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Research Article

Combining ability analysis for drought tolerance in rice (*O. sativa* L.) under reproductive stage

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Abstract
An investigation in rice (*Oryza sativa* L.) was carried out to study the nature of gene action governing drought tolerant and yield contributing traits under reproductive stage drought stress. Nine genotypes from varied sources including land races, pre-release cultures, drought tolerant varieties and tropical *japonica* types were crosses in diallel analysis. The results indicated that predominant role of dominance gene action for all the drought tolerant traits except leaf drying and all the yield contributing traits except days to 50% flowering and plant height. Additive gene action was predominant for plant height, while both additive and dominance gene actions were equal in magnitude for days to 50% flowering and leaf drying. The parents *viz.*, CT 9993, Moroberekan, Nootripathu, Kallurundaikar, PMK 2 and Norungan are found to be promising in producing superior segregants for physiological and morphological mechanisms of drought tolerance along with grain yield. The hybrids Nootripathu / Moroberekan, Nootripathu / CT 9993, MDU 5 / Moroberekan, CPMB ACM 04001 / Moroberekan, CPMB ACM 04001 / CT 9993 and PMK 2 / Kallurundaikar could be recommended for recombination breeding to get useful segregants for yield and drought tolerance. Based on *per se*, *sca* effects and standard heterosis, the hybrids MDU 5 / CT 9993, Nootripathu / Moroberekan, Kallurundaikar / Moroberekan, Kallurundaikar / CT 9993, PMK 2 / Moroberekan and Norungan / Nootripathu are ideal for heterosis breeding.

Key words
Rice, Gene action, combining ability, diallel, heterosis, drought tolerance.

Introduction:

Rice is the fundamental commodity and primary food source for more than half of the world population. As a global food, it has a large influence on human nutrition and food security all over the world. Rice is being cultivated in about 155m ha globally over a wide range of agro-ecological conditions with varying temperature, water regime and soil texture. With the ever increasing population, rice production must be increased by about 40% by 2025 to satisfy the growing demand without adversely affecting the resource base (Khush, 2004). This increased demand will have to be met from the ever shrinking arable land, using less water, less labour and less chemicals. One of the serious constraints to rice production in rainfed upland ecosystems is the insufficient/inconsistent water supply. Rice succumbs to drought much faster than other cereals as it needs anaerobic conditions to complete its life cycle. But, the inherent capacity and genetic variability of rice for adaptations to varied hydrological ecosystems offers a wider scope for improvement of drought tolerance in them. Rice is grown as a rainfed crop in more than half of the rice growing areas in the World, where drought often decreases yield due to insufficient and uneven rainfall during the crop growth period (Kumar and Kujur, 2003). In India, about 33 % of rice growing area is under rainfed lowlands and about 15 % area is under rainfed uplands aggregating to about 58% under rainfed situations (Siddiq, 1996). In coming years, even the available water for agriculture will be reduced to 71 per cent from the present level of 85 per cent. Expanding the irrigation potential has been found remote even with all the available sources of water. Therefore, one third of the country is always under the threat of drought (Sivanappan, 2004). Prolonged drought spell most frequently occurs during vegetative and / or reproductive stages of crop growth. However water shortage around flowering and grain filling stages reduces yield drastically than at any other stages as this affects various physiological mechanisms (Boonjung and Fukai, 1996). When drought occurs during flowering, it reduces grain number and hence grain yield are affected markedly (Lafitte *et al*., 2003). High yielding varieties with inbuilt potential to withstand severe drought situations that prevail during the reproductive stages should be developed in order to overcome the problems of rainfed farmers.

Drought tolerance is a complex character explained to be controlled by a number of morpho-physiological characters being independently controlled by more than two genes (Fukai and Cooper, 1995). The ability of root systems to provide for evapo transpirational demand from deep soil moisture and the capacity for osmotic adjustment are considered as the major drought resistant traits in rice (Nguyen *et al*., 1997). Genotypic differences widely occur for the presence of a deeper and denser root system and the capacity to osmotic adjustment. Hence such morphological and physiological mechanisms of drought tolerance must be thoroughly studied and clearly understood before designing a breeding programme for improving drought tolerance in rice. Hence a study was undertaken to assess the combining ability of rice varieties for physiological and morphological characters of drought tolerance and attributes of grain yield under reproductive stage.

Materials and method

The present investigation was undertaken at Agricultural College and Research Institute, Madurai during 2005 using 9 diverse parents *viz*., CPMB ACM 04001, CPMB ACM 04004, PMK 2, MDU 5, Norungan, Nootripathu, Kallurundaikar, Moroberekan and CT 9993 and the resultant 36 hybrids obtained by crossing the parents in half–diallel fashion. The genotypes were raised in a Randomized block design with 3 replications adopting a spacing of 20cm between rows and 15cm between plants in rows of 3m length.

*Imposing drought stress:*Drought stress was imposed artificially by withholding irrigation at 86th day of sowing *i*.e., during flowering stage for about 20 days in order to study the drought tolerance capacity of genotypes.

Following drought tolerant attributes were recorded at the time of drought stress:

*Days to 70% RWC:*RWC was estimated as suggested by Weatherley (1950) from the 3rd leaf of the selected plant in each replication starting from 7th day of withholding irrigation in alternate days to study the days taken by each genotype to attain 70% RWC.

*Leaf rolling and Leaf drying:*Leaf rolling and drying scores were recorded after attaining 70% on a 0 to 9 scale according to Standard Evaluation System for rice (IRRI, 1996).

*Chlorophyll Content:*Total Chlorophyll content was measured using SPAD meter at five different places in selected plants and averaged to express in lux units.

*Drought recovery rate:*The crop was irrigated after the stress period upto maturity. Drought recovery rate was recorded 10 days after irrigation according to SES for rice.

Observations on other drought tolerant characters *viz*., root length, dry root weight, root volume, root thickness and root / shoot ratio and yield contributing characters *viz*., days to 50 % flowering, plant height, productive tillers / plant, panicle length, filled grains / panicle, 100 grain weight, harvest index and grain yield / plant were recorded on five plants selected at random / replication at the time of harvest. The analysis of variance of RBD and their significance for all the characters were worked out as suggested by Panse and Shukatme (1964). Analysis on combining ability was performed as per Method 2 and Model 1 of Griffings (1956).

Result and discussion

In the present study, the ANOVA for RBD indicated significant differences among the genotypes (Table 1) and the ANOVA for combining ability indicated significance for variance of *GCA* and *SCA* (Table 2).

Combining ability analysis helps breeders to ascertain the nature of gene action governing the traits under study thereby to decide the breeding strategy to be followed for the improvement of traits. In the present study, dominance gene action was predominant for the yield contributing traits *viz*., productive tillers/plant, panicle length, filled grains/panicle, 100 grain weight, harvest index and grain yield/plant. This is in accordance to the findings of Priya (2003) for productive tillers/plant, Banumathy *et al*. (2003) for panicle length and 100 grain weight and Sharma *et al*. (2005) for filled grains/panicle, harvest index and grain yield / plant. The drought tolerant traits *viz*., days to 70% RWC, leaf rolling, chlorophyll content, drought recovery rate, root length, dry root weight, root thickness, root volume and root / shoot ratio are also found to be controlled by dominance gene action. Dominance gene action was reported by earlier workers like Priya (2003) and Anbumalarmathi (2005) for days to 70% RWC and leaf rolling, Ganesh *et al*. (2004) for drought recovery rate and dry root weight, Sheeba (2005) for chlorophyll content, Souframanien *et al*. (1998) for root length and root / shoot ratio and Ekanayake *et al*. (1985) for root volume and root thickness. Heterosis breeding procedures are effective in harnessing dominance gene action to the full extent. However this requires a suitable male sterile line conversion as rice is a self-pollinated crop. Hence hybridization followed by selection in later generations may be recommended for improving these traits.

Additive gene action was predominant in plant height. This is in conformity to the findings of Lavanya (2000) and Michael Gomez (2001). Simple selection procedures and pedigree breeding are sufficient to improve the traits controlled by additive gene action. The characters days to 50% flowering and leaf drying are governed by both additive and dominance gene action. Padmavathy *et al*. (1997) opined the predominance of both additive and dominance gene action for days to 50% flowering and Ganesh *et al*. (2004) for leaf drying. Biparental mating design or reciprocal recurrent selection can be followed which allows further recombination of alleles to produce desirable segregants. These methods can also be well adopted in order to harness the epistatic interactions by way of breaking the undesirable linkages. Diallel selective mating system proposed by Jensen (1970) could also be followed to break such undesirable linkages between two or more genes and to produce desirable recombinants. (Table 3).

Selection of parents is a crucial step in breeding programmes for improving drought tolerance. Parents with high mean performance and general combining ability for drought tolerant and yield contributing characters are ideal for getting desirable segregants. Parents with high *gca* would produce transgressive segregants in F_2 or later generations. This method has been widely used by several workers for analysing the parents critically for their ability to transmit superior performance to their progenies. In the present study, parents with high mean and positive *gca* are preferred for positive characters of grain yield while parents with low mean and negative *gca* are preferred for negative traits of grain yield *viz*., days to 50% flowering, plant height, leaf drying and drought recovery rate.

The mean performance was found to be significantly high for different yield contributing traits and physiological and morphological drought tolerant traits in different parents. Among them, P_5 (Norungan), P_7 (Kallurundaikar) and P_9 (CT 9993) excelled in mean performance for a maximum of nine characters followed by P_6 (Nootripathu) for eight characters; P_3 (PMK 2) and P_8 (Moroberekan) for seven traits each and P_2 (CPMB ACM 04004) for six traits.

Among the parents, the local land races in general recorded good mean performance for morphological drought tolerant traits especially root characters. The parents P_6 (Nootripathu) and P_7 (Kallurundaikar) showed significant mean performance for all the root characters studied while P_5 (Norungan) had high *per se* for four out of five root characters studied along with grain yield/plant besides few yield contributing traits. In contrast, the *japonica* types P_9 (CT 9993) had high mean performance for physiological mechanisms of drought tolerance such as days to 70% RWC, leaf rolling, leaf drying and chlorophyll content along with harvest index while P_8 (Moroberekan) was found to have superior mean performance for days to 70% RWC and chlorophyll content along with harvest index.

This clearly shows that the drought tolerant local land races have an excellent rooting system, which could draw water from deeper layers and could withstand the heavy transpirational water loss. On the other hand, the *japonica* types have a sound physiological basis of drought tolerance, which conserve more water by preventing transpirational water loss.

Based on the general combining ability of the parents, Moroberekan expressed high *gca* effects for a maximum of 15 characters under study except for 100 grain weight, drought recovery rate, root thickness and root/shoot ratio. This was followed by Nootripathu for a maximum of 14 traits *viz*., productive tillers/plant, panicle length, filled grains/panicle, 100 grain weight, spikelet fertility, days to 70% RWC, leaf rolling, leaf drying, root length, dry root weight, root volume, root thickness, harvest index and grain yield/plant. The parent PMK 2 recorded high gca effects for 10 characters *viz*., days to 50% flowering, productive tillers / plant, filled grains / panicle, drought recovery rate, dry root weight, root thickness, root volume, root/shoot thickness, harvest index and grain yield / plant followed by Kallurundaikar and CT 9993 for nine characters each.

Based on both *per se* and *gca*, the parent CT 9993 showed significant mean and *gca* effects for days to 50% flowering, spikelet fertility, physiological traits *viz*., days to 70% RWC, leaf rolling, leaf drying and chlorophyll content along with harvest index. The parent Moroberekkan recorded significant mean and *gca* for yield traits *viz*., plant height, productive tillers/plant, spikelet fertility and harvest index and physiological drought tolerant traits *viz*., days to 70% RWC and chlorophyll content along with root length while the parent Nootripathu registered significant *gca* and mean values for panicle length, 100 grain weight, root traits *viz*., root length, dry root weight, root volume and root thickness along with grain yield/plant. The parent PMK 2 registered significant *per se* and *gca* for productive tillers/plant, filled grains/panicle, root volume, root/shoot ratio, harvest index and grain yield/plant; Kallurundaikar for 100 grain weight, spikelet fertility, root length, dry root weight, root volume, root thickness and root/shoot ratio and Norungan for 100 grain weight, days to 70% RWC, dry root weight, root volume and root thickness.

In the present study it could be assessed that the land races in general, excelled well for root characters while the tropical *japonica* types performed well for physiological mechanisms of drought tolerance. Hence pre-breeding procedures may be followed combining tropical *japonica* types and land races for augmenting physiological and morphological mechanisms of drought tolerance before going in for improvement of grain yield under drought situations (Table 3).

The prime objective of hybridization is to converge the desirable genes present in two or more different parents into a single genetic background and also to create new variability. Rice being a self-pollinated crop, recombination breeding procedures are widely followed for varietal improvement. However, certain hybrids may fail to produce superior segregants due high specific combining ability and/or heterosis present in them. Such hybrids are suited to heterosis breeding procedures after careful male sterile line conversion and restorer identification. Hence hybrids should be analysed carefully before choosing specific breeding procedures. In the present study, the suitability of hybrids to heterosis or recombination breeding procedures is assessed based on their mean performance, specific combining ability and heterosis over a standard variety.

Among the 36 hybrids obtained by crossing 9 parents in half diallel fashion, the hybrids MDU 5 / CT 9993, Nootripathu / Moroberekkan, Kallurundaikar / Moroberekkan and Kallurundaikar / CT 9993 are ideal for improvement of grain yield and yield contributing characters under drought stress through heterosis breeding based on their mean, *sca* and heterosis. MDU 5 / CT 9993 showed improved performance for days to 50 % flowering, productive tillers / plant, panicle length, filled grains / panicle, 100 grain weight, spikelet fertility, harvest index and grain yield / plant along with days to 70 % RWC and root length, while Nootripathu / Moroberekkan satisfied the three criteria for productive tillers / plant, panicle length, filled grains / panicle, 100 grain weight, harvest index and grain yield / plant along with dry root weight, root thickness and root / shoot ratio. Kallurundaikar / Moroberekkan and Kallurundaikar / CT 9993 can also be selected based on their favourable performance for days to 50 % flowering, productive tillers /plant, filled grains / panicle, 100 grain weight, harvest index and grain yield / plant along with days to 70 % RWC and root length in the former and for days to 50 % flowering, filled grains / panicle and harvest index along with days to 70 % RWC, leaf rolling, leaf drying and root thickness in the latter.

Root traits can be improved through heterosis breeding by exploiting the hybrids *viz*., Nootripathu / CT 9993 (root length, dry root weight and root volume), Nootripathu / Moroberekkan (dry root weight, root thickness and root / shoot ratio) and PMK 2 / Moroberekkan (dry root weight and root volume). The hybrids PMK 2 / CT 9993 and Kallurundaikar / CT 9993 are ideal for heterosis breeding for improving physiological drought tolerance mechanisms *viz*., Days to 70% RWC, leaf rolling, leaf drying and chlorophyll content (Table 4).

Recombination breeding allows further recombination of alleles in segregating generations, so that we could obtain genotypes with favourable combination of alleles for the traits under improvement. Selection of such genotypes will not mislead if such characters and genotypes are under the control of additive genetic effects. Hence the hybrids suitable for recombination breeding were selected based on the presence of additive genetic effects *i.e*., significant *gca* effects of the parents and absence of non additive genetic effects *i.e*., non significant *sca* effects of the corresponding hybrids. Such hybrids are believed to throw suitable segregants with favourable combination of alleles for the selected traits.

Based on above said criteria, the hybrids Nootripathu / CT 9993 (for leaf rolling and leaf drying along with filled grains / panicle and spikelet fertility), Nootripathu / Moroberekkan (for days to 70% RWC, leaf rolling and leaf drying), MDU 5 / Moroberekkan (days to 50% flowering, days to 70% RWC and leaf rolling), CPMB ACM 04001 / Moroberekkan and CPMB ACM 04001 / CT 9993 (for panicle length, leaf rolling and leaf drying) are selected for improvement of physiological drought tolerance mechanisms through recombination breeding. The hybrid PMK 2 / Kallurundaikar is ideal for improving root traits *viz*., root thickness and root / shoot ratio along with drought recovery rate through recombination breeding. Only one hybrid *viz*., PMK 2 / Nootripathu could be resorted to recombination breeding for improving grain yield under drought stress. However, the yield contributing traits like filled grains / panicle and spikelet fertility may be improved by recombination breeding using hybrids Nootripathu / CT 9993; harvest index through the hybrids Moroberekkan / CT 9993 and PMK 2 / CT 9993; days to 50% flowering through the hybrids PMK 2 / CT 9993 and CPMB ACM 04004 / Moroberekkan; plant height through CPMB ACM 04004 / Moroberekkan; panicle length through CPMB ACM 04001 / Moroberekkan, CPMB ACM 04001 / CT 9993 and Moroberekkan / CT 9993 and 100 grain weight through CPMB ACM 04004 / Kallurundaikar (Table 5).

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Table 1. ANOVA for various traits

Source	Df	DFF	PH	PT/P	PL	FGP	100 GW	SF	DRWC	LR	LD	CC	DRR	RL	DRW	RT	RV	R/S	HI	GY/P
Replication	2	1.21	3.9	3.07	0.26	0.001	1.47	0.47	0.67	0.01	0.01	0.5	0.09	0.46	0.01	0.28	0.002	0.00001	0.0002	0.19
Treatment	44	235*	1056.76*	32.31*	24.68*	1624.62*	0.17*	264.08*	16.08*	16.97*	5.95*	26.35*	3.58*	35.64*	1.84*	59.37*	0.24*	0.0009*	0.017*	61.57*
Error	88	0.94	5.93	0.73	1.16	23.39	0.0006	4.78	0.51	1.11	1.25	1.86	0.54	0.64	0.004	0.24	0.013	0.00003	0.0001	0.56

* Denotes significant at 5% level

Table 2. ANOVA for combining ability for various traits

Source	**Df**	**DFF**	**PH**	**PT/P**	**PL**	**FGP**	**100GW**	**SF**	**DRWC**	**LR**	**LD**	**CC**	**DRR**	**RL**	**DRW**	**RT**	**RV**	**R/S**	**HI**	**GY/P**
Gca	8	236.68*	1410.06*	23.84*	17.04*	628.39*	0.105*	54.24*	11.66*	7.09*	5.10*	11.96*	1.40*	30.39*	1.58*	54.54*	0.11*	0.0004*	0.006*	30.17*
Sca	36	43.18*	117.19*	7.87*	6.27*	522.24*	0.04*	95.54*	3.96*	5.34*	1.29*	8.08*	1.15*	7.77*	0.40*	12.07*	0.07*	0.0003*	0.006*	18.38*
Error	88	0.314	1.98	0.24	0.39	7.8	0.0002	1.59	0.17	0.37	0.42	0.62	0.18	0.21	0.001	0.08	0.004	0.00001	0.00004	0.19
$\sigma^2 A$	-	42.98	256.01	4.29	3.03	112.84	0.02	9.57	2.1	1.22	0.86	2.06	0.22	5.49	0.29	9.9	0.02	0.00004	0.001	5.45
$\sigma^2 D$	-	43.18	115.21	7.63	5.88	514.44	0.04	93.95	3.79	4.97	0.87	7.46	0.97	7.56	0.4	11.99	0.07	0.0003	0.006	18.19
$\sigma^2 A/\sigma^2 D$	-	0.99	2.22	0.56	0.52	0.22	0.5	0.1	0.55	0.25	0.99	0.28	0.23	0.73	0.73	0.83	0.29	0.13	0.17	0.3

* Denotes significant at 5% level

DFF – Days to 50% flowering; PH – Plant height; PT/P – Productive tillers/plant; PL – Panicle length; FGP – Filled grains/panicle; 100GW – 100 grain weight; SF – Spikelet fertility; DRWC – Days to 70% RWC; LR – Leaf rolling; LD – Leaf drying; CC – Chlorophyll content; DRR – Drought recovery rate; Root length; DRW- Dry root weight; RT – Root thickness; RV - Root volume; R/S – Root / Shoot ratio; HI – Harvest index; GY/P – Grain Yield / plant

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Table 3. Mean performance and gca effects of parents

Parents	Mean performance / gca effects																		
	DFF	**PH**	**PT/P**	**PL**	**FGP**	**100GW**	**SF**	**DRWC**	**LR**	**LD**	**CC**	**DRR**	**RL**	**DRW**	**RT**	**RV**	**R/S**	**HI**	**GY/P**
CPMB ACM	106	114.23	6.7	27.37*	98.87	2.29	65.25	7.67	3	3.67	30.13	1.67	15.63	1.88	7.93	0.87	0.03	0.18	7.87
04001	**0.19**	**2.41***	**-1.93***	**1.76***	**-0.09**	**-0.11***	**-1.11***	**-0.92***	**0.41***	**-0.46***	**-0.33***	**0.04**	**-1.96***	**-0.19***	**-1.45***	**-0.12***	**0.0**	**-0.05***	**-2.01***
CPMB ACM	99.67*	87.80*	8	21.13	113.93*	2.63*	74.65	8.67	1	3.67	34.27*	2.33	14.8	1.96	8.83	0.93	0.04	0.30*	11.46
04004	**-0.42***	**-16.10***	**-1.25***	**-2.30***	**-3.13***	**0.06***	**0.56**	**-1.83***	**-1.65***	**1.18***	**0.24**	**0.40***	**-2.62***	**-0.45***	**-2.39***	**-0.10***	**-0.01***	**0.0**	**-1.22***
PMK 2	101	105.53*	12.27*	23.43	122.43*	2.24	68.92	10.33	1.67	1.67	25.63	1	18.83	2.24	10.83*	1.07	0.05*	0.32*	14.55*
	-0.57*	**2.27***	**1.74***	**-0.2**	**14.92***	**-0.03***	**-2.44***	**-0.22**	**-0.53***	**0.03**	**-0.49***	**-0.57***	**0.26**	**0.17***	**1.25***	**0.07***	**0.01***	**0.02***	**2.20***
MDU 5	80.33*	83.40*	7.6	18.3	86.3	2.15	55.28	10.67	6.33*	6.33	31.67	4.33	15.23	1.08	4	1	0.03	0.21	6.99
	-9.30*	**-14.24***	**-1.15***	**-1.58***	**-9.52***	**-0.05***	**-3.01***	**0.26***	**0.41***	**0.63***	**0.74***	**0.46***	**-1.24***	**-0.53***	**-3.30***	**-0.09***	**0.0**	**-0.02***	**-1.68***
Norungan	107.67	128.7	11.73*	27.17*	99.23	3.00*	73.69	12.00*	0.67	3.67	29.6	1	15.87	2.89*	13.00*	1.33*	0.05*	0.22	15.89*
	1.98*	**5.32***	**-0.70***	**0.03**	**-6.95***	**0.18***	**-2.06***	**0.44***	**0.11**	**0.33**	**-0.28**	**0.28***	**0.52***	**0.26***	**1.35***	**0.15***	**0**	**-0.01***	**0.24**
Nootripathu	113.33	154.03	11.4	26.40*	109.17	2.56*	75.92	11.33	1	2.33	25.83	1	22.33*	3.00*	14.90*	1.27*	0.06*	0.23	14.90*
	6.89*	**18.46***	**2.00***	**0.60***	**2.63***	**0.05***	**1.16***	**0.29***	**0.41***	**-0.40***	**-1.51***	**-0.2**	**1.08***	**0.20***	**1.51***	**0.07***	**0**	**0.03***	**2.21***
Kallurundaikar	111	124.17	11.03	26.43*	83.97	2.85*	84.38*	9	1	3.67	27.6	1	20.87*	3.06*	14.70*	1.47*	0.05*	0.24	13.47*
	4.89*	**10.17***	**0.74***	**0.3**	**-6.47***	**0.05***	**2.16***	**-0.53***	**-0.68***	**0.3**	**-1.18***	**-0.32***	**1.36***	**0.61***	**3.41***	**0.08***	**0.01***	**0**	**-0.06**
Moroberekkan	103.33	90.90*	12.37*	24	105.97	2.25	84.53*	12.67*	3.67	1.67	32.57*	1	22.33*	1.83	9.43	0.93	0.04	0.27*	10.64
	-0.54*	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***	**-0.54***
CT 9993	99.33*	105.70*	10.2	25.63	102.17	2.05	81.14*	13.67*	5.00*	1.00*	34.07*	1	17	1.48	5	0.83	0.05*	0.31*	9.94
	-3.11*	**0.64**	**-0.84***	**0.55***	**4.44***	**-0.13***	**3.21***	**1.75***	**0.87***	**-0.97***	**1.55***	**0.16**	**0.05**	**-0.27***	**-1.53***	**-0.08***	**0**	**0.01***	**-1.21***
Grand mean	102.41	110.5	10.14	24.43	102.45	2.45	73.75	10.67	2.59	3.08	30.15	1.59	18.1	2.16	9.84	1.08	0.04	0.25	11.75
SEd (5%)	0.79	1.99	0.7	0.88	3.95	0.02	1.79	0.58	0.86	0.91	1.11	0.6	0.65	0.05	0.4	0.09	0.005	0.008	0.61
	(0.17)	(0.42)	(0.15)	(0.19)	(0.83)	(0.004)	(0.38)	(0.12)	(0.18)	(0.19)	(0.24)	(0.13)	(0.14)	(0.01)	(0.09)	(0.02)	(0.001)	(0.002)	(0.13)
CD (5%)	1.58	3.98	1.4	1.76	7.9	0.04	3.58	1.16	1.72	1.82	2.22	1.2	1.3	0.1	0.8	0.18	0.01	0.02	1.22

* Denotes significant at 5% level Values in bold denotes *gca* effects Values in Parentheses indicate Standard Error (SE)

Table 4. Hybrids for Heterosis Breeding based on mean performance, *sca* effects and heterosis

Characters	Hybrids chosen	Characters	Hybrids chosen
Days to 50% flowering	P_1 x P_4, P_1 x P_8, P_1 x P_9, P_2 x P_3, P_2 x P_4, P_2 x P_5, P_3 x P_4, P_3 x P_8, P_4 x P_9, P_5 x P_7, P_6 x P_9, P_7 x P_8, P_7 x P_9	Chlorophyll content	P_2 x P_4, P_2 x P_5, P_3 x P_9, P_4 x P_8, P_8 x P_9
Plant height	P_1 x P_3, P_1 x P_5, P_2 x P_4, P_2 x P_5, P_2 x P_7, P_4 x P_7, P_4 x P_8, P_8 x P_9	Drought recovery rate	-
Productive tillers/plant	P_3 x P_4, P_3 x P_7, P_3 x P_8, P_4 x P_6, P_4 x P_9, P_5 x P_6, P_6 x P_7, P_6 x P_8, P_6 x P_9, P_7 x P_8	Root length	P_2 x P_8, P_3 x P_4, P_4 x P_6, P_4 x P_9, P_5 x P_7, P_5 x P_8, P_5 x P_9, P_6 x P_9, P_7 x P_8, P_8 x P_9
Panicle length	P_1 x P_2, P_1 x P_6, P_1 x P_7, P_3 x P_6, P_4 x P_9, P_5 x P_8, P_6 x P_8	Dry root weight	P_1 x P_3, P_1 x P_9, P_3 x P_7, P_3 x P_8, P_4 x P_8, P_5 x P_7, P_6 x P_7, P_6 x P_8, P_6 x P_9
Filled grains/panicle	P_1 x P_2, P_1 x P_6, P_1 x P_8, P_3 x P_4, P_3 x P_6, P_3 x P_9, P_4 x P_9, P_6 x P_8, P_7 x P_8, P_7 x P_9	Root volume	P_3 x P_5, P_3 x P_7, P_3 x P_8, P_5 x P_7, P_6 x P_7, P_6 x P_9, P_8 x P_9
100 grain weight	P_1 x P_8, P_2 x P_3, P_2 x P_8, P_2 x P_9, P_3 x P_5, P_3 x P_7, P_4 x P_5, P_4 x P_6, P_4 x P_7, P_4 x P_9, P_5 x P_6, P_6 x P_8, P_7 x P_8	Root thickness	P_1 x P_8, P_3 x P_5, P_5 x P_9, P_6 x P_8, P_7 x P_9
Spikelet fertility	P_1 x P_2, P_1 x P_3, P_1 x P_6, P_1 x P_9, P_2 x P_7, P_2 x P_8, P_3 x P_6, P_4 x P_8, P_4 x P_9, P_5 x P_6, P_7 x P_9	Root /Shoot ratio	P_1 x P_3, P_1 x P_5, P_3 x P_4, P_4 x P_6, P_5 x P_7, P_6 x P_7, P_6 x P_8
Days to 70% RWC	P_1 x P_7, P_1 x P_9, P_3 x P_6, P_3 x P_9, P_4 x P_5, P_4 x P_9, P_5 x P_6, P_5 x P_8, P_6 x P_9, P_7 x P_8, P_7 x P_9	Harvest index	P_1 x P_2, P_2 x P_6, P_2 x P_7, P_2 x P_8, P_3 x P_5, P_3 x P_6, P_3 x P_7, P_3 x P_8, P_4 x P_6, P_4 x P_9, P_5 x P_6, P_5 x P_9, P_6 x P_8, P_6 x P_9, P_7 x P_8, P_7 x P_9
Leaf rolling	P_1 x P_6, P_1 x P_7, P_2 x P_8, P_3 x P_6, P_3 x P_8, P_3 x P_9, P_4 x P_5, P_5 x P_6, P_5 x P_8, P_5 x P_9, P_7 x P_9	Grain yield/plant	P_1 x P_2, P_2 x P_8, P_3 x P_5, P_3 x P_7, P_3 x P_8, P_3 x P_9, P_4 x P_6, P_4 x P_9, P_5 x P_6, P_6 x P_8, P_7 x P_8
Leaf drying	P_7 x P_9		

P_1 – CPMB ACM 04001; P_2 – CPMB ACM 04004; P_3 - PMK 2; P_4 – MDU 5; P_5 – Norungan; P_6 – Nootripathu; P_7 – Kallurundaikar; P_8 – Moroberekkan; P_9 - CT 9993

Table 5. Hybrids chosen for Recombination Breeding based on *gca* effect of parents and *sca* effect of hybrids

Sl. No.	Characters	Parents with significant *gca* effects	Hybrids chosen based on non significant *sca* effects
1.	Days to 50% flowering	P_2, P_3, P_4, P_8, P_9	P_2 x P_8, P_3 x P_9, P_4 x P_8
2.	Plant height	P_2, P_4, P_8	P_2 x P_8
3.	Productive tillers/plant	P_3, P_6, P_7, P_8	-
4.	Panicle length	P_1, P_6, P_8, P_9	P_1 x P_8, P_1 x P_9, P_8 x P_9
5.	Filled grains/panicle	P_3, P_6, P_8, P_9	P_3 x P_8, P_6 x P_9
6.	100 grain weight	P_2, P_5, P_6, P_7	P_2 x P_7
7.	Spikelet fertility	P_6, P_7, P_8, P_9	P_6 x P_8, P_6 x P_9
8.	Days to 70% RWC	P_4, P_5, P_6, P_8, P_9	P_4 x P_8, P_5 x P_9, P_6 x P_8
9.	Leaf rolling	P_1, P_4, P_6, P_8, P_9	P_1x P_4, P_1x P_8, P_1x P_9, P_4 x P_6, P_4 x P_8, P_4 x P_9, P_6 x P_8, P_6 x P_9
10.	Leaf drying	P_1, P_6, P_8, P_9	P_1 x P_6, P_1 x P_8, P_1 x P_9, P_6 x P_8, P_6 x P_9, P_8 x P_9
11.	Chlorophyll content	P_4, P_8, P_9	P_4 x P_9
12.	Drought recovery rate	P_3, P_7	P_3 x P_7
13.	Root length	P_5, P_6, P_7, P_8	-
14.	Dry root weight	P_3, P_5, P_6, P_7, P_8	P_3 x P_5, P_5 x P_8
15.	Root Volume	P_3, P_5, P_6, P_7, P_8	-
16.	Root thickness	P_3, P_5, P_6, P_7	P_3 x P_7, P_6 x P_7
17.	Root/Shoot ratio	P_3, P_7	P_3 x P_7
18.	Harvest index	P_3, P_6, P_8, P_9	P_3 x P_9, P_8 x P_9
19.	Grain yield/plant	P_3, P_6, P_8	P_3 x P_6
	Overall	**P_8, P_6, P_3, P_7, P_9, P_5**	**P_6 x P_9, P_6 x P_8, P_3 x P_7, P_4 x P_8, P_1 x P_8, P_1 x P_9**

P_1 – CPMB ACM 04001; P_2 – CPMB ACM 04004; P_3 - PMK 2; P_4 – MDU 5; P_5 – Norungan; P_6 – Nootripathu; P_7 – Kallurundaikar; P_8 – Moroberekkan; P_9 - CT 9993