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Research Article

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 × DRR DHAN 42, ADT (R) 45 ×DRR DHAN 42, ASD 16 × DRR DHAN 42 and MDU 6 × 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 68 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 70thday 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	L_1	CO 51	Department of rice, TNAU, Coimbatore	ADT 43 RR 272 – 1745	High yielding, semi dwarf rice variety
2	L_2	MDU 6	Agricultural College and Research Institute, Madurai	MDU 5 ACM 96136	High yielding, long slender with good grain quality
3	L_3	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	L_4	ASD 16	Rice Research Station,, Ambasamudram	ADT 31/CO 39	Medium tillering, resistant to blast, high yielder
Testers					
1	T_1	CR Dhan 201	National Rice Research Institute, Cuttack	IRRI 76569-259-1-2-1/CT 6510-24-1-2	Drought tolerant
2	T_2	CR Dhan 203	National Rice Research Institute, Cuttack	IR 78877/ IRRI 132	Drought tolerant
3	T_3	DRR DHAN 42	IIRR & IRRI, Philippines	MAS derived rice variety	Drought tolerant
4	T_4	Apo (IR 554231)	IRRI, Philippines	UPLRI 5/IR 12979-24-1	Drought tolerant
5	T_5	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(m^3) 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 F_1 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, Karpagam *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	DRW	DSW	R/S ratio	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	8.82*	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
σ² GCA		0.59	1.80	0.19	0.03	23.91	0.002	0.78	0.08	0.14	0.001	0.58	3.35	0.0004	0.10	0.52
σ² 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
σ² gca/ σ² 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; DRW-Dry root weight; DSW-Dry shoot weight; R/S ratio- Root/shoot ratio, RWC –Relative water content, CSI-Chlorophyll stability index

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

Parents	DFF	PH (cm)	NPT	PL (cm)	NFG	HGW (g)	SPY (g)	RL (cm)	RV (m^3)	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	22.2	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	16.5	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.

Among the testers, DRR DHAN 42 was the good general combiner as it possessed a significant *gca* effect for all yield and drought tolerant root and physiological traits. From the above discussion, it was observed that favourable genes for yield and drought traits are available in MDU 6, ADT (R) 45 and DRR DHAN 42. These results were in agreement with those reported by Manonmani and Fazhullah Khan (2005) for relative water content and root length in rice and Yogameenakshi and Vivekanadan (2015) for root length, dry root weight, root volume, root thickness and root/shoot ratio in rice.

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 51x 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, ASD 16 x DRR DHAN 42 and ASD 16 x Apo showed higher mean value for single plant yield. The hybrids 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 4. General combining ability of parents for yield and drought tolerant traits

Parents	DFF	PH	NPT	PL	NFG	HGW	SPY	RL	RV	RT	DRW	DSW	R/S ratio	RWC	CSI
Lines															
CO 51	-2.03**	-7.29**	1.33**	-1.21**	-9.43**	-0.21**	-3.23**	-1.24**	-1.66**	-0.08**	-3.74**	-8.04**	-0.02**	-2**	-1.95**
MDU 6	-1.52**	0.76	1.13**	0.74**	16.88**	0.22**	2.57**	0.62**	0.8**	0.09**	1.88**	-4.22**	0.08**	3.3**	2.75*
ADT (R) 45	0.57	5.71**	-0.98**	0.7**	4.78*	0.03	0.81**	0.51**	0.69**	0.03**	1.32**	8.18**	-0.04**	-0.3	0.75
ASD 16	2.97**	0.81	-1.48**	-0.22	-12.23**	-0.03	-0.16	0.11	0.18	-0.05**	0.53**	4.08**	-0.02**	-1*	-1.55**
SE	0.44	0.72	0.31	0.20	0.49	0.01	0.13	0.10	0.10	0.007	0.11	0.45	0.006	0.58	0.57
Testers															
CR Dhan 201	-0.32	-0.71	-0.68	-0.11	-8.77**	-0.12**	-1.61**	-0.6**	-0.67**	-0.06**	-0.06	1.05	-0.01	0.55	0
CR Dhan 203	1.05*	0.29	0.08	-0.47	-1.15	-0.03	-0.17	-0.62**	-0.7**	-0.08**	-1.25**	1.1*	-0.02**	-2.08**	-0.63
DRR DHAN 42	-2.58**	-1.21	2.2**	0.65*	25.98**	0.19**	5.15**	1.58**	2.16**	0.26**	3.32**	-4.59**	0.11**	2.8**	3.13**
Apo (IR 554231)	3.3**	3.47**	-0.93*	0.59*	0.98	0.03	0.25	0.04	-0.2	-0.02**	-0.45**	-0.48	-0.02*	-0.57	0.5
GP 239	-1.45*	-1.84*	-0.68	-0.66**	-17.02**	-0.08**	-3.62**	-0.41**	-0.59**	-0.1**	-1.57**	2.92**	-0.07**	-0.7	-3**
SE	0.49	0.81	0.35	0.22	0.52	0.02	0.14	0.11	0.11	0.008	0.13	0.50	0.007	0.65	0.64

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

Table 5. Mean performance of F_1s under moisture stress

Crosses	DFF	PH (cm)	NPT	PL (cm)	NFG	HGW (g)	SPY (g)	RL (cm)	RV (m3)	RT (mm)	DRW (g)	DSW (g)	R/S Ratio	RWC (%)	CSI (%)
$L_1 \times T_1$	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
$L_1 \times T_2$	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
$L_1 \times T_3$	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	75.5
$L_1 \times T_4$	79.5	76*	13*	22.15	193*	1.5	13.61	12.25	12.8	0.55	14.8	39.5	0.38	73.5	77
$L_1 \times T_5$	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
$L_2 \times T_1$	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
$L_2 \times T_2$	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
$L_2 \times T_3$	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
$L_2 \times T_4$	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
$L_2 \times T_5$	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
$L_3 \times T_1$	78	86.5	10.5	21.3	172	1.45	13.3	13	13.85	0.48	17.4*	58*	0.3	76.5	77.5
$L_3 \times T_2$	77	92.5	10	23.1*	191*	1.6	15.6	12.75	13.8	0.54	18*	57*	0.32	77	80
$L_3 \times T_3$	72.5*	86	15.5*	24*	232*	2*	24.7*	16*	17.9*	1.1*	22.7*	42.5	0.53*	86.5	84.5
$L_3 \times T_4$	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
$L_3 \times T_5$	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
$L_4 \times T_1$	80.5	83*	10	21.75	151.5	1.35	11.07	12.3	12.85	0.55	16.85	48.5*	0.35	77.5	74.5
$L_4 \times T_2$	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
$L_4 \times T_3$	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
$L_4 \times T_4$	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
$L_4 \times T_5$	75.5*	83*	10.5	21.6	159	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

L_1 – CO 51, L_2- MDU6, L_3 – ADT (R) 45, L_4 – ASD 16, T_1 – CR Dhan 201, T_2 - CR Dhan 203, T_3 - DRR DHAN 42, T_4 – Apo (IR 554231), T_5 - GP 239 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 51x 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 51x 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 Sathya 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 F_1s for yield and drought tolerant traits

Crosses	DFF	PH	NPT	PL	NFG	HGW	SPY	RL	RV	RT	DRW	DSW	R/S ratio	RWC	CSI
$L_1 \times T_1$	-2.47*	1.41	1.67*	0.88	2.67	0.19**	0.03	0.02	-0.02	0.05**	-1.01**	-4.79**	0.01	5.25**	4.2**
$L_1 \times T_2$	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
$L_1 \times T_3$	0.28	-0.09	-2.2**	-2.63**	-29.58**	-0.12**	-5.62**	-2.01	-2.6**	-0.21**	-4.14**	0.66	-0.1**	-5**	-4.43**
$L_1 \times T_4$	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
$L_1 \times T_5$	-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
$L_2 \times T_1$	-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
$L_2 \times T_2$	-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
$L_2 \times T_3$	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
$L_2 \times T_4$	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
$L_2 \times T_5$	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
$L_3 \times T_1$	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*
$L_3 \times T_2$	-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
$L_3 \times T_3$	-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
$L_3 \times T_4$	-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
$L_3 \times T_5$	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
$L_4 \times T_1$	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**
$L_4 \times T_2$	-0.35	3.81*	-0.77	-0.74	0.35	0.07	-1.27**	-0.46	-0.53*	0	-1.25**	7.89**	-0.09**	-2.13*	-2.08*
$L_4 \times T_3$	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
$L_4 \times T_4$	-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
$L_4 \times T_5$	-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	1.11	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

L_1 – CO 51, L_2- MDU6, L_3 – ADT (R) 45, L_4 – ASD 16, T_1 – CR Dhan 201, T_2 - CR Dhan 203, T_3 - DRR DHAN 42, T_4 – Apo (IR 554231), T_5 - 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

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

	DFF	PH	NPT	PL	NFGP	100	SPY	RWC	CSI	RL	RV	RT	DRW	DSW	R/S
L_1 x T_1	-6.58**	-21.83**	15.38	-13**	8.81*	-26.19**	-41.25**	3.05	5.88**	-17.27**	-17.36**	-31.25**	-19.67**	-8.92*	-11.36*
L_1 x T_2	0.66	-26.4**	19.23*	-18**	18.55**	-30.95**	-17**	-1.83	1.31	-3.96	-2.78	-29.37**	-6.23*	-14.24**	9.09*
L_1 x T_3	-5.92*	-23.86**	7.69	-24**	10.38**	-26.19**	-35.72**	-6.71**	-1.31	-16.19**	-15.63**	-23.75**	-18.03**	-9.5*	-10.23*
L_1 x T_4	4.61	-22.84**	0	-11.4**	21.38**	-28.57**	-31.97**	-10.37**	0.65	-11.87**	-11.11**	-31.25**	-2.95	13.67**	-14.77**
L_1 x T_5	-7.24**	-17.77**	-3.85	-14**	4.09	-35.71**	-41**	-4.27**	-4.58**	-16.19**	-15.97**	-35.62**	-16.39**	28.06**	-34.09**
L_2 x T_1	-4.61	-13.71**	-3.85	-6*	39.94**	-7.14*	18.25**	5.49**	7.19**	1.44	9.38**	-8.12**	40.98**	14.39**	22.73**
L_2 x T_2	-1.97	-16.75**	15.38	-10**	22.33**	-9.52**	-8.25**	-0.61	5.23**	-11.15**	-8.33**	-23.75**	3.93	0.14	3.41
L_2 x T_3	-4.61	-13.71**	26.92**	-1	47.48**	0	25.5**	7.93**	11.11**	15.83**	23.96**	35.63**	58.36**	14.68**	37.5**
L_2 x T_4	3.29	-6.35**	-15.38	-10.6**	21.38**	-11.9**	-15.75**	1.22	5.88**	0	0.69	-16.87**	14.75**	20.14**	-4.55
L_2 x T_5	-3.29	-21.32**	7.69	-14**	14.78**	-16.67**	-41.75**	-1.83	3.27	-4.68	-3.12	-33.12**	2.95	14.68**	-10.23*
L_3 x T_1	2.63	-12.18**	-19.23*	-14.8**	8.18*	-30.95**	-33.5**	-6.71**	1.31	-6.47*	-3.82	-40**	14.1	66.91**	-31.82**
L_3 x T_2	1.32	-6.09*	-23.08**	-7.6**	20.13**	-23.81**	-22**	-6.1**	4.58**	-8.27**	-4.17	-32.5**	18.03**	64.03**	-27.27**
L_3 x T_3	-4.61	-12.69**	19.23*	-4	45.91**	-4.76	23.52**	5.49**	10.46**	15.11**	24.31**	37.5**	48.85**	22.3**	21.59**
L_3 x T_4	0.66	-2.54	-11.54	-2	21.07**	-14.29**	-10.25**	0.61	4.58**	-0.36	0.69	-20.62**	12.46**	29.5**	-12.5**
L_3 x T_5	2.63	-13.2**	-15.38	-14**	12.58**	-16.67**	-23.75**	-3.05	-1.31	-2.52	1.74	-26.25**	9.18**	59.71**	-31.82**
L_4 x T_1	5.92*	-15.74**	-23.08**	-13**	-4.72	-35.71**	-44.67**	-5.49**	-2.61	-11.51**	-10.76**	-31.25**	10.49**	39.57**	-20.45**
L_4 x T_2	4.61	-10.15**	-19.23*	-17**	10.38**	-19.05**	-25.25**	-7.93**	-2.61	-11.15**	-8.33**	-36.87**	-0.98	62.59**	-38.64**
L_4 x T_3	0.66	-15.23**	3.85	-5.6*	35.85**	-9.52**	20.75**	0.61	7.84**	14.03**	23.26**	-1.25	45.25**	19.42**	21.59**
L_4 x T_4	7.89**	-14.72**	-11.54	-11.6**	12.89**	-16.67**	-6.13**	-0.61	3.27	-3.24	0	-25**	11.48**	30.94**	-14.77**
L_4 x T_5	-0.66	-15.74**	-19.23*	-13.6**	0	-23.81**	-35*	-0.61	-1.31	-5.04	-3.12	-36.25**	10.49**	30.94**	-15.91**
SE	0.99	1.37	3.58	1.26	3.20	2.32	5.18	1.08	0.99	2.21	2.81	4.86	4.89	5.43	4.77

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

L_1 – CO 51, L_2- MDU6, L_3 – ADT (R) 45, L_4 – ASD 16, T_1 – CR Dhan 201, T_2 - CR Dhan 203, T_3 - DRR DHAN 42, T_4 – Apo (IR 554231), T_5 - 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

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 results are in agreement with those supported by El-Mouhamady *et al*. (2013), Utharasu and Anandkumar (2013) and Karpagam *et al.* (2016). Such identified hybrids could have immense potential towards increasing the drought tolerance and yield in rice.

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* 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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