Electronic Journal of Plant Breeding, 4(4): 1271-1279 (Dec 2013)
ISSN 0975-928X

Research Article

Heterosis and combining ability analysis for grain yield and its component traits in aerobic rice (*Oryza sativa* L.) cultivars

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(Received: 28 Nov 2013; Accepted: 26 Dec 2013)

Abstract
An investigation on LxT analysis was carried out with six popular and ten improved cultures to estimate gene action, combining ability and heterosis for yield and drought tolerant traits under aerobic conditions. Both additive and non-additive gene action were found to control the expression of the traits under study. The magnitude of combining ability revealed non-additive genetic variance was higher than the additive variance for all the studied traits. Parents PMK3, RMD(R)1, ARB6, ARB7, ARB8 and CB-04-801 were found to be the good combiners for drought tolerant and yield traits. The crosses RMD(R)1/ARB7, PMK3/ARB8, PMK3/ARB7, ADT43/IR77080-B-34-3 and MDU5/Anjali recorded hight sca effects for grain yield. Crosses PMK3/ARB6, PMK3/ARB8, RMD(R)1/ARB7 and PMK3/ARB7 performed better than the check PMK 3 for most of the traits and showed significance for all the three types of heterosis. The crosses RMD(R)1/ARB7, ADT48/ARB6, PMK3/ARB7 and MDU5/Anjali were identified as the best combinations for aerobic conditions on the basis of high mean, significant *sca* effects and high standard heterosis.
Key words:
Rice, Aerobic, line x tester analysis, combining ability, heterosis, gene action

Introduction:

Rice (*Oryza sativa* L.) is one of the world's most important food crops and a primary source of food for more than half of the world population. In Asia, its main cultivation area, rice provides 35–60% of the calories consumed. It is planted in about 163 million ha annually (FAO, 2013) of the worlds cultivated land (Degenkolbe *et al*., 2013). Among the rice growing countries in the world, India has the largest area under rice crop (about 42.5 million ha, FAO 2013) and ranks second in production next to China. Rice contributes 43 per cent of total food grain production and 46 per cent of total cereal production in India. Rice is the only crop in the world that is grown in most fragile ecosystem and hence second green revolution is possible only if rice research is under taken vigorously and persistently to address specific abiotic and biotic stress problems (Bouman *et al*., 2002).

Water is becoming increasingly scarce and most of the Asian nations including India are expected to face absolute water scarcity in the next 10-15 years, thus, threatening the sustainability of irrigated rice production in Asia. Unlike other cereal crops like wheat, maize, sorghum *etc.*, rice requires more water per unit grain production. Therefore, in order to sustain and to increase the rice production to meet the future demands with limited water supplies, there is a need to genetically alter the basic water requirements of rice. Aerobic rice is one such new concept to decrease water requirements in rice production (Vijayakumar, 2006). The distinguishing future of aerobic production system is that crops are direct seeded in free draining; non-puddled soils where no standing water layer is maintained in the field and roots grow mainly in aerobic environment (Atlin *et al*., 2006). Saving irrigation water and increased water productivity would be possible, if rice is grown under aerobic soil conditions. However, a key component for the success of aerobic system is to develop appropriate cultivars (Sheeba *et al*., 2005).

The current ideotype of aerobic rice cultivation is that it should combine certain traits found in germplasm adapted to the irrigated environment with other traits found in upland germplasm (Okami *et al*., 2012). Adequate tillering, high harvest index and input responsiveness of irrigated cultivars have to be combined with early weed competitiveness and tolerance of continuous mild water deficit of upland cultivars. To combine these traits, breeders have to overcome the potential antagonisms between them. Discovery of the genes, pathways and regulatory networks underlying the above traits would greatly aid the breeding programme (Lafitte and Bennett, 2002).

The success of a plant breeding programme greatly depends on correct choice of parents for hybridization and the gene action involving different economic and drought tolerant traits. Combining ability analysis provides such information so as to frame the breeding programme effectively (Dwivedi and Pandey, 2012). Among the different methods adopted, the Line x Tester analysis has been recommended for early evaluation of parents, because of its simplicity in both experimentation and analysis (Dhillion, 1975). Knowledge on association of grain yield with its component characters and other morpho-physiological traits governing drought tolerance would be of immense use to breeders in improving efficiency of selection for high yield coupled with drought tolerance (Michael Gomez and Rangasamy, 2002). The objectives of this study were to assess the combining ability of ten drought tolerant advanced cultures and heterosis for yield component traits aiming to a parental and hybrid selection and germplasm improvement for breeding programs to increase rice production.

Material and method

Experimental material**:** Sixteen rice genotypes representing six popular varieties with wide compatibility genes and ten elite drought tolerant aerobic cultures with desirable drought tolerance genes were crossed in a Line x Tester mating design to develop 60 F_1 hybrids during Kharif 2007. Six lines of high yielding genotypes have early to mid - early duration and are widely adopted varieties with multiple tolerance to several biotic and abiotic stresses, whereas ten improved drought tolerant testers obtained from several research institutes (Table 1). Crosses were made using wet cloth emasculation method as suggested by Chaisang *et al.* (1967).

Field experiment**:** The experiment was laid out with 60 hybrids and 16 parents replicated two times in a randomized block design (RBD). These genotypes were sown in non - puddled and non - flooded aerobic soil, during Rabi 2007. Each treatment was accommodated in two rows of 1.5 m length with a spacing of 20 cm row to row and 15 cm plant to plant distance in each replication. A uniform population of 20 hills per treatment with single seedling was maintained in each replication. Agronomic and plant protection measures with external inputs such as supplementary irrigation and fertilizers were given at appropriate time as recommended. Observations were recorded for eight agronomic traits like days to 50% flowering, plant height, productive tillers plant^{-1}, panicle length, grains panicle^{-1}, 100 grain weight, harvest index and grain yield plant^{-1} and six drought related physiological traits like spikelet fertility, chlorophyll stability index, days to 70% relative water content, root length, root dry weight and root : shoot ratio. Five randomly selected plants per line were used for recording observations related to various drought tolerance and yield attributing traits as per standard evaluation system for rice (IRRI, 1996). The RWC was calculated using the formula suggested by Weatherly (1950). Chlorophyll stability index in leaf was estimated by spectrophotometeric method as suggested by Koloyereas (1958).

The mean data derived from five plants per replication were subjected to statistical analysis. The analysis of variance was carried out following the procedure by Panse and Sukhatme (1964). The combining ability analysis was done by using Line x Tester mating design as described by Kempthorne (1957). The performance of F_1 hybrids was evaluated on the basis of heterosis estimates (Fonseca and Patterson, 1968) and standard heterosis against the best high yielding variety PMK3 by Virmani *et al.* (1982).

Results and Discussion

The analysis of variance showed significant differences among the materials under study (Table 2). Variance due to parents was significant for all the traits studied, indicating good amount of genetic differences among the parents. Variance due to hybrids was also significant for all the fourteen traits studied. The analysis of variance for combining ability (Table 3) showed significant GCA and SCA variances for all the characters. The results revealed that, dominance variance (σ^2D) was high and additive genetic variance (σ^2A) was low in magnitude for all the traits. The ratio of (σ^2A) / (σ^2D) ranged from zero (root : shoot ratio and harvest index) to 0.024 (100 grain weight).

The observations on partioning of combining ability variance into additive genetic variance and dominance variance indicated role of both additive and dominance gene action. The magnitude of non-additive genetic variance was higher than the additive variance for all the 14 traits. Similar results were also reported by Panwar (2005) and Sharma (2006) for days to 50% flowering, Patil *et al*. (2003) and Rita Binse and Modiramani (2005) for productive tillers plant^{-1}; Ganesh *et al*. (2004) for panicle length; Panwar (2005) for filled grains panicle^{-1}; Manonmani and Fazlullah Khan (2003) for 100 grain weight; Ganesh *et al*. (2004) and Sharma *et al*. (2006) for plant height; Lavanya (2000) for spikelet fertility; Kalita and Upadyaya (2001) for root length; Yogameenakshi *et al*. (2003), Ganesh *et al*. (2004) for root dry weight, root : shoot ratio and chlorophyll stability index; Ganesh *et al*. (2004), and Das *et al*. (2005) for days to 70% relative water content and Gnanasekaran *et al*. (2005) for grain yield plant^{-1}.

In the present study, the estimates of *gca* effects indicated that the female parents ADT43, MDU5, PMK3 and RMD(R)1 were adjudged as the best combiners, since these lines recorded significant *gca* effects for various traits (Table 5). Among the testers, ARB6, ARB8 and CB-04-801 was adjudged to be the good general combiner, as it showed significant *gca* effects for different traits. From the above, it is inferred that ADT43, MDU5, PMK3 and RMD(R)1 among lines and ARB6, ARB8 and CB-04-801 among testers were found to be the best general combiners, since they exhibited high *gca* effects for majority of the traits including drought tolerance and yield.

On the basis of *per se* performance and *gca* effects together, the parents PMK3, MDU5, ARB6, CB-04-801, IR 77080-B-34-3, ARB7 and R-1216-6-1 showed significant mean value and *gca* effects for various yield and drought tolerance traits (Table 5). Based on both mean and *gca* effects of parents for all the characters, PMK3 was considered as best line, MDU5 ranked next in order, while in testers, ARB6 was considered as best followed by IR77080-B-34-3, ARB7 and R-1216-6-1.

The hybrids obtained by Line x Tester fashion in the present investigation were evaluated for their suitability for recombination and heterosis breeding. Nadarajan and Sreerangasamy (1990) suggested that *per se* of hybrids appeared to be a useful index for judging the hybrids. Mean value of hybrids PMK3/ARB7, PMK3/ARB8, RMD(R)1/ARB7, MDU5/ARB8 and PMK3/IR74371-70-1-1 indicated their significant performance for various characters (Table 5). Among the 60 hybrids studied, the cross combinations PMK3/ARB7, PMK3/ARB8 and RMD(R)1/ARB7 were considered as out-standing hybrids based on mean performance.

The second important criterion for the evaluation of hybrids is the specific combining ability effects which could be related with hybrid vigour. The *sca* effects signify the role of non-additive gene action in trait expression. According to Ping and Virmani (1990), *sca* effects are the index to determine the usefulness of a particular cross combination for exploitation of heterosis. The hybrids RMD(R)1/ARB7, PMK3/ARB7, ADT48/R1216-6-1, MDU5/Anjali and ADT43/WAB878-6-27-17-2-P1-HB was adjudged as the specific combiner which showed desirable *sca* effects for various traits (Table 5). Hence, from the above discussion, it could be concluded that two crosses *viz*., RMD(R)1/ARB7 and PMK3/ARB7 were found to have specific combiners for most of the yield contributing and drought tolerant traits including single plant yield.

A hybrid is commercially valuable only when it exhibits significantly high standard heterosis over the best locally adopted variety or hybrid. Biju *et al*.(2006), reported , the presence of exploitable level of heterosis is yet another pre - requisite for the success of hybrid breeding and is recognized as the genetic yield ceiling in areas where yields have already approached their potential. In the present study, the hybrids were evaluated based on all the three types of heterosis. Significant for all the three heterosis over check PMK3 was observed in hybrids PMK3/ARB7, PMK3/ARB8 and RMD(R)1/ARB7 for various traits including single plant yield (Table 5). Hence, these hybrids were adjudged as the best cross combinations for aerobic conditions based on all the three heterosis.

From this study, it was inferred that all of the traits are governed by non-additive gene action. Earlier workers Dwivedi and Pandey (2012) and Manonmani and Fazlullah Khan (2003) reported the presence of non-additive gene action for grain yield and most of the yield contributing and 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. Kalaimani and Kadambavana Sundaram (1988) suggested reciprocal recurrent selection to accumulate the favourable genes will be useful to exploit these types of gene action. The most appropriate breeding technique to exploit this type of gene action will be through heterosis breeding. Apart from this, a breeding strategy like double haploid production through anther culture technique can also be tested (Manonmani and Fazlullah Khan, 2003). The hybrids which showed additive gene action can be improved by pedigree breeding and selection can be postponed to later generations.

The partitioning of cross combinations exhibiting significant *sca* effects and desirable *per se* performance for different traits involved, parents with good x good, good x poor, poor x good and poor x poor combining abilities was made and tabulated (Table 6). The lines PMK3, RMD(R)1, MDU5 and ADT43 were the good general combiners along with significant *per se* performance for different traits comprising of yield and drought tolerant traits. Among the testers, ARB6 and ARB7 were good general combiners along with significant *per se* performance. The cross combination (good x good) of these parents PMK3/ARB7 and PMK3/ARB6 showed significant *sca* effects and high *per se* performance for some of the yield contributing and drought tolerant traits including grain yield plant^{-1}. Hence these parents are considered as potential for the exploitation in varietal development programme. If these hybrids are utilized in pedigree breeding, there is a possibility of isolating high yielding genotypes along with drought tolerance. This is in accordance with the findings of Manonmani and Fazlullah Khan (2003).

The hybrids RMD(R)1/ARB7, PMK3/ARB8 and ADT48/ARB6 recorded significant *sca* effects with desirable *per se* performance for most of the traits including grain yield plant^{-1} involved either with one good and one average combiners (good x average, or average x good). This suggests that high sca effect of any cross combination does not necessarily depend upon the *gca* effects of the parent (Sarsar *et al*., 1986; Ramalingam *et al*., 1993). This is in agreement with the findings of Sarsar *et al*. (1986) and Ramalingam *et al*. (1993). These hybrids in their segregating generations may results into transgressive segregants. To obtain desirable early segregants, the appropriate breeding method would be biparental mating or reciprocal recurrent selection method as reported by Wilfred Manuel and Palanisamy (1989). The crosses of either one poor parent or both the poor combiners (Poor x Poor) like MDU5/ARB6, ADT43/CB-04-801, ADT43/IR77080-B-34-3 and MDU5/Anjali showed significant *sca* and desirable *per se* performance for grain yield plant^{-1} and some of the yield and drought tolerant traits. As these combinations had non-additive gene action, cyclic method of breeding involving selection of desired recombinants and their inter se crossing would be more desirable. This finding is in agreement with Sankarapandian (1986). For getting best segregants from these hybrids selection could be postponed to later generations. The superiority of *sca* effects may be due to complementary gene action or involvement of non-allelic interaction of fixable and non-fixable genetic variance. The crosses involved at least one parent with good general combining ability which indicated that presence of additive x additive or additive x dominance genetic interaction, while, remaining crosses involved poor combiners suggesting the epistatic gene action, which could be mainly due to genetic diversity in the form of heterozygous loci (Ram *et al*., 1998).

High *sca* effects alone may not be the appropriate choice for heterosis exploitation because hybrids with low mean values may also possess high *sca* effects. Further, heterosis value alone may also mislead the identity of superior hybrids. Exploitation of hybrids for heterosis breeding is best judged by *per se, sca* effects and magnitude of heterosis (Table 5). Based on these three criteria, the hybrids RMD(R)1/ARB7, PMK3/ARB7 and PMK3/ARB8 was suitable for heterosis breeding under aerobic condition, since it exhibited desirable mean, *sca* effects and standard heterosis for various traits including grain yield plant^{-1}. Similar findings were reported by Kshirsagar *et al*. (2005). Hence based on the above findings, the hybrids RMD(R)1/ARB7 and PMK3/ARB7 are highly suitable for commercial exploitation of heterosis under aerobic conditions.

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Electronic Journal of Plant Breeding, 4(4): 1271- 1279 (Dec 2013)
ISSN 0975-928X

Table 1. Origin, Parentage and salient features of rice genotypes used in the study

Genotype	Pedigree	Source
Local high yielding varieties		
ADT36	Tiruveni/IR20	Aduthurai, India
ADT43	IR50/Improved white ponni	Aduthurai, India
ADT48	IET11412/IR64	Aduthurai, India
MDU5	*O.glaberimma*/Pokkali	Madurai , India
PMK3	UPLRI7/CO43	Paramakudi, India
RMD(R)1	Selection from TGR75	Ramanathapuram, India
Aerobic rice Cultures		
ARB6	IR64/Buddha	UAS, Bangalore, India
ARB7	IR64/Buddha	UAS, Bangalore, India
ARB8	IR64/Buddha	UAS, Bangalore, India
Anjali	Sneha/RR149-1129	Paramakudi, India
CB-04-801	Swarna/IR42253-55-207	Coimbatore, India
IR74371-70-1-1	IR55419-42/Way Rarem	IRRI, Philippines
IR77080-B-34-3	IR68077-82-2-2-23/IR59548-122-1-4-1	IRRI, Philippines
R-1216-6-1	R671/R371-1	Coimbatore , India
RR-286-1	RR165-1160/RR145-22	Coimbatore , India
WAB878-6-27-17-2-P1-HB	-	Warda, Africa

Table 2. Analysis of variance for agronomic and drought related physiological traits

		Agronomic traits							Physiological traits						
Source	df	DFF	PH	PT	PL	GP	HGW	HI	RL	RDW	R/S	SF	CSI	RWC	SPY
Replication	1	0.01	0.63	0.52	7.87	4.75	0.0001	0.0006	1.54	0.16	0.0001	33.2	5.53	2.16	1.90
Genotypes	75	63.14*	98.30*	9.55*	3.89*	1666.30*	0.1031*	0.0055*	11.63*	6.07*	0.0018*	35.10*	75.42*	4.49*	131.03*
Error	75	2.13	0.51	0.19	0.35	1.70	0.0016	0.0001	0.43	0.03	0.0001	2.87	1.00	0.13	1.04

* Significant at 5% level

DFF-Days to 50% flowering; PH-Plant height (cm); T- Productive tillers plant^{-1}; PL-Panicle length (cm); GP-Grains panicle^{-1}; SF-Spikelet fertility (%0; HGW-100 Grain weight (g); RL-Root length (cm); RDW-Dry root weight (g); R/S-Root : shoot ratio; HI-Harvest index (%); CSI-Chlorophyll stability index; RWC-70% Relative water content; SPY-Grain yield plant^{-1} (g)

Table 3. Mean squares from analysis of variance for combining ability for agronomic and drought related physiological traits

		Agronomic traits							**Physiological traits**						
Source	**df**	**DFF**	**PH**	**PT**	**PL**	**GP**	**HGW**	**HI**	**RL**	**RDW**	**R/S**	**SF**	**CSI**	**RWC**	**SPY**
Replication	1	0.01	0.63	0.52	7.87	4.75	0.00	0.001	1.54	0.16	0.0001	33.2	5.53	2.16	1.9
Hybrids	59	56.49*	103.07*	10.02*	4.08*	1656.44*	0.07*	0.003*	13.50*	7.16*	0.002*	39.75*	41.29*	2.37*	141.71*
Lines	5	306.64*	626.39*	17.92*	23.06*	7235.36*	0.42*	0.002*	43.84*	21.23*	0.0005*	154.05*	45.88*	1.87*	292.17*
Testers	9	93.00*	104.40*	21.97*	0.93*	1717.21*	0.14*	0.009*	7.13*	6.84*	0.002*	24.95*	119.51*	6.44*	225.98*
L x T interaction	45	21.40*	44.66*	6.76*	2.60*	1024.41*	0.02*	0.002*	11.40*	5.66*	0.002*	30.01*	25.13*	1.62*	108.14*
Error	75	2.13	0.51	0.19	0.35	1.7	0.00	0.0001	0.43	0.03	0.0001	2.87	1.00	0.13	1.04
GCA variance		0.71	1.18	0.07	0.03	12.81	0.00	0	0.04	0.03	0	0.2	0.33	0.02	0.68
SCA variance		65.32	122.67	7.33	4.09	1593.68	0.09	0.0019	9.95	5.44	0.0007	32.35	29.51	1.51	100.23
σ^2 A		1.42	2.37	0.13	0.06	25.61	0.00	0	0.09	0.06	0	0.39	0.65	0.03	1.36
σ^2D		65.32	122.67	7.33	4.09	1593.68	0.09	0.0038	9.95	5.44	0.0014	32.35	29.51	1.51	100.23
σ^2A/ σ^2 D		0.022	0.019	0.018	0.015	0.016	0.02	0	0.009	0.011	0	0.012	0.022	0.02	0.014

* Significant at 5% level

DFF-Days to 50% flowering; PH-Plant height (cm); T- Productive tillers plant^{-1}; PL-Panicle length (cm); GP-Grains panicle^{-1}; SF-Spikelet fertility (%0; HGW-100 Grain weight (g); RL-Root length (cm); RDW-Dry root weight (g); R/S-Root : shoot ratio; HI-Harvest index (%); CSI-Chlorophyll stability index; RWC-70% Relative water content; SPY-Grain yield plant^{-1} (g)

Table 4. Top 4 crosses of each trait for per se performance, gca effect, sca effect and standard heterosis

Traits	Per se performance	gca effect	sca effect	Standard heterosis
Days to 50% flowering	ADT36/RR-286-1, ADT48/ARB8, RMD(R)1/ARB7, RMD(R)1/ARB8	ARB 6, RMD(R)1, ADT 48, Anjali	ADT36/RR-286-1, PMK3/Anjali, MDU5/CB-04-801, PMK3/R-1216-6-1	ADT36/RR-286-1, ADT48/ARB8, RMD(R)1/ARB7, RMD(R)1/ARB8
Plant Height (cm)	ADT48/IR77080-B-34-3, MDU5/R-1216-6-1, ADT48/R-1216-6-1, RMD(R)1/R-1216-6-1	IR 77080-B-34-3, R-1216-6-1, ADT 48, MDU 5	ADT43/ARB6, RMD(R)1/R-1216-6-1, PMK3/R-1216-6-1, ADT43/RR-286-1	ADT48/IR77080-B-34-3, MDU5/R-1216-6-1, ADT48/R-1216-6-1, RMD(R)1/R-1216-6-1
Productive tillers	MDU5/ARB6, MDU5/Anjali, ADT48/ARB6, MDU5/ARB8	ARB 6, MDU 5, ARB 7, Anjali	MDU5/ARB6, ADT48/ARB7, ADT43/IR77080-B-34-3, MDU5/Anjali	MDU5/ARB6, MDU5/Anjali, ADT48/ARB6, ADT48/ARB7
Panicle length (cm)	PMK3/ARB8, PMK3/ARB7, PMK3/ARB6, PMK3/IR74371-70-1-1	PMK 3, ADT 43, Anjali, ARB 7	PMK3/ARB8, RMD(R)1/ARB7, ADT48/R-1216-6-1, MDU5/WAB878-6-27-17-2-P1-HB	PMK3/ARB8, PMK3/ARB7, PMK3/ARB6, PMK3/IR74371-70-1-1
Grains/Panicle	RMD(R)1/ARB7, PMK3/ARB7, RMD(R)1/Anjali, PMK3/ARB8	PMK 3, ARB 7, RMD(R)1, Anjali	RMD(R)1/ARB7, PMK3/ARB7, RMD(R)1/Anjali, ADT48/R-1216-6-1	RMD(R)1/ARB7, PMK3/ARB7, RMD(R)1/Anjali, PMK3/ARB8
100 grain weight (g)	RMD(R)1/CB-04-801, ADT43/ARB6, PMK3/IR74371-70-1-1, PMK3/ARB7	PMK 3, ARB 6, RMD(R)1, CB-04-801	ADT36/ARB8, ADT43/WAB878-6-27-17-2-P1-HB, ADT48/R-1216-6-1, ADT36/ARB7	RMD(R)1/CB-04-801, ADT43/ARB6, PMK3/IR74371-70-1-1, PMK3/ARB7
Harvest index (%)	MDU5/WAB878-6-27-17-2-P1-HB, ADT48/ARB8, ADT43/ARB6, ADT43/ARB7	ARB 8, WAB 878-6-27-17-2-P1-HB, RR-286-1, IR 74371-70-1-1	MDU5/WAB878-6-27-17-2-P1-HB, ADT43/ARB6, ADT43/ARB7, ADT48/ARB8	MDU5/WAB878-6-27-17-2-P1-HB, ADT48/ARB8, ADT43/ARB6, ADT43/ARB7
Root length (cm)	ADT48/R-1216-6-1, PMK3/R-1216-6-1, PMK3/RR-286-1, MDU5/R-1216-6-1	R-1216-6-1, PMK 3, ADT 48, WAB 878-6-27-17-2-P1-HB	PMK3/RR-286-1, ADT43/IR77080-B-34-3, RMD(R)1/ARB7, ADT43/WAB878-6-27-17-2-P1-HB	ADT48/R-1216-6-1, PMK3/R-1216-6-1, PMK3/RR-286-1, MDU5/R-1216-6-1
Root dry weight (g)	PMK3/ARB8, PMK3/Anjali, ADT43/IR77080-B-34-3, PMK3/ARB7	PMK 3, Anjali, ARB 7, IR 77080-B-34-3	ADT43/IR77080-B-34-3, PMK3/ARB8, PMK3/Anjali, ADT36/IR74371-70-1-1	PMK3/ARB8, PMK3/Anjali, ADT43/IR77080-B-34-3, PMK3/ARB7
Root : shoot ratio	PMK3/ARB7, RMD(R)1/ARB7, PMK3/ARB8, MDU5/ARB6	PMK 3, ARB 7, RMD(R)1, IR 77080-B-34-3	RMD(R)1/ARB7, PMK3/ARB7, MDU5/ARB6, ADT43/CB-04-801	PMK3/ARB7, RMD(R)1/ARB7, PMK3/ARB8, MDU5/ARB6
Spikelet fertility (%)	ADT43/ARB8, ADT36/ARB8, MDU5/ARB8, MDU5/Anjali	ARB 8, ARB 6, CB-04-801, ADT 43	MDU5/R-1216-6-1, MDU5/Anjali, RMD(R)1/IR77080-B-34-3, ADT48/IR77080-B-34-3	ADT43/ARB8, ADT36/ARB8, MDU5/ARB8, MDU5/Anjali
Chlorophyll stability index	ADT43/ARB8, MDU5/ARB8, PMK3/CB-04-801, ADT36/ARB8	ARB 8, CB-04-801, ARB 6, MDU 5	MDU5/Anjali, RMD(R)1/ARB7, ADT48/IR77080-B-34-3, PMK3/CB-04-801,	ADT43/ARB8, MDU5/ARB8, PMK3/CB-04-801, ADT36/ARB8
Days to 70% relative water content	ADT36/ARB8, MDU5/ARB8, ADT43/WAB878-6-27-17-2-P1-HB, ADT43/ARB6	ARB 8, ARB 6, CB-04-801, ADT 43	ADT48/IR77080-B-34-3, ADT48/R-1216-6-1, ADT36/ARB8, ADT43/RR-286-1	ADT36/ARB8, MDU5/ARB8, ADT43/WAB878-6-27-17-2-P1-HB, ADT43/ARB6
Single plant yield (g)	RMD(R)1/ARB7, PMK3/ARB7, PMK3/ARB8, MDU5/ARB6	ARB 7, PMK 3, ARB 6, ARB 8	RMD(R)1/ARB7, PMK3/ARB8, PMK3/ARB7 , ADT43/IR77080-B-34-3	RMD(R)1/ARB7, PMK3/ARB7, PMK3/ARB8, MDU5/ARB6

Table 5. *Per se* performance, sca effect, and heterosis per cent of top 10 hybrids and general combining ability of parents involved in crosses

Crosses	*Per se* performance	sca effect	Heterosis			GCA of parents
			Average heterosis	Heterobeltiosis	Standard heterosis	
RMD(R)1/ ARB7	56.05	24.11**	236.54**	218.10**	110.28**	A/G
PMK3/ ARB7	48.87	12.09**	120.73**	83.32**	83.32**	G/G
PMK3/ ARB8	43.39	12.66**	118.87**	62.77**	62.77**	G/A
MDU5/ ARB6	33.18	7.49**	58.28**	53.59**	24.46**	P/G
PMK3/ARB6	32.32	-0.81	33.96**	21.25**	21.25**	G/G
ADT48/ ARB6	31.58	7.68**	30.21**	17.38**	18.46**	A/G
ADT43/ CB-04-801	31.42	9.03**	96.13**	85.26**	17.88**	P/A
ADT43/ IR77080-B-34-3	30.29	11.95**	92.72**	85.20**	13.64**	P/P
MDU5/ Anjali	29.68	9.35**	109.16**	46.06**	11.35**	P/P
PMK3/IR74371-70-1-1	27.77	2.39**	22.99**	4.18	4.18	G/A

G: Good combiner; A: Average combiner; P: Poor combiner