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Combining ability and heterosis analysis for drought tolerant traits in rice *(Oryza sativa L.)*

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Abstract: Rice is the most important staple food for more than half of the world's population and also for most of the countries. A Line x Tester analysis was undertaken to study the nature of gene action for yield and drought tolerant traits. The ratio of SCA and GCA was less than unity for all the characters which revealed that the preponderance of non- additive gene action governing the traits concerned. The lines *viz.,* ADT 43, ADT (R) 49, CO (R) 50 and the testers *viz.,* PMK (R) 3, Chandikar and Anna (R) 4 were adjudged as the best general combiners for drought tolerant traits. The cross combinations *viz.,* ADT 39 x Vellaichitraikar had exhibited significant values for dry root weight (9.66), root/shoot ratio (0.31), root length (3.82), number of roots per plant (37.08), root thickness (0.11), root volume (4.27) and root length density (0.03) ADT (R) 49 x Chandikar for 70 percent relative water content (8.85), dry root weight (18.03), dry shoot weight (40.55), root length (3.10), number of roots per plant (140.16) root thickness (0.38) and root volume (23.14) were found to be specific combiners for most of the drought tolerant traits. The cross combinations, *viz.,* ADT 43 x Anna (R) 4, ADT (R) 49 x Chandikar and ADT 43 x PMK (R) 3 had highly significant standard heterosis. Breeding for drought tolerance in rice would be of immense value to the farmers economic health, family well-being and harmony in the society.

Keywords: Combining, Drought, GCA, Heterosis and SCA

INTRODUCTION

Rice is the most important food source for more than half of the world's population and also main staple food for most of the countries which comprises of 86 million people (Luu *et al.,* 2012). Globally rice is cultivated under 158.4 million hectares with an annual production of around 697.2 million tonnes and an average productivity of 2.85 t/ha. Climate change threatens the sustainability of modern-day agriculture. Constantly changing climatic conditions around the world demand constant efforts to understand and adapt to environmental challenges for sustainable crop production (Dixit and Kumar, 2014). Land races are one of the important components of the germplasm and serve as the donors for the drought tolerance. Local land races are naturally adapted to utilize the natural resource-base better than the introduced modern cultivars (Bhattacharya and Ghosh 2004). Moreover the land races have broad genetic base, which provides wider adaptability and protection from various biotic and abiotic stresses. Hence, we could develop the high yielding hybrids with an added advantage of drought tolerance by crossing the drought tolerant land races with high yielding varieties, which are susceptible to drought (Muthuramu *et. al.,* 2010).

The concept of combining ability helps the breeder to determine the nature of gene action involved in the expression of quantitative traits of economic importance. The choice of suitable breeding method for the improvement of drought tolerant traits primarily depends on the relative importance of GCA and SCA variances. Proper choice of parents on the basis of their combining ability status for putative drought tolerant attributes as well as productive traits and selection in typical target environment will help in combining complex traits such as productivity and drought tolerance (Hanamaratti *et al*., 2004). Heterosis for drought tolerant traits will be a boon to drought tolerance breeding since most of the hybrids developed so far lack tolerance to abiotic and biotic stresses (Muthuramu *et. al.,* 2010). The drought resistant variety is expected to possess the ability to withstand drought stress. Breeding for drought tolerance in rice has immense value to the farmers economic health, family well-being and harmony in the society. Besides

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providing information on nature and magnitude of gene action governing yield and yield attributes, combining ability analysis also helps in the identification of the potential parents, cross combinations and formulation of systematic breeding plan for augmenting grain yield. The present study was undertaken to estimate the nature and magnitude of gene action governing important quantitative and drought traits of rice, *Oryza sativa* under drought situation and to estimate the general combining ability of parents, specific combining ability of hybrids and heterosis.

MATERIALS AND METHODS

The genetic materials consisted of ten lines, *viz.,* ADT 36, ADT 39, ADT 43, ADT (R) 49, ASD 16, BPT 5204, CO 47, CO(R) 49, CO (R) 50 and IR 50 (high yielding cosmopolitan rice varieties) and six testers *viz.,* Anna (R) 4, Chandikar, Chinnar 20, Nootripathu, PMK(R) 3 and Vellaichitraikar (drought tolerant genotypes), which were crossed in a Line x Tester design and CO (R) 50 was used as check variety. Seeds from the 60 cross combinations along with their parents were sown in raised nursery beds during Kharif, 2013. Twenty two days old seedlings of 60 crosses along with parents were transplanted under moisture stress condition in a Randomized Block Design replicated twice adopting a spacing of 25cm between rows and 20cm between plants within a row for studying combining ability and heterosis. Single seedling was transplanted per hill in two rows of three meter row length for each cross combination and in each replication. For estimating heterosis, the seedlings of parents were also transplanted on 22nd day of sowing in an adjacent plot with two replications adopting the same spacing as that of hybrids in rows three metre length. The recommended package of practices and plant protection measures were followed to obtain good standing of the crop. The stress was imposed at active tillering stage. Irrigation was stopped on 70th day after sowing and the stress was imposed for 15 days. Observations were recorded individually on five random plants in each replication for each hybrid and parents for estimating combining ability and heterosis. The mean values recorded for biometrical characters in the parents and F_1 generations were used for statistical analysis. The analysis was done using the TNAUSTAT statistical package.

Analysis of variance of ten lines, six testers and 60 hybrids were carried out for the quantitative characters following the procedure outlined by Panse and Sukhatme (1964). Combining ability analysis was carried out according to the methodology of Kempthorne (1957). The general combining ability of the parents and specific combining ability of the hybrids were assessed. The expected mean squares due to the different sources of variation and their genetic expectations were calculated as indicated in the following ANOVA table.

Where, r = number of replications, l= number of lines, t = number of testers

Estimates of covariance of full sibs and half sibs were calculated from the genetic expectations of mean squares as:

Cov (F.S.) = $(M_1 - M_4) + (M_2 - M_4) + (M_3 - M_4)$ + 6r Cov (H.S.) - r (l + t) Cov (H.S.) / 3r

Cov (H.S.) = $(M_1 - M_3) + (M_2 - M_4)$ / r (l + t)

Where, Cov (F.S.) = Covariance between full sibs, Cov (H.S.) = Covariance between half sibs.

From the covariance of full sibs and covariance of half sibs, variance due to general combining ability (GCA) and specific combining ability (SCA) were estimated as follows:

σ^2 GCA = Cov. H.S.

σ^2 SCA = Cov. F.S. - 2 Cov. H.S.

Estimation of GCA and SCA effects: The GCA and SCA effects of parents and hybrids respectively were estimated based on the following model.

$$X_{ijk} = \mu + g_{i.} + g_{.j} + s_{ij} + e_{ijk}$$

Where, X_{ijk} = value of the ijkth observation, μ = population mean, $g_{i.}$ = *gca* effect of ith line, $g_{.j}$ = *gca* effect of the jth tester, S_{ij} = *sca* effect of the ijth hybrid, e_{ijk} = error effect associated with ijkth observation, i = number of lines, j = number of testers, k = number of replications.

The individual effects of GCA and SCA were obtained from the two way table of lines versus testers, in which each figure was a total over replications.

And was calculated as follows:

$$\mu = X\ldots / rlt$$

GCA effects of lines, $g_i = \frac{X_{i..}}{rt} - \frac{X_{...}}{rlt}$

GCA effects of testers, $g_j = \frac{X_{.j.}}{rl} - \frac{X_{...}}{rlt}$

SCA effects of hybrids, $S_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{rt} - \frac{X_{.j.}}{rl} + \frac{X_{...}}{rlt}$

Where,

X… = total of all hybrid combinations; $X_{i..}$ = total of ith line over 'l' testers and 'r' replications; $X_{ij.}$ = total hybrids between ith line and jth tester over replications; $X_{.j.}$ = total of jth tester over 'l' lines and 'r' replications.

The standard errors pertaining to GCA and SCA effects were calculated as given below:

Standard error for testing the GCA effects of lines

$SE(g_i) = [EMS/rt]^{1/2}$

Standard error for testing the GCA effects of testers

$SE(g_j) = [EMS/rl]^{1/2}$

Standard error for testing the SCA effects of hybrids

$SE(s_{ij}) = [EMS/r]^{1/2}$

Test of significance:

For lines, $t_{gi} = gi / SE(gi)$

For testers, $t_{gj} = gj / SE(gj)$

For hybrids, $t_{sij} = sij / SE(sij)$

Estimation of heterosis: Heterosis was estimated from the overall mean of each hybrid for each trait. Standard heterosis (d_{iii}) for each character was expressed as per cent increase or decrease of F_1 value

ANOVA Table

Source	Degrees of Freedom	Mean squares	Expected mean squares
Replication	(r - 1)	-	
Hybrids	(lt – 1)	-	
Lines	(l – 1)	M_1	EMS +r [Cov (F.S.) – 2 Cov (H.S.)] + rt [Cov (H.S.)]
Testers	(t – 1)	M_2	EMS +r [(Cov (F.S.) – 2 Cov (H.S.)] + rl [Cov (H.S.)]
Lines x Testers	(l – 1)(t -1)	M_3	EMS +r [Cov (F.S.) – 2 Cov (H.S.)]
Error	(r – t) (lt – 1)	M_4	EMS
Total	rtl – 1		

over the standard variety (SV).

Standard heterosis (diii)

$$\text{diii} = \frac{\overline{F1} - \overline{SV}}{\overline{SV}} \times 100$$

Where,

$\overline{F1}$ = Average performance of the hybrid

$\overline{SV}$ = Average performance of standard variety

Significance of heterosis was tested using the formula given by Snedecor and Cochran (1967).

$SE_{(diii)} = \sqrt{2EMS/r}$

Where, EMS = error mean square, obtained from analysis of variance.

r = number of replications

t (cal) = d_{iii}/SEd_{iii}

The calculated 't' value was tested against table't' value at error degrees of freedom for five and one per cent probability levels.

RESULTS AND DISCUSSION

In the estimate of variances, the mean squares due to lines, testers, hybrids and line x tester interactions for different drought tolerant traits are presented in Table 1. In the present investigation, results showed that these ratios were less than unity for all the characters and greater proportion of SCA variance was observed for all the characters studied which revealed that the preponderance of non- additive gene action governing the traits concerned. This showed the presence of greater variance of non-additive gene action for all the characters, which offer scope for exploitation of hybrid vigour through heterosis breeding and selection procedure in late or advanced generation will be very important to improve these traits. These results were in agreement with those reported by Hosseini *et al.* (2005) and Malar*vizh*i *et al.* (2010) for spad chlorophyll meter reading and dry shoot weight in rice, Gnanasekaran *et al*. (2006) for biomass yield in rice, Das *et al*. (2005) for relative water content in rice; Ganesh *et al*. (2004), Sathya and Jebaraj (2013) and Utharasu and Anandakumar (2013) for dry root weight and root/shoot ratio in rice.

The GCA effects represent the nature of gene action. A best general combiner is characterized by its better breeding value when crossed with number of other parents. Dhillon (1975) pointed out that combining ability of parents gives useful information on the choice of parents in terms of expected performance of their progenies. The general combining ability effects of parents are furnished in Table 2 for different drought tolerant traits. The lines *viz.,* ADT 43, ADT (R) 49, BPT 5204 and CO 47 were adjudged as the best general combiners for yield and drought tolerant traits. Based on GCA performance, the testers *viz.,* PMK (R) 3, Chandikar and Anna (R) 4 were considered as good general combiners for drought component traits and crosses involving them would result in the identification of superior segregants with favourable genes for yield and drought tolerant traits in rice This is in accordance with the earlier findings of Manonmani and Fazhullah Khan (2005) for relative water content and root length in rice.

SCA is defined as the deviation from the mean performance, predicted on the basis of GCA (Allard, 1960) and specific combining ability is due to non-additive genetic interaction (Sprague and Tatum, 1942). The SCA effects of 60 hybrids are presented in Table 4 for drought tolerant related traits. The cross combinations *viz.,* ADT 39 x Vellaichitraikar had exhibited significant values for dry root weight (9.66), root/shoot ratio (0.31), root length (3.82), number of roots per plant (37.08), root thickness (0.11), root volume (4.27) and root length density (0.03) ADT (R) 49 x Chandikar for 70 percent relative water content (8.85), dry root weight (18.03), dry shoot weight (40.55), root length (3.10), number of roots per plant (140.16) root thickness (0.38) and root volume (23.14) were found to be specific combiners for most of the drought tolerant traits. The hybrids viz., ADT (R) 49 x Chinnar 20, ADT 43 x Anna (R) 4, ADT 36 x Anna (R) 4, BPT 5204 x Chinnar 20, CO (R) 50 x Nootripathu and CO (R) 50 x PMK (R) 3 were also found to be specific combiners. Similar results were obtained by Sathya and Jebaraj (2013) for the traits 70 percent relative water content, dry root weight, dry shoot weight and root length in rice. For these combinations, since they involved non-additive gene action, cyclic method of breeding involving selection of desired recombinants and their inter crossing would be more desirable (Muthuramu *et al.,* 2010).

In the estimation of heterosis, The cross combination, ADT 43 x Anna (R) 4 (L_3 x T_1) had significantly high values for spad chlorophyll meter reading (16.63) , dry root weight, (44.64), dry shoot weight (42.68), root length (24.30), number of roots per plant (78.14) root thickness (42.38) and root volume (44.37) (Table 5). The hybrid, ADT (R) 49 x Chandikar (L_4 x T_2) observed significant and high standard heterosis value for dry root weight (81.96), dry shoot weight (50.77),

Table 1. Analysis of variance for combining ability for different drought tolerant traits.

Source of variation	df	Mean squares: SPAD chlorophyll meter reading	70% relative water content	Dry root weight	Dry shoot weight	Root/shoot ratio	Root length	No. of roots per plant	Root thickness	Root volume	Root length density
Replication	1	0.5562	39.68	0.04	0.05	0.032	0.71	91.87	0.008	1.77	0.0009
Hybrids	59	20.95**	65.71**	257.25**	1506.81**	0.07**	20.54**	11979.94**	0.12*	276.79**	0.25*
Lines	9	22.24**	63.46**	324.90**	1388.36**	0.06**	38.58**	12425.32**	0.24**	291.11**	0.32**
Testers	5	36.30**	61.33**	386.99**	1755.05**	0.046**	28.68**	10843.87**	0.18*	320.47**	0.22*
L X T	45	18.99**	66.65**	229.30**	1502.92**	0.07**	16.02**	12017.09**	0.09**	269.08**	0.25*
Error	59	0.90	20.39	1.66	2.15	0.01	0.19	58.18	0.02	0.60	0.02
σ^2 GCA		0.03	0.01	0.56	0.07	0.01	0.09	0.75	0.0006	0.15	0.02
σ^2 SCA		9.04	23.12	113.82	750.38	0.03	7.91	5979.45	0.04	134.23	0.12
σ^2 GCA / SCA		0.004	0.0008	0.004	0.0001	0.29	0.01	0.0001	0.01	0.001	0.17

*Significant at 5% level, **Significant at 1% level.

Table 2. General combining ability effects of lines and testers for different drought tolerant traits.

Parents		SPAD chlorophyll meter reading	70% relative water content	Dry root weight	Dry shoot weight	Root/ shoot ratio	Root length	No. of roots per plant	Root thick-ness	Root volume	Root length density
Lines											
ADT 36	L_1	1.16**	-1.02	-0.29	5.13**	-0.02*	-1.63**	-28.34**	-0.19**	-3.65**	-0.04**
ADT 39	L_2	-2.11**	-4.18**	-1.56**	-6.53**	0.08**	-1.12**	9.32**	-0.17**	-0.12	-0.13**
ADT 43	L_3	1.76**	-1.81	7.52**	18.07**	0.02	-0.45**	46.58**	0.07**	2.93**	-0.12**
ADT (R) 49	L_4	-1.72**	0.21	5.81**	8.43**	0.03**	0.82**	57.24**	0.19**	7.30**	-0.15**
ASD 16	L_5	1.65**	-1.17	-9.00**	-15.46**	-0.10**	0.25	-34.51**	0.02	-5.21**	0.22**
BPT 5204	L_6	-0.04	0.64	-2.62**	7.97**	-0.07**	0.85**	-8.68**	0.10**	3.82**	-0.10**
CO 47	L_7	-1.05**	0.35	2.47**	-9.66**	0.14**	-1.66**	10.16**	0.08**	0.23	-0.16**
CO (R) 49	L_8	-0.35	0.25	5.03**	4.30**	0.04**	-0.31*	-2.01	-0.1**	-2.73**	0.03*
CO (R) 50	L_9	-0.21	4.12**	-2.14**	0.42	-0.08**	4.39**	-11.26**	0.17**	5.44**	0.24**
IR 50	L_{10}	0.91**	2.61*	-5.21**	-12.67**	-0.04**	-1.13**	-38.51**	-0.15**	-8.01**	0.21**
Testers											
Anna (R)4	T_1	2.20**	-1.23	-2.18**	2.73**	-0.05**	0.55**	26.16**	-0.01	-0.35	0.13**
Chandikar	T_2	-0.02	0.27	1.61**	2.87**	0.01	0.78**	12.51**	0.04**	4.76**	-0.09**
Chinnar 20	T_3	-2.01**	1.24	1.06**	-6.70**	0.06**	-0.23*	-16.79**	0.08**	-0.37*	0.04**
Nootripathu	T_4	0.19	-1.83	-5.43**	-8.23**	-0.06**	-2.22**	-21.94**	-0.10**	-4.23**	-0.02
PMK(R) 3	T_5	-0.36	-1.18	7.30**	16.22**	0.04**	1.13**	23.56**	0.11**	4.53**	-0.15**
Vellaichitraikar	T_6	0.01	2.73**	-2.35**	-6.89**	0.01	0.02	-23.49**	-0.13**	-4.34**	0.10**

*Significant at 5% level, **Significant at 1% level.

Table 3. Specific combining ability of hybrids for different drought tolerant traits.

S. N.	Hybrids	Spad chlorophyll meter reading	70% relative water content	Dry root weight	Dry shoot weight	Root/shoot ratio	Root length	No. of roots per plant	Root thickness	Root volume	Root length density
1	L_1 x T_1	2.43**	-2.29	6.23**	16.27**	-0.01	4.91**	18.09**	-0.05	7.55**	-0.16**
2	L_1 x T_2	-1.86**	-5.87	4.40**	-24.71**	0.27**	0.20	-76.76**	0.05	-10.30**	0.42**
3	L_1 x T_3	-0.43	-9.64**	-0.68	-17.01**	0.11**	-0.27	-45.96**	0.06	-6.17**	0.26**
4	L_1 x T_4	-4.06**	1.42	-4.46**	4.99**	-0.12**	-0.60	32.69**	0.03	9.34**	-0.31**
5	L_1 x T_5	4.05**	6.85*	-3.63**	22.22**	-0.17**	-0.81*	11.19*	0.05	-0.92	0.01**
6	L_1 x T_6	-0.12	9.53*	-1.85*	-1.76	-0.07**	-3.43**	60.74**	-0.15**	0.50	-0.20**
7	L_2 x T_1	-0.40	8.16*	7.69**	41.17**	-0.15**	0.82**	-42.08**	0.17	1.62**	-0.16**
8	L_2 x T_2	1.65*	-5.52	3.99**	19.04**	-0.13**	-0.26	71.07**	0.07	6.62**	-0.15**
9	L_2 x T_3	0.89	2.99	-11.29**	-5.17**	-0.28**	1.91**	17.88**	-0.09*	-9.11**	0.51**
10	L_2 x T_4	-0.65	-1.40	-2.83**	2.88**	-0.16	-1.80**	-32.47**	0.02	1.50**	-0.17**
11	L_2 x T_5	0.69	-2.72	-7.22**	-46.90**	0.40**	-4.47**	-51.47**	-0.28**	-4.90**	-0.05**
12	L_2 x T_6	-2.18**	-1.51	9.66**	-11.01**	0.31**	3.82**	37.08**	0.11**	4.27**	0.03**
13	L_3x T_1	2.73**	-0.36	10.38**	25.08**	0.01	5.18**	163.68**	0.42**	21.02**	-0.37**
14	L_3 x T_2	3.82**	-1.73	-18.44**	-47.13**	-0.04	-4.95**	-137.18**	-0.07	-16.74**	0.17**
15	L_3 x T_3	-0.40	-2.06	-3.93**	23.26**	-0.18**	0.33	-45.88**	-0.05	-3.75**	-0.04**
16	L_3 x T_4	1.16	1.20	16.28**	28.32**	0.06**	0.52	23.77**	-0.05	8.40**	-0.24**
17	L_3 x T_5	0.61	4.07	-4.29**	-50.02**	0.29**	-0.44	28.77**	0.08*	1.35*	-0.05**
18	L_3 x T_6	-7.93**	-1.12	-0.01	20.49**	-0.12**	-0.64*	-33.17**	-0.33**	-10.28**	0.52**
19	L_4 x T_1	-1.47*	-1.24	-0.91	-27.96**	0.21**	-4.80**	20.51**	-0.36**	-16.85**	0.13**
20	L_4 x T_2	0.20	8.85**	18.03**	40.55**	0.02	3.10**	140.16**	0.38**	23.74**	-0.22**
21	L_4 x T_3	-3.04**	4.42	15.74**	3.34**	0.21**	1.09**	69.46**	0.08*	15.12**	-0.31**
22	L_4 x T_4	-1.76*	3.93	-10.73**	-17.19**	-0.10**	-0.82**	-34.39**	0.17**	-1.52**	-0.11**
23	L_4 x T_5	2.21**	-2.43	-22.21**	-47.86**	-0.12**	0.59	-151.89**	0.07	-16.08**	0.46**
24	L_4 x T_6	3.86**	-13.53**	0.09	49.13**	-0.20**	0.83**	-43.84**	-0.33**	-4.41**	0.04**
25	L_5x T_1	-4.35**	2.28	0.85	-2.87**	0.02	3.88**	61.76**	0.31**	16.01**	-0.55**
26	L_5 x T_2	2.35**	0.05	-0.92	-10.78**	0.07**	-4.58**	-68.09**	-0.10*	-9.04**	-0.05**
27	L_5 x T_3	-1.47*	-6.27	-5.07**	3.22**	-0.13**	-2.39**	18.71**	-0.29**	-5.06**	0.01**
28	L_5 x T_4	0.54	-0.93	5.72**	-2.21*	0.16**	1.55**	-44.64**	0.11**	-1.45**	0.27**
29	L_5x T_5	-0.79	-2.80	3.94**	25.50**	-0.06**	1.28**	18.86**	-0.08*	2.44**	-0.14**
30	L_5 x T_6	3.72**	7.67*	-4.51**	-12.88**	-0.06**	0.25	13.41**	0.04**	-2.89**	0.45**

Contd.

Table 3. *Contd……..*

31	L_6 x T_1	0.04	0.22	-2.08*	-8.24**	-0.03	0.35	-29.57**	-0.05	-1.17**	-0.15**
32	L_6 x T_2	-0.50	-1.60	4.45**	41.23**	-0.10**	0.85**	43.08**	-0.20**	11.07**	-0.19**
33	L_6 x T_3	1.84**	0.57	9.71**	23.24**	-0.02	0.59	76.88**	0.11**	16.90**	-0.36**
34	L_6 x T_4	1.43*	-0.42	-6.16**	-45.60**	0.31**	-3.95**	-31.47**	-0.01	-11.49**	0.22**
35	L_6x T_5	-2.24**	-1.21	-3.97**	-7.62**	-0.07**	4.16**	-11.97**	-0.07	-9.99**	0.47**
36	L_6x T_6	-0.57	2.45	-1.95*	-3.00**	-0.08**	-1.99**	-46.92**	0.22**	-5.33**	0.03**
37	L_7 x T_1	-1.59*	0.10	9.66**	-10.76**	0.29**	-0.32	61.59**	-0.03	6.87**	-0.30**
38	L_7 x T_2	0.41	-2.93	-1.32	21.46**	-0.20**	3.41**	-37.26**	-0.08*	-9.84**	0.45**
39	L_7 x T_3	-2.57**	-4.36	8.61**	-4.49**	0.30**	-2.26**	17.04**	0.14**	7.19**	-0.31**
40	L_7 x T_4	-0.81	-0.36	-7.24**	-6.31**	-0.14**	0.19	-19.81**	-0.03	-5.95**	0.27**
41	L_7 x T_5	-2.41**	1.07	-7.44**	7.04**	-0.25**	-2.81**	-65.31**	0.10**	-5.80**	0.05**
42	L_7 x T_6	6.98**	6.49*	-2.28*	-6.94	0.01	1.79**	43.74**	-0.11**	7.51**	-0.15**
43	L_8 x T_1	4.05**	1.21	-14.11**	-3.50**	-0.21**	-4.56**	-65.74**	-0.45**	-10.67**	0.27**
44	L_8 x T_2	-2.97**	9.67**	-14.53**	-25.76**	-0.10**	0.11	33.91**	0.42**	6.82**	-0.25**
45	L_8 x T_3	-2.44**	3.26	-3.53**	-13.77**	0.07**	-0.83**	-62.79**	-0.08*	-6.90**	0.22**
46	L_8 x T_4	0.60	-5.27	2.96**	25.43**	-0.08**	2.67**	72.36**	-0.07	7.16**	-0.15**
47	L_8 x T_5	0.78	-4.15	12.07**	20.67**	-0.02	0.90**	-8.14	0.03	-1.54**	0.05**
48	L_8 x T_6	-0.02	-4.72	17.14**	-3.08**	0.33**	1.71**	30.41**	0.15**	5.12**	-0.13**
49	L_9x T_1	-0.61	-3.37	-11.86**	-4.78**	-0.16**	-4.50**	-126.49**	0.09*	-20.54**	1.11**
50	L_9 x T_2	-0.14	2.00	-8.14**	-11.02**	-0.06**	-0.67*	-41.34**	-0.10*	1.26**	-0.38**
51	L_9 x T_3	3.11**	-5.45	-2.17**	-2.61*	0.01	1.52**	19.46**	-0.06	-5.76**	-0.13**
52	L_9 x T_4	2.67**	2.39	7.00	6.63**	0.11**	2.43**	-27.89**	0.18**	-9.50**	0.38**
53	L_9 x T_5	0.99	4.51	25.57**	45.04**	0.08**	2.72**	231.61**	-0.19**	32.29**	-0.54**
54	L_9 x T_6	-6.01**	-0.07	-10.40**	-33.27**	0.04	-1.51**	-55.34**	0.08*	2.26**	-0.45**
55	L_{10} x T_1	-0.83	-4.71	-5.86**	-24.42**	0.05*	-0.95**	-61.74**	-0.07	-3.84**	0.18**
56	L_{10}x T_2	-2.97**	-2.91	12.49**	-2.89**	0.30**	2.77**	72.41**	-0.36**	-3.59**	0.20**
57	L_{10}x T_3	4.52**	16.54**	-7.40**	-10.02**	-0.07**	0.33	-64.79**	0.17**	-2.46**	0.16**
58	L_{10}x T_4	0.90	-0.55	-0.54	3.06**	-0.04	-0.19	61.86**	-0.33**	3.50**	-0.17**
59	L_{10}x T_5	-3.90**	-3.20	7.18**	31.95**	-0.07**	-1.12**	-1.64	0.27**	3.14**	-0.24**
60	L_{10}x T_6	2.27**	-5.17	-5.88**	2.32*	-0.16**	-0.83**	-6.09	0.32**	3.26**	-0.14**

*Significant at 5% level, **Significant at 1% level.

Table 4. Standard heterosis for different drought tolerant traits.

S. N.	Hybrids	Spad chlorophyll meter reading	70% relative water content	Dry root weight	Dry shoot weight	Root/shoot ratio	Root length	No. of roots per plant	Root thickness	Root volume	Root length density
1	L_1 x T_1	14.48**	-42.18**	-1.36	13.21**	-12.86	15.00**	-7.80**	-27.14**	-19.18**	42.00**
2	L_1 x T_2	-1.04	-47.73**	6.17	-42.12**	84.29**	-13.42**	-50.10**	-13.33*	-59.59**	114.00**
3	L_1 x T_3	-2.38	-55.15**	-15.42**	-44.67**	54.29**	-22.8**	-49.51**	-7.62	-62.76**	108.00**
4	L_1 x T_4	-5.76*	-33.92**	-54.92**	-16.92**	-45.71**	-37.52**	-20.86**	-27.62**	-25.83**	-16.00
5	L_1 x T_5	12.23**	-17.73	-2.80	39.55**	-28.57**	-17.54**	-11.50**	-5.71	-30.59**	19.00
6	L_1 x T_6	3.17	-0.21	-33.02**	-24.25**	-11.43	-41.42**	-10.53**	-48.10**	-54.20**	28.00*
7	L_2 x T_1	-0.07	-22.81	-0.60	31.14**	-22.86**	-7.71*	-16.57**	-4.76	-26.78**	26.00*
8	L_2 x T_2	-0.48	-55.22**	-0.25	1.36	-1.43	-13.10**	22.22**	-10.48**	5.23*	-17.00
9	L_2 x T_3	-7.02**	-30.00*	-61.06**	-44.42**	-30.00**	-5.71	-9.94**	-20.95**	-60.86**	141.00**
10	L_2 x T_4	-5.44*	-49.86**	-53.52**	-35.59**	-27.14**	-41.86**	-31.58**	-28.10**	-39.46**	-4.00
11	L_2 x T_5	-3.57	-51.62**	-21.48**	-69.92**	162.86**	-37.52**	-21.25**	-36.19**	-32.01**	-8.00
12	L_2 x T_6	-9.52**	-37.99**	6.32	-52.59**	127.14**	7.83*	-5.07	-21.90**	-31.06**	57.00**
13	L_3x T_1	16.63**	-39.16**	44.64**	42.68**	1.43	24.20**	78.17**	42.38**	44.37**	-14.00
14	L_3 x T_2	13.93**	-38.81**	-51.54**	-54.97**	7.14	-38.57**	-44.44**	0.10	-59.11**	50.00**
15	L_3 x T_3	-0.87	-37.12**	2.13	27.44**	-18.57*	-11.51**	-20.27**	6.19	-34.23**	34.00**
16	L_3 x T_4	8.10**	-36.61**	54.82**	32.22**	18.57*	-22.93**	4.87	-10.95**	-7.92**	-16.00
17	L_3 x T_5	5.48*	-27.23*	24.70**	-40.81**	112.86**	-7.71*	24.56**	20.95**	-2.54	-6.00
18	L_3 x T_6	-13.98**	-30.65*	4.07	23.42**	-14.29	-16.18**	-17.93**	-40.48**	-67.51**	158.00**
19	L_4 x T_1	-1.67	-36.13**	-5.36	-42.26**	65.71**	-31.08**	26.51**	-21.43**	-61.81**	80.00**
20	L_4 x T_2	-2.98	-5.28	81.96**	50.77**	21.43*	20.52**	67.84**	53.33**	83.04**	-34.00**
21	L_4 x T_3	-15.44**	-14.47	71.11**	-12.63**	98.57**	1.36	28.85**	29.52**	39.46**	-27.00*
22	L_4 x T_4	-7.14**	-23.97*	-55.57**	-42.51**	-22.86**	-23.34**	-13.65**	20.48**	-25.52**	3.00
23	L_4 x T_5	1.00	-39.15**	-50.77**	-50.95**	0.14	6.88*	-41.72**	31.43**	-43.90**	91.00**
24	L_4 x T_6	5.80*	-58.29**	-2.13	49.17**	-32.86**	1.17	-17.93**	-30.00**	-35.02**	56.00**
25	L_5x T_1	-0.51	-30.44*	-55.47**	-40.61**	-24.29**	20.39**	6.82*	25.24**	2.69	17.00
26	L_5 x T_2	10.15**	-32.39**	-47.69**	-51.13**	7.14	-31.81**	-49.12**	-9.05	-60.54**	73.00**
27	L_5 x T_3	-3.69	-46.61**	-65.71**	-45.14**	-37.14**	-24.33**	-26.71**	-22.86**	-64.18**	111.00**

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28	L_5 x T_4	6.35**	-40.57**	-49.25**	-54.57**	12.86	-11.96**	-53.41**	-2.38	-64.98**	152.00**
29	L_5x T_5	1.86	-43.82**	-7.18	16.10**	-20.00*	7.61*	-10.92**	0.23	-24.88**	43.00**
30	L_5 x T_6	13.49**	-5.57	-76.66**	-67.21**	-28.57**	-6.12*	-31.38**	-12.38*	-69.89**	211.00**
31	L_6 x T_1	5.92*	-31.10**	-42.18**	-16.14**	-31.43**	1.81	-18.71**	0.36	-23.14**	33.00**
32	L_6 x T_2	-0.67	-31.97**	-2.55	51.08**	-34.29**	6.47*	4.29	-9.52	31.85**	-19.00
33	L_6 x T_3	0.15	-23.60*	15.58**	13.73**	2.86	-1.59	6.04*	23.81**	34.07**	-27.00*
34	L_6 x T_4	4.45	-34.40**	-70.34**	-81.62**	64.29**	-43.01**	-38.21**	-4.76	-68.15**	79.00**
35	L_6x T_5	-5.63*	-34.79**	-13.04**	2.96	-14.29	29.72**	-12.87**	10.00	-35.66**	102.00**
36	L_6x T_6	-0.76	-14.63	-42.32**	-22.09**	-25.71**	-16.49**	-44.83**	14.29**	-48.97**	63.00**
37	L_7 x T_1	-0.36	-32.19**	22.44**	-43.45**	120.00**	-18.36**	24.17**	0.27	-9.03**	-10.00
38	L_7 x T_2	-0.90	-36.26**	-5.19	0.41	-4.29	6.76*	-19.69**	0.35	-45.80**	98.00**
39	L_7 x T_3	-12.74**	-37.46**	30.89**	-47.74**	152.86**	-35.62**	-9.94**	24.76**	-8.08**	-30.00**
40	L_7 x T_4	-3.30	-35.01**	-54.99**	-52.28**	-4.29	-32.67**	-26.32**	-8.57	-61.97**	77.00**
41	L_7 x T_5	-8.42**	-29.48*	-6.84	-1.06	-5.71	-30.45**	-26.32**	23.81**	-33.76**	5.00
42	L_7 x T_6	14.81**	-4.66	-24.05**	-51.31**	57.14**	-8.47**	-2.14	-19.05**	-19.65**	14.00
43	L_8 x T_1	14.73**	-29.49*	-59.03**	-14.70**	-50.00**	-36.66**	-30.21**	-57.14**	-74.01**	143.00**
44	L_8 x T_2	-7.30**	-3.01	-46.10**	-44.67**	-2.86	-5.58	3.31	29.52**	-2.38	-3.00
45	L_8 x T_3	-10.76**	-17.47	-5.94	-41.40**	61.43**	-17.95**	-45.81**	-13.33*	-62.12**	116.00**
46	L_8 x T_4	1.71	-48.36**	-5.95	9.65**	-14.29	-8.34**	4.87	-29.52**	-29.79**	31.00**
47	L_8 x T_5	0.83	-43.62**	77.95**	36.31**	31.43**	1.71	-8.77**	0.18	-29.64**	44.00**
48	L_8 x T_6	-0.20	-34.75**	60.39**	-27.17**	122.86**	-0.41	-12.09**	-11.90**	-36.61**	57.00**
49	L_9x T_1	3.98	-31.40**	-77.97**	-21.68**	-71.43**	-6.53*	-57.50**	19.05**	-79.40**	355.00**
50	L_9 x T_2	-0.20	-13.12	-49.10**	-29.95**	-25.71**	19.25**	-29.63**	5.71	5.86*	13.00
51	L_9 x T_3	2.79	-30.36*	-28.24**	-31.52**	5.71	26.74**	-17.35**	14.29**	-32.65**	88.00**
52	L_9 x T_4	6.99**	-17.68	-17.98**	-21.07**	4.29	19.89**	-37.82**	19.52**	-56.74**	179.00**
53	L_9 x T_5	1.67	-10.31	102.27**	64.09**	24.29**	43.04**	81.09**	4.76	103.49**	-30.00**
54	L_9 x T_6	-14.12**	-12.09	-72.97**	-73.33**	2.86	8.98**	-49.12**	7.62**	-19.81**	36.00**
55	L_{10} x T_1	6.11*	-38.98**	-66.65**	-66.04**	0.12	-19.03**	-42.88**	-25.71**	-69.10**	162.00**
56	L_{10}x T_2	-4.29	-30.20*	18.40**	-36.67**	88.57**	6.06*	4.09	-48.57**	-52.14**	121.00**
57	L_{10}x T_3	8.81**	24.15*	-60.12**	-59.30**	-1.43	-15.83**	-60.82**	5.71	-64.82**	139.00**
58	L_{10}x T_4	5.44*	-29.52*	-58.70**	-43.66**	-25.71**	-31.72**	-13.45**	-59.05**	-58.16**	63.00**
59	L_{10}x T_5	-7.31**	-34.83**	19.86**	28.61**	-5.71	-16.37**	-20.47**	18.57**	-31.54**	23.00*
60	L_{10}x T_6	8.26**	-29.68*	-67.35**	-42.84**	-41.43**	-21.76**	-40.55**	0.43	-59.27**	92.00**

* Significant at 5% level, **Significant at 1% level.

root/shoot ratio (21.43), root length (20.53), number of roots per plant (67.84), root thickness (53.33) and root volume (83.04). The cross, ADT 43 x PMK (R) 3 (L_3 x T_5) had significant standard heterosis for the traits *viz.,* spad chlorophyll meter reading (5.48), dry root weight (24.70) Root/Shoot ratio (112.86), number of roots per plant (24.56) and root thickness (20. 59) over check variety. CO (R) 50 x PMK (R) 3 (L_9 x T_5) had observed positively significant heterosis for dry root weight (102.27) dry shoot weight (64.09), Root/Shoot ratio (24.29), root length (43.04), number of roots per plant (81.09) and root volume (103.49). Presence of non-additive gene action for drought tolerant traits in the hybrids resulted in high amount of vigour in F_1 indicating the possibility of augmenting yield and drought tolerance by exploiting heterosis (Manonmani and Fazullah Khan, 2003). These results are in agreement with those reported by Abd Allah (2004) and El-Mouhamady *et al.* (2013) in rice. These hybrids can be used as a potential genetic source for better root system with higher efficiency to absorb moisture effectively for tolerating drought condition and increasing yield.

Conclusion

In this present study, it was inferred that all the traits were governed by non additive gene action. The most appropriate breeding technique to exploit non additive gene action will be through heterosis breeding. The hybrids showing additive action can be improved by pedigree breeding and selection can be postponed to later generations. The hydrids which shows significant heterosis are highly suitable for commercial exploitation of heterosis under moisture stress conditions.

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