decreased by 25.4 per cent due to the effect of drought (Zhang et al., 2019). Water scarcity affects more than 23 million hectares of rainfed rice growing areas in South and Southeast Asia. To maintain the rice productivity under a water stress situation, drought tolerant rice varieties have to be cultivated. Hence, high yielding varieties with drought tolerance are to be developed by crossing the drought tolerant genotypes with high yielding varieties, which are susceptible to water stress (Muthuramu et al., 2010).

The line x tester analysis provides reliable information about the nature and magnitude of gene action and combining ability effects. Knowledge on combining ability is important in selecting suitable parents for hybridization, proper understanding of the inheritance of quantitative traits and also in identifying the promising crosses for further use in a breeding programme. Combining ability analysis helps in the identification of parents with high general combining ability (gca) effects and cross combinations with high specific combining effects (sca) for commercial exploitation of heterosis. Heterosis breeding is a very important genetic tool for the enhancement of yield and yield related traits in all crops under stress conditions (Verma and Srivstava. 2004). Considering all these facts the present investigation was undertaken to analyze the nature and magnitude of inheritance of yield and drought tolerant traits.

**MATERIALS AND METHODS**

The experimental material consists of four high yielding rice varieties viz., CO 51, MDU 6, ADT (R) 45 and ASD 16 as lines and five drought tolerant genotypes viz., CR Dhan 201, CR Dhan 203, DRR DHAN 42, Apo and GP 239 as testers (Table 1), which were crossed in Line x Tester fashion. Twenty cross combinations along with their parents were sown during Kharif, 2018. Twenty two days old seedlings were transplanted under moisture stress conditions in Randomized Block Design (RBD) in three replications by adopting a spacing of 20 cm × 20 cm. The single seedling was transplanted per hill in two rows of three meter rows for each hybrid in each replication. The recommended nutrient management practices and plant protection measures were followed to get a good crop stand. Irrigation was stopped on the 70th day after sowing to impose stress for a period of 15 days. Observation viz., Relative water content (RWC%) and Chlorophyll stability index (CSI%) were recorded at the end of the stress period. At the time of maturity, biometrical and yield observations viz., plant height(cm), the number of productive tillers per plant, length of the panicle (cm), the number of filled grains per panicle, spikelet fertility, 100 seed weight(g) and single plant yield (g) were recorded.

**Table 1. Details of rice genotypes used as parents for crossing**

| S.No. | Symbol | Genotypes | Developed Institute | Parentage | Characters |
|-------|--------|------------|---------------------|-----------|------------|
| **Lines** | | | | | |
| 1 | L1 | CO 51 | Department of rice, TNAU, Coimbatore | ADT 43 RR 272 – 1745 | High yielding, semi dwarf rice variety |
| 2 | L2 | MDU 6 | Agricultural College and Research Institute, Madurai | MDU 5 ACM 96136 | High yielding, long slender with good grain quality |
| 3 | L3 | ADT (R) 45 | Tamil Nadu Rice Research Institute, Aduthurai | IR 50/ADT 37 | High yielding, moderately resistant to pests like BPH and Gall midge |
| 4 | L4 | ASD 16 | Rice Research Station, Ambasamudram | ADT 31/CO 39 | Medium tillering, resistant to blast, high yielder |
| **Testers** | | | | | |
| 1 | T1 | CR Dhan 201 | National Rice Research Institute, Cuttack | IRRI 76569-259-1-2-1/CT 6510-24-1-2 | Drought tolerant |
| 2 | T2 | CR Dhan 203 | National Rice Research Institute, Cuttack | IR 78877/ IRRI 132 | Drought tolerant |
| 3 | T3 | DRR DHAN 42 | IIRR & IRRI, Philippines | MAS derived rice variety | Drought tolerant |
| 4 | T4 | Apo (IR 554231) | IRRI, Philippines | UPLRI 5/IR 12979-24-1 | Drought tolerant |
| 5 | T5 | GP 239* | NICRA project | | Drought tolerant |

*Genotypes identified from NICRA project, Department of Rice, TNAU, Coimbatore.
In addition to this, drought tolerant traits viz., root length (cm), dry root weight(g), dry shoot weight(g), root/ shoot ratio, root volume(m³) and root thickness(mm) were also recorded.

The combining ability and heterosis data analysis were done using the TNAUSTAT software. The standard heterosis was estimated as per cent deviation of the mean F₁ performance over the mean of the standard parent. The variety MDU 6 was used as a standard parent. Estimates of general combining ability (gca), specific combining ability (sca) and heterosis were analysed using TNAUSTAT Statistical package (v1.1) (Manivannan, 2014).

RESULTS AND DISCUSSION

Analysis of variances for mean square due to lines, testers, crosses and lines × tester interaction for different yield and drought tolerant traits are presented in Table 2. The study on the nature of gene action of important quantitative character is essential to decide the breeding methods to be adopted for further improvement of such traits. The gene action is decided by the ratio of GCA and SCA variance. The ratio of GCA and SCA were less than unity revealed the predominance of dominance gene action for all the drought tolerant and yield attributing traits. This result is in accordance with the earlier findings of Suresh et al. (2013) for grain yield and productive tillers per plant, Utharasu and Anandkumar (2013) for dry root weight and root/shoot ratio, Yogameenkshi and Vivekanandan (2015) for productive tillers per plant, panicle length, filled grains per panicle and 100 grain weight, Sathya and Jebaraj (2013) for drought and related character, Karpa gam et al. (2016) for 70 % relative water content, dry root weight, root length, root thickness, root volume and root/shoot ratio.

Parents with high mean performance are preferred for all traits except days to 50 per cent flowering and plant height because earliness and dwarfness are the desirable attributes. Gilbert (1958) indicated that the parents with high per se performance will yield superior hybrids. The mean performance of many parents was found to be significantly high for various yield contributing characters and physiological and drought tolerant traits.

The mean performance of lines and testers is presented in Table 3. In the present study, the line MDU 6 exhibited a higher mean value for maximum 14 traits except plant height. The next best line was ADT (R) 45 expressing significant per se performance for nine traits viz., productive tillers per plant, grain yield, root length, CSI, Relative water content (RWC) root volume, root thickness, dry root weight and dry shoot weight. The tester, DRR DHAN 42 excelled by recording significant per se performance for 12 characters except days to flowering, plant height, dry shoot weight. The next best testers were CR Dhan 201 and CR Dhan 203 possessing high mean performance for eight characters.

From the above discussion, the line MDU 6 was adjudged as best since it had significant high mean values for 13 yield and drought tolerant traits followed by DRR DHAN 42 which had significance mean value for 12 traits.

Table 2. Analysis of variance for combining ability for yield and drought tolerant traits

| Source of variation | df | Mean squares |
|---------------------|----|--------------|
|                     |    | DFF | PH | NPT | PL | NFG | HGW | SPY | RL | RV | RT | DW | DSW | R/S | RWC | CSI |
| Replication         | 1  | 4.22 | 28.05 | 4.22 | 0.4 | 11.02 | 0.01 | 0.65 | 0.32 | 0.81 | 0.001 | 0.50 | 0.01 | 0.0007 | 0.62 | 0.62 |
| Crosses             | 19 | 22.85* | 73.62* | 8.69* | 3.98* | 1036.34* | 0.09 | 42.98* | 3.79* | 6.58* | 0.060 | 22.26* | 142.67* | 0.0177 | 31.20* | 23.34* |
| Lines               | 3  | 52.02* | 289.93* | 20.49* | 8.41* | 1819.49* | 0.31 | 59.02* | 7.31* | 13.01* | 0.057 | 65.15* | 553.36* | 0.0281 | 51.07* | 51.10* |
| Testers             | 4  | 41.66* | 35.02* | 13.22* | 2.88* | 2087.6* | 0.12 | 84.73* | 6.80* | 11.98* | 0.175 | 30.44* | 64.38* | 0.0359 | 23.39* | 38.18* |
| L x T               | 12 | 9.29* | 32.40* | 4.24* | 3.24* | 490.116* | 0.03 | 25.05* | 1.90* | 3.17* | 0.022 | 8.62* | 66.09* | 0.009 | 28.83* | 11.45* |
| Error               | 19 | 1.961 | 5.29 | 1.01 | 0.42 | 36.02 | 0.003 | 0.17 | 0.11 | 0.11 | 0.0005 | 0.13 | 2.04 | 0.0004 | 0.25 | 0.33 |
| G² GCA              | 0.59 | 1.80 | 0.19 | 0.03 | 23.91 | 0.002 | 0.78 | 0.08 | 0.14 | 0.01 | 0.58 | 3.35 | 0.0004 | 0.10 | 0.52 |
| G² SCA              | 3.66 | 13.55 | 1.61 | 1.41 | 227.04 | 0.01 | 12.44 | 0.89 | 1.53 | 0.01 | 4.34 | 32.02 | 0.001 | 14.28 | 0.55 |
| G² gca G² sca       | 0.16 | 0.13 | 0.11 | 0.02 | 0.10 | 0.2 | 0.06 | 0.08 | 0.09 | 0.10 | 0.13 | 0.10 | 0.40 | 0.007 | 0.94 |

*Significant at 5 per cent level

**Note:** DFF- Days to 50 per cent flowering; PH- Plant height; NPT-Number of productive tillers per plant; PL- Panicle length; NFG- Number of filled grains per panicle; HGW- Hundred grain weight; SPY- Single plant yield; RL- Root length; RV- Root volume; RT- Root thickness; DW- Dry root weight; DSW- Dry shoot weight; R/S ratio- Root/shoot ratio; RWC- Relative water content, CSI- Chlorophyll stability index

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Table 3. Mean performance of parents for yield and drought tolerant traits

| Parents | DFF (cm) | PH (cm) | NPT (cm) | PL (cm) | NFG | HGW (g) | SPY (g) | RL (cm) | RV (mm) | RT (mm) | DRW (g) | DSW (g) | R/S ratio (%) | RWC (%) | CSI (%) |
|---------|----------|---------|----------|---------|-----|---------|---------|---------|---------|---------|---------|---------|----------|-----------|---------|
| Lines   |          |         |          |         |     |         |         |         |         |         |         |         |           |           |         |
| CO 51   | 74*      | 93.5    | 10.5     | 22.55   | 146*| 1.75    | 13.65   | 11.6    | 11.9    | 0.58    | 12.65   | 32.5    | 0.39*     | 81       | 76*     |
| MDU 6   | 76*      | 98.5    | 13       | 25*     | 159*| 2.1*    | 20*     | 13.9*   | 14.4*   | 0.8*    | 15.25   | 34.75   | 0.44*     | 82*      | 76.5*   |
| ADT (R) 45 | 84    | 94      | 15.5*    | 22.5    | 139  | 1.85    | 18.35*  | 12.5*   | 13.4*   | 0.71*   | 14.15*  | 41.5*   | 0.34      | 83*      | 76.5*   |
| ASD 16  | 91.5     | 85.5*   | 13       | 21.35   | 120  | 1.8     | 17.5    | 11.25   | 11.85   | 0.56    | 11.85   | 45.5*   | 0.26      | 79       | 74      |

Mean  

|           | 81.3     | 92.87   | 13.00    | 22.85   | 141.00| 1.87    | 17.37   | 12.31   | 12.88   | 0.65    | 13.47   | 38.56   | 0.35      | 81.25    | 75.75   |

SE  

|           | 4.00     | 2.70    | 0.88     | 0.66    | 8.13  | 0.07    | 1.34    | 0.59    | 0.61    | 0.05    | 0.75    | 3.00    | 0.03      | 0.85     | 0.59    |

Testers  

| CR Dhan 201 | 82.5     | 106.5*  | 15.5*    | 22.9*   | 168.5*| 2.05*   | 23.85*  | 14.9    | 16.25*  | 0.97*   | 15.9    | 37.5    | 0.42    | 84.5*    | 81      |
| CR Dhan 203 | 79*      | 109.5*  | 15*      | 23.15*  | 172*  | 2.1*    | 24.9*   | 14.9    | 16.15   | 0.93    | 15.5    | 35.5    | 0.43*   | 81.5     | 82.5*   |
| DRR DHAN 42 | 81       | 108*    | 15.5*    | 24*     | 182.5*| 2.05*   | 24.8*   | 15.9*   | 17.3*   | 1.14*   | 18.85*  | 34.8    | 0.54*   | 85*      | 85.5*   |
| Apo (IR 554231) | 80.5     | 116.5   | 14       | 22.2    | 151.5*| 1.85    | 22.4    | 14.3    | 15.45   | 0.86    | 16.65   | 45.5*   | 0.36    | 81.5     | 80.5    |
| GP 239    | 76*      | 117     | 12.5     | 20.95   | 132.5*| 1.8     | 21.9    | 14.85   | 15.75   | 0.87    | 16.65   | 47.5*   | 0.35    | 80.5     | 77.5    |
| Mean      | 79.8     | 111.50  | 14.50    | 22.64   | 161.40| 1.97    | 23.53   | 14.97   | 16.18   | 0.95    | 16.68   | 40.16   | 0.42    | 82.60    | 81.40   |

SE  

|           | 1.09     | 2.18    | 0.56     | 0.50    | 8.72  | 0.06    | 0.62    | 0.25    | 0.31    | 0.05    | 0.57    | 2.62    | 0.03     | 0.89     | 1.29    |

*Significant at 5 per cent level

Note: DFF- Days to 50 per cent flowering; PH- Plant height; NPT-Number of productive tillers per plant; PL-Panicle length; NFG-Number of filled grains per panicle; HGW-Hundred grain weight; SPY-Single plant yield; RL-Root length; RV-Root volume; RT-Root thickness; DRW-Dry root weight; DSW-Dry shoot weight; R/S ratio- Root/shoot ratio, RWC –Relative water content, CSI-Chlorophyll stability index

The testers arrived next best with desirable traits were CR Dhan 201 and CR Dhan 203 possessing significant desirable mean values for ten characters. According to Chandra et al. (1969) high mean performance of parents will not produce hybrids with superior characters. Hence, always for selection of parents both per se performance and gca effect are essential. These selected parental genotypes could be used in developing cross combinations to produce desirable segregants with the various mechanism of drought tolerance and grain yield. The gca effect represent the additive gene action and it is fixable (Simmonds, 1979). The parents with high gca will yield favourable segregants with expected performance in advanced generations (Dhillon, 1975). The general combining ability of parents is presented in Table 4 for different yield and drought tolerant traits. Parents with negative significant gca effects were considered for the traits viz., days to 50 per cent flowering and plant height, while for remaining traits, parents which had excelled with positive significant gca effects were taken into consideration. In the present study, MDU 6 was considered as a good general combiner for all the yield and root and physiological traits related to drought tolerance. In addition ADT (R) 45 registered significant gca effects for panicle length, number of filled grains per panicle, single plant yield, root length, root volume, root thickness, dry root weight and dry shoot weight. Based on gca performance, the lines viz., MDU 6 and ADT (R) 45 were adjudged as the best general combiner for yield and drought tolerant traits.

The mean performance is the important criterion to assess the worth of hybrids. The per performance is a useful index for analyzing the value of hybrids (Nadarajan, 1986). Positive and significant mean values were considered for all characters except days to flowering, plant height for which negative significance was considered. The mean performance of hybrids is presented in Table 5. In the current study ten hybrids viz., CO 51 x CR Dhan 203, MDU 6 x CR Dhan 201, MDU 6 x CR Dhan 203, MDU 6 x DRR DHAN 42, MDU 6 x Apo, ADT (R) 45 x DRR DHAN 42, ADT (R) 45 x Apo, ASD 16 x CR Dhan 203, MDU 6 x DRR DHAN 42, and ADT (R) 45 x DRR DHAN 42 registered high per se performance for nine traits. In MDU 6 x CR Dhan 201 and ASD 16 x DRR DHAN 42
Table 5. Mean performance of F₄ₛ under moisture stress

| Crosses | DFF (cm) | PH (cm) | NPT (cm) | PL (cm) | NFG  | HGW  | SPY  | RL (cm) | RV (cm) | RT (cm) | DRR  | R/S Ratio | RWC (%) | CSI (%) |
|---------|----------|---------|----------|---------|------|------|------|---------|---------|---------|------|-----------|---------|---------|
| L₁ × T₁ | 71*      | 77*     | 15*      | 21.75*  | 173  | 1.55* | 11.75| 11.5    | 11.9    | 0.55   | 12.25| 31.65     | 0.39    | 84.5    | 81 |
| L₁ × T₂ | 76.5     | 72.5*   | 15.5*    | 20.5    | 188.5| 1.45  | 16.6 | 13.35   | 14      | 0.56  | 14.3 | 29.8      | 0.48*   | 80.5    | 77.5 |
| L₂ × T₁ | 71.5*    | 75*     | 14*      | 19      | 175.5| 1.55  | 12.86| 11.65   | 12.15   | 0.61  | 12.5 | 31.45     | 0.39    | 76.5    | 75 |
| L₂ × T₂ | 79.5     | 76*     | 13*      | 22.15   | 193*  | 1.5  | 13.61| 12.25   | 12.8    | 0.55  | 14.8 | 39.35     | 0.38    | 73.5    | 77 |
| L₃ × T₁ | 70.5*    | 81*     | 12.5    | 21.5    | 165.5| 1.35  | 11.8 | 11.65   | 12.1    | 0.51  | 12.75| 44.5*     | 0.29    | 78.5    | 73 |
| L₃ × T₂ | 72.5*    | 85      | 12.5    | 23.5    | 222.5*| 1.95* | 23.65*| 14.1    | 15.75*  | 0.74* | 21.5*| 39.75     | 0.54*   | 86.5    | 82 |
| L₄ × T₁ | 74.5*    | 82*     | 15      | 22.5    | 194.5*| 1.9*  | 18.35*| 12.35   | 13.2    | 0.61  | 15.85| 34.8      | 0.45*   | 81.5    | 80.5 |
| L₄ × T₂ | 72.5*    | 85      | 16.5*   | 24.75*  | 234.5*| 2.1*  | 25.1* | 16.1    | 17.85*  | 1.08  | 24.15*| 39.85     | 0.6*    | 88.5    | 85 |
| L₅ × T₁ | 78.5     | 92.25   | 11      | 22.35   | 193*  | 1.85* | 16.85*| 13.9    | 14.5*   | 0.66  | 17.5*| 41.75     | 0.42*   | 83      | 81 |
| L₅ × T₂ | 73.5*    | 77.5*   | 14*     | 21.5    | 182.5| 1.75* | 11.65| 13.25   | 13.95   | 0.53  | 15.7 | 39.85     | 0.39    | 80.5    | 79 |
| L₆ × T₁ | 78       | 86.5    | 10.5    | 21.3    | 172   | 1.45  | 13    | 13      | 13.85*  | 0.48  | 17.4*| 58*       | 0.3     | 76.5    | 77.5 |
| L₆ × T₂ | 77       | 92.5    | 10      | 23.3    | 191*  | 1.6  | 15.6 | 12.75   | 13.8    | 0.54  | 18*  | 57*       | 0.32    | 77      | 80 |
| L₇ × T₁ | 72.5*    | 86      | 15.5*   | 24*     | 232*  | 2*   | 24.7*| 16*     | 17.9*   | 1*    | 22.7*| 42.5      | 0.53*   | 86.5    | 84.5 |
| L₇ × T₂ | 76.5     | 96      | 11.5    | 24.5*   | 192.5*| 1.8* | 17.95*| 13.85*  | 14.5*   | 0.63  | 17.15*| 45*       | 0.38    | 82.5    | 80 |
| L₈ × T₁ | 78       | 85.5    | 11      | 21.5    | 179   | 1.75* | 15.25| 13.55*  | 14.65*  | 0.59  | 16.65| 55.5*     | 0.3     | 79.5    | 75.5 |
| L₈ × T₂ | 80.5     | 83*     | 10      | 21.75   | 151.5| 1.35  | 11.07| 12.3    | 12.85   | 0.55  | 16.85| 48.5*     | 0.35    | 77      | 74.5 |
| L₉ × T₁ | 79.5     | 88.5    | 10.5    | 20.75   | 175.5| 1.7*  | 14.95| 12.35   | 13.2    | 0.5   | 15.1 | 56.5*     | 0.27    | 75.5    | 74.5 |
| L₉ × T₂ | 76.5     | 83.5*   | 13.5*   | 23.6*   | 216*  | 1.9* | 24.15*| 15.85*  | 17.75*  | 0.79* | 22.15*| 41.5      | 0.53*   | 82.5    | 82.5 |
| L₁₀ × T₁ | 82       | 84      | 11.5    | 22.1    | 179.5| 1.75* | 18.77*| 13.45*  | 14.4    | 0.6   | 17   | 45.5*     | 0.38    | 81.5    | 79 |
| L₁₀ × T₂ | 75.5*    | 83*     | 10.5    | 21.6    | 156   | 1.6  | 13    | 13.2    | 13.95   | 0.51  | 16.85| 45.5*     | 0.37    | 81.5    | 75.5 |
| Mean    | 75.83    | 83.59   | 12.68   | 22.19   | 188.53| 1.69 | 16.55| 13.32   | 14.25   | 0.65  | 17.06| 43.42     | 0.40    | 80.5    | 79.0 |
| SE      | 0.75     | 1.35    | 0.46    | 0.31    | 5.09  | 0.04 | 1.03  | 0.30   | 0.40    | 0.03  | 0.74 | 1.88       | 0.02    | 0.88    | 0.76 |

*Significant at 5 per cent level

Note: DFF: Days to 50 per cent flowering; PH: Plant height; NPT: Number of productive tillers per plant; PL: Panicle length; NFG: Number of filled grains per panicle; HGW: Hundred grain weight; SPY: Single plant yield; RL: Root length; RV: Root volume; RT: Root thickness; DRR: Dry root weight; DSW: Dry shoot weight; R/S ratio: Root/shoot ratio; RWC: Relative water content; CSI: Chlorophyll stability index
significant mean values were observed for nine yield and drought tolerant traits viz., days to flowering, productive tillers, panicle length, filled grains per panicle, 100 grain weight, single plant yield, root length, root/shoot ratio and root volume. Specific combining ability is defined as the deviation in performance of a specific cross combination from that predicted on the basis of the general combining abilities of the parents involved in the cross (Allard, 1980). The sca effect of 20 crosses is presented in Table 6 for yield and drought traits. The sca effect is due to non-additive genetic action (Sprague and Tatum, 1942) in the expression of character, hence used for exploitation of heterosis. Negative sca effects were taken for days to flowering and plant height, while for all other characters positive and significant sca effects were considered. Among the 20 hybrids, CO 51 x CR Dhan 203 and MDU 6 x CR Dhan 201 were good specific combiners, which had significant sca effects for many yield and drought tolerant traits. The cross combination, MDU 6 x CR Dhan 201 had significant and positive sca effects for nine characters viz., panicle length, filled grains per panicle, 100 grain weight, grain yield, root thickness, dry root weight, root length, root volume and root/shoot ratio. The cross CO 51 x CR Dhan 203 was identified as the second best hybrid which showed significant sca effects for eight characters. Positive and significant sca effects for seven yield and drought tolerant traits were registered by the hybrids ADT (R) 45 x DRR DHAN 42, ASD 16 x DRR DHAN 42 and MDU 6 x DRR DHAN 42. Similar results were obtained by Sathy and Jebaraj (2013) for dry root weight, dry shoot weight and root length in rice and Karpagam et al. (2016) for relative water content, dry root weight, root length, root volume, root thickness and root/shoot ratio.

### Table 6. Specific combining ability of F3 for yield and drought tolerant traits

| Crosses | DFF | PH | NPT | PL | NFG | HGW | SPY | RL | RV | RT | DRW | DSW | R/S ratio | RWC | CSI |
|---------|-----|----|-----|----|-----|-----|-----|----|----|----|-----|-----|-------|-----|-----|
| L1 x T1 | -2.47* | 1.41 | 1.67* | 0.68 | 0.88 | 2.67 | 0.19** | 0.03 | 0.02 | -0.02 | 0.05** | -1.01** | -4.79** | 0.01 | 5.25** | 4.2** |
| L1 x T2 | 1.65 | -4.09* | 1.42 | -0.01 | 10.55* | 0 | 3.45** | 1.89** | 2.11** | -0.09** | 2.23** | -6.68** | 0.12** | 3.88** | 1.33 |
| L1 x T3 | 0.28 | -0.09 | -2.2** | -2.63** | -29.58** | -0.12** | -5.62** | -2.01 | -2.6** | -0.21** | -4.14** | 0.86 | -0.1** | -5** | -4.43** |
| L1 x T4 | 2.4* | -3.78* | -0.08 | 0.58 | 12.93** | -0.01 | 0.04 | 0.13 | 0.41 | 0.02 | 1.93** | 4.6** | 0 | -4.63** | -0.3 |
| L1 x T5 | -1.85 | 6.54** | -0.83 | 1.18* | 3.42 | -0.05 | 2.1** | -0.02 | 0.1 | 0.06** | 1** | 6.2** | -0.03* | 0.5 | 0.8 |
| L1 x T6 | -1.48 | 1.36 | -0.63 | 0.69 | 25.88** | 0.16** | 6.14** | 0.76** | 1.37** | 0.07** | 2.62** | -0.51 | 0.07** | 1.95* | 0.5 |
| L1 x T7 | -0.85 | -2.64 | 1.13 | 0.05 | -9.75* | 0.02 | -0.6 | -0.97** | -1.15** | -0.03* | -1.85** | -5.51** | -0.01 | -0.42 | -0.38 |
| L1 x T8 | 0.78 | 1.86 | 0.5 | 1.18* | 3.12 | -0.01 | 0.83* | 0.58* | 0.64* | 0.1** | 1.89** | 5.24** | 0.01 | 1.7 | 0.38 |
| L1 x T9 | 0.9 | 4.43* | -1.88* | -1.16* | -13.38** | -0.09* | -2.52** | -0.08 | -0.35 | -0.04* | -0.99* | 3.03** | -0.05** | -0.42 | -1 |
| L1 x T10 | 0.65 | -5.01** | 0.88 | -0.76 | -5.88 | -0.08 | -3.85** | -0.28 | -0.51* | -0.09** | -1.67** | -2.27** | -0.02 | -2.8** | 0.5 |
| L1 x T11 | 1.92 | -2.09 | -0.52 | -1.47** | -12.53** | -0.15** | -2.45** | -0.24 | -0.43 | -0.13** | -0.92** | 5.34** | -0.06** | -4.45** | -2* |
| L1 x T12 | -0.45 | 2.91 | -1.77* | 0.69 | -1.15** | -0.09** | -1.59** | -0.46 | -0.44 | -0.05** | 0.87** | 4.29** | -0.02 | -1.32 | 1.13 |
| L1 x T13 | -1.32 | -2.09 | 1.6* | 0.47 | 12.72** | 0.08* | 2.19** | 0.59** | 0.8** | 0.17** | 1** | -4.51** | 0.05** | 3.3** | 1.88 |
| L1 x T14 | -3.2** | 3.22 | 0.73 | 1.03* | -1.78 | 0.05 | 0.34 | -0.02 | -0.24 | -0.01 | -0.79** | -6.12** | 0.03* | 2.67** | 0 |
| L1 x T15 | 3.05** | -1.96 | -0.02 | -0.72 | 2.72 | 0.11* | 1.51** | 0.13 | 0.3 | 0.02 | -0.16 | 0.98 | 0 | -0.2 | -1 |
| L1 x T16 | 2.03 | -0.69 | -0.52 | -0.1 | -16.02** | -0.19** | -3.72** | -0.53** | -0.92** | 0.02 | -0.68** | -0.05 | -0.02 | -2.75** | -2.7** |
| L2 x T2 | -0.35 | 3.81* | -0.77 | -0.74 | 0.35 | 0.07 | -1.27** | -0.46 | -0.53** | 0 | -1.26** | 7.89** | -0.09** | -2.13** | -2.08* |
| L2 x T3 | 0.28 | 0.31 | 0.1 | 0.99* | 13.73** | 0.04 | 2.61** | 0.84** | 1.16** | -0.06** | 1.24** | -1.41 | 0.04** | 0 | 2.17 |
| L2 x T4 | -0.1 | -3.88* | 1.23 | -0.45 | 2.23 | 0.06 | 2.14** | -0.02 | 0.17 | 0.03 | -0.15 | -1.52 | 0.01 | 2.38 | 1.3 |
| L2 x T5 | -1.85 | 0.44 | 0.02 | 0.3 | -0.28 | 0.02 | 0.23 | 0.18 | 0.11 | 0.02 | 0.83** | -4.92** | 0.06** | 2.5 | 1.3 |
| SE | 0.99 | 1.02 | 0.71 | 0.45 | 0.11 | 0.04 | 0.29 | 0.23 | 0.23 | 0.01 | 0.26 | 1.01 | 0.01 | 0.66 | 1.73 |

*Significant at 5 percent level. ** Significant at 1 per cent level
L1 – CO 51, L2 – MDU 6, L3 – ADT (R) 45, L4 – ASD 16, T1 – CR Dhan 201, T2 – CR Dhan 203, T3 – DRR DHAN 42, T4 – Apo (IR 554231), T5 – GP 239

**Note:** DFF- Days to 50 per cent flowering; PH- Plant height; NPT- Number of productive tillers per plant; PL- Panicle length; NFG- Number of filled grains per panicle; HGW- Hundred grain weight; SPY- Single plant yield; RL- Root length; RV- Root volume; RT- Root thickness; DRW- Dry root weight; DSW- Dry shoot weight; R/S ratio- Root/shoot ratio, RWC- Relative water content, CSI- Chlorophyll stability index

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in rice. For these combinations, due to the involvement of non-additive gene action, a cyclic method of breeding involving the selection of desired recombinants and their inter-crossing would be more desirable (Muthuramu et al., 2010).

The hybrids selected based on standard heterosis is presented in Table 7. The analysis showed that the hybrid DRR DHAN 42 ranked first for standard heterosis for grain yield. This hybrid also exhibited significantly positive heterosis for the length of the panicle, productive tillers, CSI, RWC, filled grains per panicle, grain yield, root length, dry root weight, root volume, root thickness, and root/shoot ratio. The hybrid ADT (R) 45 x DRR DHAN 42 was the next best as it also had significant heterosis for twelve characters. The next best crosses were MDU 6 x CR Dhan 201 and ASD 16 x DRR DHAN 42 and they excelled for eight and nine traits respectively. Hence these four crosses can be utilized for heterosis breeding.

The present investigation on studies on combining ability and heterosis of drought tolerance traits in rice explicated the nature of gene action, combining ability of parents and hybrids, the extent of heterosis between drought tolerant and yield contributing characters. The non-additive gene action can be exploited through heterosis breeding and hybrids with additive gene action can be improved by pedigree breeding and selection can be postponed to later generations. Based on both per se

Table 7. Standard heterosis for yield and physiological related traits in hybrids (per cent)

| Trait                  | L₁ x T₁ | L₁ x T₂ | L₁ x T₃ | L₁ x T₄ | L₂ x T₁ | L₂ x T₂ | L₂ x T₃ | L₂ x T₄ |
|------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| L₁ x T₁                | -6.58** | -21.83**| 15.38   | -13**   | 8.81**  | -26.19**| -41.25**| 3.05    |
| L₁ x T₂                | 0.66    | -26.4** | 19.23*  | -18**   | 18.55** | -30.95**| -17**   | -1.83   |
| L₁ x T₃                | -5.92   | -23.86**| 7.69    | -24**   | 10.38** | -26.19**| -35.72**| -6.71** |
| L₁ x T₄                | 4.61    | -22.84**| 0       | -11.4** | 21.38** | -28.57**| -31.97**| -10.37**|
| L₂ x T₁                | -14.72**| -17.77**| -3.85   | -14**   | 4.09    | -35.71**| -41**   | -4.27** |
| L₂ x T₂                | -6.11   | -13.71**| -3.85   | -6*     | 39.94** | -7.14** | 18.25** | 5.49**  |
| L₂ x T₃                | -1.97   | -16.75**| 15.38   | -10**   | 22.33** | -9.52** | -8.25** | -0.61   |
| L₂ x T₄                | -4.61   | -13.71**| 26.92** | -1      | 47.48** | 0       | 25.5**  | 7.93**  |
| L₃ x T₄                | 3.29    | -6.35** | -15.38 | -10.6** | 21.38** | -11.9** | -15.75**| 1.22    |
| L₄ x T₄                | -3.29   | -21.32**| 7.69    | -14**   | 14.78** | -16.67**| -41.75**| -1.83   |
| L₅ x T₄                | 2.63    | -12.18**| -19.23**| -14.8** | 8.18    | -30.95**| -33.5** | -6.71** |
| L₆ x T₄                | 1.32    | -6.09** | -23.08**| -7.6**  | 20.13** | -23.81**| -22**   | -6.1**  |
| L₇ x T₄                | 4.61    | -12.69**| 19.23*  | -4      | 45.91** | -4.76   | 23.52** | 5.49**  |
| L₈ x T₄                | 0.68    | -2.54   | -11.54  | -2      | 21.07** | -14.29**| -10.25**| 0.61    |
| L₉ x T₄                | 2.63    | -13.2** | -15.38 | -14**   | 12.58** | -16.67**| -23.75**| -3.05   |
| L₁₀ x T₄               | 5.92    | -15.74**| -23.08**| -13**   | -4.72   | -35.71**| -44.67**| -5.49** |
| L₁¹ x T₄               | 4.61    | -10.15**| -19.23**| -17**   | 10.38** | -19.05**| -25.25**| -7.93** |
| L₁² x T₄               | 0.66    | -15.23**| 3.85    | -5.6**  | 35.85** | -36.92**| 20.75** | 0.61    |
| L₁³ x T₄               | 2.69    | -7.89** | -14.72**| -11.54 | -11.6** | 12.89** | -16.67**| -6.13** |
| L₁⁴ x T₄               | -0.66   | -15.74**| -19.23**| -13.6** | 0       | -23.81**| -35**   | -0.61   |
| SE                     | 0.99    | 1.37    | 3.58    | 1.26    | 3.20    | 2.32    | 5.18    | 1.08    |

*Significant at 5 percent level, ** Significant at 1 per cent level

L₁ – CO 51, L₂ – MDU6, L₃ – ADT (R) 45, L₄ – ASD 16, T₁ – CR Dhan 201, T₂ – CR Dhan 203, T₃ – DRR DHAN 42, T₄ – Apo (IR 554231), T₅ – GP 239

Note: DFF- Days to 50 per cent flowering; PH- Plant height; NPT-Number of productive tillers per plant; PL-Panicle length; NFGP- Number of filled grains per panicle; HGW-Hundred grain weight; SPY-Single plant yield; RL-Root length; RV-Root volume; RT-Root thickness; DRW-Dry root weight; DSW-Dry shoot weight; R/S ratio- Root/shoot ratio, RWC –Relative water content, CSI-Chlorophyll stability index

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performance and gca, MDU 6, ADT (R) 45 and DRR DHAN 42 were identified as superior parents and hence, these parental genotypes could be used in developing cross combinations to produce desirable segregants with various mechanisms of drought tolerance and grain yield. Combining per se performance, sca and standard heterosis, the crosses MDU 6 x DRR DHAN 42, ADT (R) 45 x DRR DHAN 42, ASD 16 x DRR DHAN 42 and MDU 6 x CR Dhan 201 were identified as superior since they possessed good performance for many drought tolerant traits viz., root length, root volume, root thickness, dry root weight and root/shoot ratio in addition to yield characters. Hence, these four crosses could be highly suitable for the improvement of root characters along with grain yield.

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