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Heterosis Analysis for Physio-Morphological Traits in Relation to Drought Tolerance in Rice (*Oryza sativa* L.)

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Abstract: Rice (*Oryza sativa* L.) is the most important food crop of the world; but drought stress is a serious limiting factor to rice production and yield stability in rainfed areas. Breeding for drought tolerance is a challenging task because of the complexicity of the component traits, screening technique, environmental factors and their interaction. The major setback in drought tolerance breeding is the poor understanding of genetics and inheritance of drought tolerance traits and complete ignorance about the physiological drought tolerance attributes. Alternatively, yield improvements in water-limited environments can be achieved by selecting for secondary traits contributing to drought resistance in breeding programs. Hence, the present investigation was undertaken to study the heterosis manifested by the 40 hybrids derived from eight lines and five testers for physio-morphological traits by line x tester analysis. Results revealed that, maximum desirable heterosis over mid parent was observed for root: shoot ratio (100.00%), leaf drying (-66.10%), followed by root length (60.58%), root dry weight (60.00%), days to 70% RWC (51.87) and chlorophyll stability index (44.19). Similar trend of desirable heterosis over better parent was observed for root: shoot ratio (71.43%) and leaf drying (-62.96%) followed by leaf rolling (-47.50%), root length (42.42%) and root dry weight (39.22%). Among 40 hybrids, CPMB ACM 03 017 x MDU 5 had considerably higher desirable heterosis over mid parent and better parents for physiological traits whereas CT 9993 x IR 50, CT 9993 x ASD 18, CPMB ACM 03 015 x ASD 18 and Moroberekan x ASD 16 exhibited positive and significant favorable heterosis over mid parent and better parents for root traits.

Key words: Rice · Heterosis · Physio-morphological traits · Drought tolerance

INTRODUCTION

Rice (*Oryza sativa* L.), one of the important food crops, is grown on 154 million hectares world-wide in a wide range of environments [1]. About 45% of the world's rice is cultivated in rainfed ecosystems [2]. These areas often experience severe water deficits due to low and uneven rainfall distribution patterns and yields are largely reduced by drought. Drought stress is a serious limiting factor to rice production and yield stability in rainfed areas and 18 million tons of rice valued at US $ 3600 millions is lost annually to drought [3]. Development of drought resistant cultivars will considerably improve rainfed rice production. Alternatively, yield improvements in water-limited environments can be achieved by selecting for secondary traits contributing to drought resistance in breeding programs. The effectiveness of selection for secondary traits to improve yield under water limiting conditions has been demonstrated in maize [4], wheat [5] and sorghum [6]. Several putative traits contributing in drought resistance in rice have been documented [7, 8]. Earlier reports have suggested the importance of many physio morphological traits for drought tolerance in rice. In rice, early genotype with high root volume and root length density at maturity gave higher yields [9]. Therefore, a deep root system with high root volume would assist in developing drought resistant upland cultivars [10]. An ideal secondary trait should be easy to measure, highly heritable, genetically correlated with grain yield under stress and should show genetic variation in the target species [11].

Three mechanism of drought tolerance *viz*., avoidance drought escape operates in tolerance to drought in rice. Drought tolerance and drought avoidance

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are operates mainly through physio-morphological and root traits respectively. Drought escape associated with (evolution) early duration. Hence, measurement of physio-morphological traits permits the rapid identification of potentially tolerant plant materials and cross combinations. Higher levels of days to 70 per cent RWC, chlorophyll stability index and lower levels of leaf rolling, leaf drying and drought recovery rate observed in drought tolerance lines than in the susceptible ones [12, 13]. However, not many studies are available on exploitation of heterosis for the above physio-morphological traits in rice which is more important. Since, the survival alone during drought is not sufficient and crop needs to produce a reasonable yield for subsistence requirements or for economic reasons. Hence, present investigation was carried out to study the heterosis manifested by the hybrids over mid parent and better parents for physio-morphological traits in relation to drought tolerance in rice.

MATERIALS AND METHODS

The present investigation was conducted at Research Farm, Agricultural College and Reseach Institute, Madurai (latitude: 9.54’ E; longitude: 78.8’ N; altitude: 147 m MSL) during October 2004-January 2005 and June 2005-September 2005.

Synthesis of F_1 Hybrids: The experimental materials consisted of eight drought tolerant genotypes *viz*., Norungan (L_1), Mattaikar (L_2), CT 9993 (L_3), Moroberekan (L_4), NPT 107 (L_5), CPMB ACM 03 015 (L_6), CPMB ACM 03 017 (L_7) and Nootripathu (L_8) (lines) and five high yielding cosmopolitan rice varieties *viz*., MDU 5 (T_1), CO 47 (T_2), IR 50 (T_3), ASD 16 (T_4) and ASD 18 (T_5) (testers). Crossing was carried out by following in a Line x Tester mating design [13] during *Rabi 2004-2005*. For crossing, wet cloth method [14] was followed and maximum numbers of crosses were made to develop sufficient F_1 seeds.

Evaluation of F_1 Hybrids under Moisture Stress Condition: The F_1 hybrids of the resultant 40 hybrids along with their parents were raised in a randomized block design (RBD) replicated twice with a spacing of 20 x 15 cm during *Kharif*, 2005. Single seedling was transplanted per hill for each hybrid in two rows of three meter length. IR 50, the susceptible variety for drought was raised along the borders as an indicator of moisture stress. The experiment was conducted in rainfed conditions with supplemented irrigation as needed. At peak tillering phase, irrigation was withheld in order to impose drought. IR 50, the stress indicator started to show stress symptoms within 5-7 days. In rice 70% Relative water content (RWC) was previously demonstrated to be a relevant screening tool of drought tolerance in cereals, as well as good indicator of plant water status [16]. In rice, once the plants attain 70% RWC, it indicates the real physiological stress of the irrespective of the environment [17]. Hence, the RWC was taken at regular intervals in each genotype.

Recording Observations: When each genotype attain 70% RWC, the drought tolerant parameters *viz*., leaf rolling, leaf drying were scored and the field was re-irrigated. After ten days, drought recovery rate was recorded. In each replication, 10 plants were randomly selected per genotype for recording observations on drought tolerant attributes *viz*., days to 70% relative water content (RWC), leaf rolling (LR), leaf drying (LD), drought recovery rate (DRR), root length (RL), root dry weight (RDW), root: shoot ratio (R/S) were recorded. The yield components traits *viz*., days to 50 per cent flowering (DFF), plant height (PH), productive tillers per plant (PT), grains per panicle (GP), spikelet fertility (SF), harvest index (HI) and grain yield per plant (GY) were recorded. The drought tolerance attributes were recorded as follows:

Days to attain 70% Relative water content (70% RWC): Stress was induced at peak tillering phase on 60 days after sowing. Observations were recorded repeatedly every day till RWC reaches 70 per cent. Leaf sampling was done at midday. In each selected plant, days to 70% RWC was recorded as follows:

A sample of 0.5 g of fresh, healthy and unblemished leaf material, excluding the apex and collar regions, was collected from each of the ten selected plants from each genotype. After taking the fresh weight (FW), the samples were placed in petridishes containing distilled water and kept in a moist chamber for 24 h to obtain full turgidity. After 24 h, the samples were removed from distilled water, blotted dry and the turgid weight (TW) was recorded. Then the turgid leaf samples were kept in hot air oven at 60ºC overnight and the oven dry weight was determined. The RWC was calculated using the formula suggested by Kramer [18].

Leaf Rolling and Leaf Drying: Leaf rolling and leaf drying were recorded at 70% RWC. It is scored on an scale of 0 to 9 according to Standard Evaluation System adopted for Rice [19].

Drought Recovery Rate: The crop was irrigated after the stress period up to maturity. Drought recovery rate was recorded seven days after irrigation, according to Standard Evaluation System adopted for Rice [19].

Chlorophyll Stability Index: Chlorophyll stability index was estimated by Spectrophotometric method as suggested by Kolyreas[20] from the third leaf of the selected plants at 70% RWC.

Root Length: At physiological maturity, selected plants were uprooted by giving a deep dig near the base after watering and the maximum root length of the longest root was recorded in centimetre.

Root Dry Weight: Roots of the selected plants at the time of harvest were cut from the stem, dried moisture free in a hot air oven at 80ºC for 48 h (till attaining constant weight), weighed and recorded in gram.

Root: Shoot Ratio: The root weight of selected plants was recorded as mentioned above. The shoot weight was recorded separately after drying the shoot portion including grains in hot air oven at 80ºC for 48 h till reaching constant weight. Root: Shoot ratio was worked out as follows:

$$\text{Root: Shoot Ratio} = \frac{\text{Root dry weight (g)}}{\text{Shoot dry weight (g)}}$$

After ascertaining the significance among the genotypes, the mean data were subjected to estimate the heterosis per cent over better and standard parents [21].

RESULTS AND DISCUSSION

Per cent heterosis over mid parent and better parents were estimated to know the possible gene action as well as to exploit heterosis for drought associated traits. The magnitude of heterosis manifested over mid parent and better parents are presented in Table 1. Literature reveals that lower levels of leaf rolling, leaf drying, drought recovery rate and higher levels of days to attain 70% RWC, chlorophyll stability index, root length,

Table 1: Magnitude of heterosis over mid parent and better parent for physio-morphological traits under moisture stress condition

	Days to attain 70% RWC		Leaf rolling		Leaf drying		Chlorophyll Stability Index	
Hybrid	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}
L_1xT_1	7.23	-7.63	-37.66*	-14.29*	-30.28*	-15.56	16.11*	4.13
L_1xT_2	29.58*	6.43	-26.93*	7.14	-31.78*	-2.22	7.82	-8.26
L_1xT_3	4.11	-18.67*	-39.22*	10.71	-18.25	24.44	9.20	-12.84*
L_1xT_4	24.53*	18.47*	-35.80*	-7.14	-26.96*	-6.67	18.53*	3.30
L_1xT_5	28.33*	6.43	-3.49	48.21*	-15.45	15.56	9.38	-6.42
L_2xT_1	6.33	-2.33	-20.00*	-5.56	-53.28*	-55.29*	11.95*	5.18
L_2xT_2	46.13*	27.44*	-28.09*	-11.11	-48.96*	-43.86*	4.06	-7.52
L_2xT_3	7.04	-11.63	-38.18*	-5.56	-33.33*	-22.86	4.04	-13.62*
L_2xT_4	38.46*	25.58*	-3.37	11.11	-20.00	-20.00	19.29*	8.74
L_2xT_5	0.26	-11.63	-21.28*	2.78	-24.32*	-20.00	8.93	-2.64
L_3xT_1	30.77*	21.43*	-9.94	-23.29*	-40.98*	-37.93*	6.79	-3.20
L_3xT_2	13.51*	0.00	-12.85	6.85	-21.13*	-3.45	3.88	-10.71*
L_3xT_3	48.57*	23.81*	-36.85*	-4.11	-20.00	3.45	27.19*	2.44
L_3xT_4	29.87*	14.29*	-15.08	4.11	-12.50	-3.45	14.19*	0.56
L_3xT_5	51.87*	35.24*	-32.28*	-12.32*	-50.00*	-41.38*	32.68*	14.66*
L_4xT_1	22.82*	6.53	-23.60*	-15.00*	-7.64	20.00	13.27*	1.37
L_4xT_2	25.43*	3.67	-35.48*	-25.00*	-45.16*	-15.00	30.11*	10.50*
L_4xT_3	9.08	-14.29*	-42.11*	-17.50*	-15.15	40.00*	16.91*	-6.85
L_4xT_4	38.10*	18.37*	-46.24*	-47.50*	-34.55*	-10.00	29.13*	12.33*
L_4xT_5	12.47*	-6.12	-34.69*	-20.00*	-25.42*	10.00	23.00*	5.02
L_5xT_1	36.84*	30.00*	-33.33*	-30.00*	-20.00	-26.32*	18.23*	13.23*
L_5xT_2	19.44*	7.50	-28.44*	-22.00*	-50.25*	-48.68*	7.02	-3.18*
L_5xT_3	-8.82	-20.00*	-26.15*	-14.00*	0.00	10.53	12.23*	-5.29*
L_5xT_4	12.00*	5.00	-3.67	-6.25	15.07	10.53	13.39*	5.29
L_5xT_5	-1.104	-10.00	0.60	1.79	9.09	10.53	-1.16	-10.05*
L_6xT_1	43.38*	34.63*	-36.71*	-16.71*	-41.46*	-38.98*	34.25*	28.57*
L_6xT_2	32.60*	18.05*	-13.25	20.57*	-56.64*	-47.46*	21.05*	9.52*
L_6xT_3	-10.14	-7.32	-23.08*	33.33*	-31.13*	-11.86	15.99*	-2.12
L_6xT_4	15.79*	17.07*	-18.07	14.33*	-13.18	-5.08	10.54*	2.65
L_6xT_5	46.34*	41.46*	-36.36*	-6.67	-59.12*	-52.54*	44.19*	31.22*
L_7xT_1	43.21*	28.89*	-59.49*	-46.66*	-66.10*	-62.96*	29.68*	14.04*

Table 1: Continued

	Days to attain 70% RWC		Leaf rolling		Leaf drying		Chlorophyll Stability Index	
Hybrid	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}
L_7xT_2	3.90	-11.11	-8.43	26.67*	-20.29*	1.85	6.04	-11.40*
L_7xT_3	4.11	-15.56*	-44.13*	-3.33	-36.99*	-14.81	6.15	-16.67*
L_7xT_4	0.00	-2.22	-6.02	30.00*	-3.23	11.11	20.00*	2.63
L_7xT_5	13.11*	4.44	-18.18	20.00*	-42.35*	-29.63*	16.45*	-2.19
L_8xT_1	-10.59	-2.04	-30.00*	-6.23	-14.36	0.00	24.87*	11.31*
L_8xT_2	23.46*	10.20	-42.86*	-22.58*	-41.54*	-17.39	31.55*	11.31*
L_8xT_3	-19.48*	-16.33*	-26.52*	19.35*	4.35	56.52*	19.66*	-4.98
L_8xT_4	23.81*	20.41*	-28.57*	-3.23	-20.69*	0.00	23.24*	6.79
L_8xT_5	19.80*	13.06*	-7.87	32.26*	22.58*	65.22*	17.02*	-0.45
S.E.	0.62	0.67	0.42	0.50	0.37	0.42	0.46	0.53

d_i-Relative heterosis d_{ii}-Heterobeltiosis, * Significant at 5% level

Table 1: Continued

	Drought recovery rate		Root length		Root dry weight		Root: root ratio	
Hybrid	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}	d_i	d_{ii}
L_1xT_1	15.56	73.33*	15.15*	2.70	28.00*	13.07*	14.29*	21.43*
L_1xT_2	4.17	66.67*	11.81*	-4.05	-11.58*	-25.80*	8.33*	-14.29
L_1xT_3	13.67	96.44*	-14.24*	-8.21*	-18.09*	-32.15*	0.00	-14.29
L_1xT_4	-14.89	33.33	-3.12	-5.41*	-17.53*	-29.32*	11.11*	14.29
L_1xT_5	-8.00	53.33*	21.26*	4.05	30.53*	9.54*	4.00	-14.29
L_2xT_1	-24.59	-25.81	-4.53	-10.60*	-2.13	-8.00*	-3.70	-7.14
L_2xT_2	-37.50*	-35.48*	24.79*	12.12*	16.85*	4.00	13.04*	-7.14
L_2xT_3	-34.21*	-19.35	-4.97	-6.96*	-29.55*	-38.00*	-52.00*	-57.14*
L_2xT_4	-36.51*	-35.48*	-9.70*	-3.94	-14.29*	-22.00*	-23.08*	28.57*
L_2xT_5	-18.18	-12.9	23.10*	10.61*	43.82*	28.00*	16.67*	0.00
L_3xT_1	-32.14*	-26.92	22.54*	7.94*	33.33*	14.75*	16.13*	0.00
L_3xT_2	18.64	34.62*	25.55*	6.69*	32.00*	8.20*	3.70	-22.22*
L_3xT_3	-40.85*	-19.23	55.56*	25.31*	51.52*	22.95*	10.34*	-11.11
L_3xT_4	3.45	15.38	8.70*	-6.95*	33.33*	11.48*	-26.67*	-38.89*
L_3xT_5	-34.43*	-23.08	60.58*	36.47*	60.00*	31.15*	14.29*	-11.11
L_4xT_1	-18.87	-6.52	20.87*	7.47*	50.98*	32.76*	29.03*	11.11
L_4xT_2	14.29	39.13*	24.81*	6.96*	54.64*	29.31*	3.70	-22.22*
L_4xT_3	17.65	73.91	-0.78	-16.24*	4.17	-13.79*	3.45	-16.67*
L_4xT_4	-30.91	-17.39	43.58*	23.97*	49.49*	27.59*	6.67	-11.11
L_4xT_5	3.45	30.43	15.79*	-0.77	50.52*	25.86*	-14.29*	-33.33*
L_5xT_1	-38.03*	-46.34*	19.53*	12.75*	38.64*	38.64*	8.33*	0.00
L_5xT_2	0.00	-9.76	-8.77*	-1.96	-3.64*	-9.09*	-10.00	0.00
L_5xT_3	6.98	12.2	-7.14*	-1.96	-19.51*	-25.00*	-45.45*	-45.45*
L_5xT_4	23.29	9.76	5.74	7.84*	-12.98*	-15.91*	13.04*	18.18
L_5xT_5	-7.89	-14.63	-12.98*	-7.18*	-12.05*	-17.05*	4.76	0.00
L_6xT_1	-19.23	-4.55	53.44*	25.75*	49.47*	39.22*	8.33*	0.00
L_6xT_2	-41.82*	-27.27	-1.17	-10.60*	-8.89*	-19.61*	30.00*	18.18
L_6xT_3	-22.39	18.18	-14.82*	-9.09*	-16.30*	-27.45*	0.00	0.00
L_6xT_4	-7.41	13.64	-1.99	-7.58*	-15.22*	-23.53**	-4.35	0.00
L_6xT_5	-33.33*	-13.64	47.40*	42.42*	37.78*	21.57*	23.81*	18.18
L_7xT_1	-23.23	-2.56	39.53*	30.81*	42.27*	30.19*	100.00*	71.43*
L_7xT_2	33.33*	79.49*	-12.90*	-11.62*	-16.60*	-27.36*	18.18*	0.00
L_7xT_3	15.63	98.00*	-14.75*	-12.79*	-17.58*	-29.25*	-8.33*	-15.38
L_7xT_4	32.04	74.36*	4.00	1.74	-9.57*	-19.81*	-28.00*	-30.77*
L_7xT_5	-26.61	2.56	25.81*	10.46*	45.67*	26.42*	-21.74*	-30.77*
L_8xT_1	3.70	16.67*	-8.70*	-4.69*	0.00	-12..07*	-21.43*	-26.67*
L_8xT_2	-47.37*	-37.5	0.75	-2.08	9.28*	-8.62*	-8.33*	-26.67*
L_8xT_3	-27.54	4.17	-8.40*	-11.22*	-6.35*	-22.41*	-15.38*	-26.67*
L_8xT_4	-30.36	-18.75	20.90*	16.18*	-19.19*	1.72	-25.93	-33.33*
L_8xT_5	5.08	29.17	12.78*	8.35*	21.35*	1.72	4.00	-13.33
SE	0.53	0.63	0.37	0.44	0.06	0.08	0.002	0.005

d_i-Relative heterosis d_{ii}-Heterobeltiosis , * Significant at 5% level, L_1-Norungan, L_2-Mattaikar, L_3-CT 9993, L_4-Moroberekan, L_5-NPT 107, L_6-CPMB ACM 03 015, L_7-CPMB ACM 03 017 and L_8-Nootripathu, T_1-MDU 5, T_2-CO 47 (), T_3-IR 50, T_4-ASD 16 and T_5-ASD 18

Table 2: Magnitude of heterosis over mid parent and better parent for physio-morphological traits under moisture stress condition

	Days to 70% RWC				G/P HGW				
Hybrids	MP	BP					SF	HI	GY
L$_1$xT$_1$	2.45*	-2.86*	-1.35*	0.28	-3.73*	0.15*	1.51*	-0.01	0.09
L$_1$xT$_2$	-1.49*	-7.94*	0.41	-0.18	20.36*	0.17*	1.46*	0.03	0.31
L$_1$xT$_3$	-1.36*	-1.46*	-0.79	-1.66*	-17.08*	-0.20*	-2.97*	-0.03	-1.84*
L$_1$xT$_4$	0.34	3.65*	0.88*	0.79	4.45*	-0.01	0.03	-0.01	1.20*
L$_1$xT$_5$	0.07	8.62*	0.85*	0.76	-4.00*	-0.12*	-0.03	0.02	0.24
L$_2$xT$_1$	0.65	-1.63*	1.80*	-1.54*	-22.97*	-0.12*	-0.68	-0.06*	-1.28*
L$_2$xT$_2$	-1.79*	3.98*	-0.04	1.75*	-22.42*	0.40*	-1.08	-0.02	0.41
L$_2$xT$_3$	-0.67	5.86*	-1.14*	-0.63	17.67*	-0.14*	2.16*	0.01	1.54*
L$_2$xT$_4$	0.54	-1.26*	0.28	1.72*	23.56*	-0.10	1.45*	0.06*	0.52
L$_2$xT$_5$	1.27*	-6.94*	-0.90*	-1.31*	4.15*	-0.03	-1.84*	0.02	-1.19*
L$_3$xT$_1$	1.71*	-0.54	-0.17	0.24	-12.39*	0.01	0.06	-0.04	-1.48*
L$_3$xT$_2$	0.31	-0.17	-0.21	-1.42*	-15.34*	-0.12*	-1.07	-0.10*	-0.64
L$_3$xT$_3$	-0.07	-1.45*	1.49*	0.80	32.55*	0.03	1.75*	0.16*	3.99*
L$_3$xT$_4$	2.14*	-3.77*	-1.44*	-0.40	-18.00*	-0.01	-1.52*	-0.01	-2.33*
L$_3$xT$_5$	-4.13*	-1.60*	0.33	0.77	13.23*	0.08	0.78	0.01	0.46
L$_4$xT$_1$	0.70	-1.37*	-0.12	0.52	8.95*	0.07	-0.63	-0.11*	-0.93
L$_4$xT$_2$	2.01*	-1.89*	0.54	-0.04	-5.34*	-0.16*	1.14	0.06*	1.71*
L$_4$xT$_3$	-1.37*	5.27*	-1.21*	0.58	-32.64*	0.23*	1.01	-0.08*	-2.31*
L$_4$xT$_4$	0.16	-0.45	1.86*	-1.02*	17.29*	0.03	1.24	0.08*	1.67*
L$_4$xT$_5$	-1.18*	-5.33*	-1.07*	-0.05	11.73*	-0.17*	-2.76*	0.04	-0.14
L$_5$xT$_1$	-1.30*	1.73*	1.19*	-0.91	12.80*	0.01	1.79*	0.15*	3.05*
L$_5$xT$_2$	-0.99	-2.89*	1.40*	0.33	3.11	-0.05	-0.34	-0.06*	1.79*
L$_5$xT$_3$	3.63*	1.13*	1.35*	0.65	5.65*	0.01	-0.02	0.01	0.42
L$_5$xT$_4$	1.34*	-3.39*	-0.58	-0.50	-6.40*	0.05	-1.29*	-0.03	-1.40*
L$_5$ XT$_5$	-2.68*	3.42*	-3.36*	0.42	-15.16*	-0.01	-0.14	-0.07*	-3.86*

Table 2: Continued

Hybrids	DFF	PH	PT	PL	GPP	HGW	SF	HI	GY
L$_6$xT$_1$	-0.15	0.65	-0.41	1.54*	1.59	-0.02	-1.29*	0.02	0.35
L$_6$xT$_2$	3.91*	2.68*	-2.22*	-1.77*	-0.95	-0.21*	-1.97*	-0.06*	-2.81*
L$_6$xT$_3$	1.53*	-4.69*	1.73*	0.20	14.69*	-0.07	0.05	-0.05*	2.37*
L$_6$xT$_4$	-3.26*	1.77*	-1.70*	0.15	-20.46*	0.03	-1.27*	-0.01	-3.35*
L$_6$xT$_5$	-2.03*	0.19	2.62*	-0.13	5.12*	0.26*	4.48*	0.09*	3.44*
L$_7$xT$_1$	-3.72*	1.62*	1.46*	-0.47	20.32*	-0.12*	1.93*	0.06*	1.93*
L$_7$xT$_2$	-3.16*	0.69	-0.58	-0.53	3.22*	-0.01	-0.85	0.06*	-1.83*
L$_7$xT$_3$	-0.54	-1.22*	-0.73	0.69	-5.07*	0.13*	0.07	-0.02	-2.60*
L$_7$xT$_4$	-0.48	-3.75*	-0.06	0.39	2.56	-0.01	0.90	-0.04	3.08*
L$_7$xT$_5$	7.90*	2.66*	-0.09	-0.09	-21.04*	0.02	-2.05*	-0.07*	-0.58
L$_8$xT$_1$	-0.35	2.39*	-2.39*	0.32	-4.57*	0.01	-2.66*	-0.01	-1.73*
L$_8$xT$_2$	1.21*	2.36*	0.72	1.86*	17.37*	-0.03	2.71*	0.09*	1.06*
L$_8$xT$_3$	-1.17*	-3.40*	-0.68	-0.67	-15.77*	0.05	-2.07*	0.01	-1.56*
L$_8$xT$_4$	-0.46	-0.34	0.74	-1.12*	-2.98	0.02	0.16	-0.04	0.62
L$_8$xT$_5$	0.77	-1.02	1.61*	-0.40	5.95*	-0.04	1.86*	-0.05*	1.61*
S.E.	0.50	0.52	0.41	0.50	1.61	0.05	0.62	0.02	0.33

• Significant at 5 % level

DFF-Days to 50% flowering	PH-Plant height	PT-Productive tillers/plant
PL-Panicle length	G/P-Grains/panicle	HGW-100 grain weight
SF-Spikelet fertility	HI-Harvest index	GY-Grain yield/plant

root dry weight and root: shoot ratio are desirable for drought tolerance in rice. Hence positive heterosis for days to attain 70% RWC, chlorophyll stability index, root length, root dry weight and root: shoot ratio and negative heterosis for leaf rolling, leaf drying and drought recovery rate is desired to exploit the heterosis for drought tolerance in rice.

Days to Attain 70% RWC: The magnitude of heterosis over mid parent varied from -19.48 (Nootripathu x IR 50) to 51.87 per cent (CT 9993 x ASD 18) for days to 70% RWC. Twenty six hybrids exhibited positive significant heterosis over mid parent. Heterobeltiosis per cent ranged from -20.00 (NPT 107 x IR 50) to 35.24 (CT 9993 x ASD 18) for this trait. Further, 15 hybrids were exhibited promising as they had over dominance gene action as measured by the positive significant heterosis over better parent.

Leaf Rolling: Heterosis per cent over mid parent ranged from -59.49 (CPMB ACM 03 017 x MDU 5) to 0.60% (NPT 107 x ASD 18). Twenty seven hybrids exhibited desirable significant negative heterosis for this trait over mid parent. However, additional 12 hybrids exhibited non significant negative heterosis over mid parent. Similarly, twenty six hybrids exhibited negative heterosis over better parent, but only 15 hybrids had significant levels. Heterobeltiosis per cent ranged from -47.50 (Moroberekan x ASD 16) to 48.21(Norungan x ASD 18) for this trait.

Leaf Drying: Twenty five hybrids had desired significant negative heterosis over mid parent. CPMB ACM 03 017 x MDU 5 recorded highest negative heterosis (-66.10) over mid parent followed by CPMB ACM 03 015 x ASD 18(-59.12). Mid parent heterosis ranged between -66.10 and 22.58%, whereas range of heterobeltiosis was also of similar magnitude with minimum limit of -62.96 and maximum limit of 65.22 per cent. Eleven hybrids including above two hybrids, recorded significantly negative heterobeltiosis for this trait.

Chlorophyll Stability Index: The highest relative heterosis (44.19%) and heterobeltiosis (31.22%) were observed in the same hybrid CPMB ACM 03 015 x ASD 18, whereas, the lowest relative heterosis (-1.16%) and heterobeltiosis (-13.62%) were observed in the crosses NPT 107 x ASD 18 and Mattaikar x IR 50 respectively. Among 40 hybrids, 28 hybrids were positive heterosis over mid parent and 10 hybrids showed significantly positive heterobeltiosis over better parent.

$$\text{RWC (\%)} = \frac{\text{Field fresh weight - Oven dry weight}}{\text{Turgid weight - Oven dry weight}} \times 100$$

Drought Recovery Rate: The mid parent heterosis per cent for this trait varied from -47.37 (Nootripathu x CO 47) to 33.33 (CPMB ACM 03 017 x CO 47). Twenty four hybrids showed negative heterosis value but only ten hybrids had significant over mid parent. Heterobeltiosis showed a variation from -446.34 (NPT 107 x MDU 5) to 98.00.00% (CPMB ACM 03 017 x IR 50). Sixteen hybrids showed negative heterosis but only seven hybrids had significant heterosis over better parent.

Root Length: Twenty one hybrids recorded desired significant positive heterosis over mid parent. CT 9993 x ASD 18 recorded the highest positive heterosis (60.58) over mid parent followed by CT 9993 x IR 50 (55.56). Mid parent heterosis ranged between -14.82 and 60.58 per cent, whereas range of heterobeltiosis was also of similar magnitude with minimum limit of -16.24 (Moroberekan x IR 50) and maximum limit of 42.42 (CPMB ACM 03 015 x ASD 18) per cent. Sixteen hybrids including above two hybrids, recorded significantly negative heterobeltiosis for this trait.

Root Dry Weight: The cross CT 9993 x ASD 18 showed the highest per cent of relative heterosis (60.00%), which the cross Mattaikar x IR 50 recorded the lowest value (-29.55%). Similarly, CPMB ACM 03 015 x MDU 5 showed the highest per cent of heterobeltiosis (39.22%), which the same cross Mattaikar x IR 50 recorded the lowest value (-38.00%). Among 40 hybrids, 20 hybrids showed significantly positive heterosis and 14 hybrids showed significantly negative heterosis over mid parent. For this trait heterobeltiosis values were significant and positive in 17 hybrids over better parent.

Root: Shoot Ratio: The lowest heterosis per cent over mid parent (-52.00) and better parent (-57.14) for root: shoot ratio was recorded by same hybrid Mattaikar x IR 50, while the highest heterosis per cent over mid parent (100.00) and better parent (71.43) was recorded by CPMB ACM 03 017 x MDU 5. Fourteen and three hybrids recorded positively significant heterosis over mid parent and better parents, respectively.

Maximum desirable heterosis over mid parent was observed for root: shoot ratio (100.00%), leaf drying (-66.10%), followed by root length (60.58%), root dry weight (60.00%), days to 70% RWC (51.87) and chlorophyll stability index (44.19). Similar trend of desirable heterosis over better parent was observed for root: shoot ratio (71.43%) followed by leaf drying (-62.96%), leaf rolling (-47.50%), root length (42.42%), root dry weight (39.22%) and chlorophyll stability index (31.22%).

More or less, Fifty per cent of the hybrids exhibited desirable significant heterosis over mid parent for days to 70% RWC, leaf rolling, leaf drying, chlorophyll stability index, root length and root dry weight indicating the importance of both additive and non-additive gene action for these traits. Further, 15 hybrids for days to attain 70% RWC, ten hybrids for chlorophyll stability index, 16 hybrids for root length and 17 hybrids for root dry weight recorded significantly positive better parent heterosis indicating different role of these traits in drought tolerance mechanism of parents and their inheritance in the hybrids. Higher levels of days to 70% RWC, chlorophyll stability index, root length and root dry weight are desired for a genotype to be resistant to drought as revealed by the earlier workers [12, 13]. Fifteen hybrids for leaf rolling and 11 hybrids for leaf drying exhibited significantly negative heterosis over better parents, thus hybrids also utilized for future breeding program for development of drought tolerance lines [13]. Thus parents producing non-heterotic hybrids for leaf drying and drought recovery rate may be preferred while aiming to produce drought tolerance hybrids.

From the results of the present investigation and forgoing discussion, it is inferred that hybrids *viz*., CPMB ACM 03 017 x MDU 5 had considerably higher desirable heterosis over mid parent and better parents for physiological traits whereas CT 9993 x IR 50, CT 9993 x ASD 18, CPMB ACM 03 015 x ASD 18 and Moroberekan x ASD 16 exhibited positive and significant favorable heterosis over mid parent and better parents for root traits. These hybrids could be used for drought tolerance variety development programs.

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