Oryza Vol. 52 No.4, 2015 (255-265)

Genetic behavior of some traits of *indica-japonica* rice hybrids

Ashraf M Elmoghazy*, Galal B Anis and Hamdy F EL-Mowafi

Rice Research and Training Center (RRTC), Rice Research Department, Field Crops Research Institute, Agricultural Research Center, 33717, Sakha, Kafr Elsheikh, Egypt

****email: drashrafmoghazy@gmail.com***

ABSTRACT

The objective of this research was to study the genetic behavior of some vegetative, yield and yield component traits at some indica *and* indica-japonica *rice (*Oryza sativa *L.) genotypes and their hybrids in Egypt. Half diallel experiment was conducted to evaluate the performance of 15* F_1 *rice hybrids along with their six parents* i.e., *Giza 178, GZ 6296, PR 78, GZ 9057, G 46B and Large stigma B at Sakha Agricultural Research Station Experimental Farm and Rice Research and Training Center (RRTC), Sakha, Kafr El-Sheikh, Egypt during 2014 and 2015 summer seasons. Analysis of variance revealed highly significant differences among genotypes, parents and crosses for days to heading, plant height, panicle length, panicles plant*$^{-1}$*, panicle weight, 1000-grain weight, spikelets fertility % and grain yield plant*$^{-1}$*. Both general (GCA) and specific (SCA) combining ability variances were found to be highly significant for all characteristics. The ratio of ó*^{2} *gca / ó*^{2} *sca was less than unity for all studied characteristics except for days to heading, indicating the preponderance of non-additive genetic variance in the inheritance of these characteristics. High broad sense heritability estimates observed for all studied characteristics which suggest high component of heritable portion of variance, which is the portion exploited by breeder and that selection for these traits can be achieved directly based on their phenotypic performance. While, heritability estimates in narrow sense were relatively low for the same traits. According to the mean performance for studied characteristics, cluster analysis divided the six rice genotypes into two major branches.*

Key words: *Rice hybrid, general and specific combining ability, heterosis, heritability, cluster analysis*

Rice is the staple food for more than half of the human population, and as such it plays a key role in ensuring food security all over the world (Khush, 2005). Rice crop plays a significant role in Egypt, for sustaining the food self-sufficiency and for exporting. Rice is considered the most popular and important field crop in Egypt for several reasons: as a staple food; as an important exporting crop; as a land reclamation crop for improving the productivity of the saline soils widely spread in Nile Delta and coastal area; and finally it is a social crop in which every person of the farm families could find work in rice fields and gain money during the growing season. In 2005 season, the total rice production in Egypt reached 6.6 million tons with a national average around 10.00 tons ha^{-1} (RRTC, 2006). Further increase in rice production through increased yield per unit area is needed. Continuously, rice breeders and producers looking for new technologies and new promising rice lines which increase rice production with acceptable grain quality. The present world rice area, production and productivity are 158.93 mha, 465.03 mt and 4.36 tons ha^{-1}, respectively (Singh *et al*., 2015). To feed the ever growing population, the targeted rice production of the world, for the year 2030 is envisaged as 771.02 million tons (Alexandratos and Bruinsma, 2012). Development of new elite hybrid rice lines represents one of the most important ways to solve this problem. Hybrid rice, produced from the first generation (F_1) of seeds between a cross of two genetically dissimilar pure line (inbred) parents, represents a relatively new option for Egyptian farmers. Commercial hybrids typically yield 15-25% more than the best inbred varieties grown under similar conditions believed to be the result of “hybrid vigour” or “heterosis” by crossing the two parents (Siddiq, 1997; Singh and Haque, 1999**;** Singh *et al*., 2013). The heterosis advantage of hybrids may be expressed by superiority over inbred varieties in grain yield, panicle size, spikelets panicle^{-1} and productive tillers.

Hybrid varieties are generally developed by the “three-line” or the “two-line” breeding systems. The cytoplasmic male sterile (CMS) lines (called also “A” line) do not produce viable pollen; therefore serve as the female parent in hybrid crosses. Because the (A) line cannot produce viable pollen it must be crossed with another source, the maintainer or (B) line to provide (A) line seed for the future maintenance. (A) and (B) lines are crossed in an isolated plot to maintain a supply of pure seeds of the (A) line. Hybrid seeds are produced by crossing an (A) line with a suitable restorer (R) line in separate isolated plots. The (R) line restores fertility to the seeds harvested from the (A) line and provides desirable traits in the resulting hybrid seeds.

Among the many genetic approaches being explored to break the yield barrier in rice, hybrid rice technology appears to be the most feasible and readily adoptable one. China has successfully demonstrated usefulness of hybrid rice to meet increased demands for rice (Yuan, 1998; Cheng Shi-hua *et al*., 2004; Singh *et al*., 2015). The area cultivated with hybrid rice at China is about 18.05 million ha which represent 60.2% of the total area cultivated with rice (Ju *et al*., 2013). Hybrid rice technology is one such innovative breakthrough that can further increase rice production leading to food security and reduction of poverty in Egypt. Hybrid rice varieties can out yield conventional cultivars by 15-25% under the same input levels. Hence, this technology can be used to break the current yield plateau in rice, where yield levels of the conventional cultivars released have stabilized (El-Mowafi *et al*., 2005).In Egypt, the three line breeding system for hybrid rice is utilized. However, the two lines systems of thermo-sensitive genic male sterility (TGMS), Photoperiod-sensitive genic male sterility (PGMS) and photo-thermo sensitive genic male sterility (PTGMS) are also utilized (El-Mowafi *et al*., 2009). The aim of this research is to study the genetic behavior of some vegetative, yield and yield component characteristics at some *indica* and *indica*/*japonica* rice (*Oryza sativa* L.) genotypes and their hybrids in Egypt.

MATERIALS AND METHODS

This study was carried out at Sakha Agricultural Research Station experimental Farm and Rice Research and Training Center (RRTC), Sakha, Kafr Elsheikh, Egypt, (31°05’36.4"N 30°55’45.6"E and 4m elevation, Google Earth) during the two successive summer seasons 2014 and 2015.

Six *indica* and *indica-japonica* parental rice genotypes *vis*., the four Egyptian genotypes, Giza 178, GZ 6296, PR 78, GZ 9057, and the two maintainer lines G 46B and Large stigma B and their half-diallel 15 F_1s were studied. These genotypes display wide differences of their characteristics due to their different genetic background showed in Table (1).

The six parental genotypes were sown in the summer season of 2014 at three sowing dates, at 15 days intervals to overcome the difference of heading date among them. After 30 days of sowing, seedlings of the parents were transplanted in the experimental field with three rows, of 5 meters long and 20 x 20 cm apart between plants and rows. A half diallel cross was conducted among the six parents in 2014 growing season to produce 15 hybrids. The six parental genotypes and the resulting 15 hybrids were evaluated and arranged in a Randomized Complete Block Design (RCBD) experiment with three replicates in 2015

Table 1. Origin, pedigree and type for the studied parental rice genotypes

Genotypes	Origin	Pedigree	Type
Giza 178	Egypt	Giza 175/Milyang 49	Indica-Japonica
GZ 6296	Egypt	AC 1225/Hualien Yu 202	Indica-Japonica
PR 78	Egypt	IR 58025A/Pusa basmati 1	Indica
GZ 9057	Egypt	GZ 1368/IRAT 112	Indica-Japonica
G46B	China	Erjiu’ai 7/V41B//Zhenshan 97/ Ya’aizao	Indica-Japonica
Large stigma B	China	not available	Indica-Japonica

growing season. All recommended cultural practices were followed to obtain normal growth.

Data were collected according to Standard Evaluation System (SYS) of IRRI, (2014) for eight agronomic traits *i.e*., days to heading (days), plant height (cm), panicle length (cm), panicles plant^{-1}, panicle weight (g), 1000-grain weight (g), spikelets fertility % and grain yield plant^{-1} (g). Data were analyzed according to (Griffing analysis, 1956), method-2, model-1. This is a fixed model and was considered most appropriate as its all requirements were met by the experiment. Variances due to general and specific combining ability were estimated.

Genetic relationships among studied genotypes were measured by similarity of studied agronomic characteristics as reported by Zhang *et al*., (1995) and Dinghuhn and Asch (1999). Analysis for clustering was conducted using the Numerical Taxonomy and Multivariate Analysis system, Ver. 2.1 (NTSYS-PC; Rolhf, 2000). Cluster analysis was conducted using distance matrix with un-weighed pair-group method based on arithmetic mean (UPGMA) to develop the phylogenetic tree (Sneath and Sokal, 1973).

RESULTS AND DISCUSSION

For days to heading, the most desirable mean values towards the earliness were obtained from the parental lines Large stigma B, G46B and the early maturing promising line GZ 6296 with values of 77.0, 88.7 and 91.7 days, respectively. For hybrids, the PR 78 / Large stigma B and GZ 9057 / Large stigma B were the earliest hybrids with values of 84.3 and 85.0 days, respectively. The genotypes Giza 178 and PR 78 were the late parents for heading. Complete to over dominance were observed in most of the hybrids towards taller parents for plant height. The results were variable from 86.7 cm to 130.0 cm among parents and 99.0 cm to 130.7 cm among crosses. Semi-dwarf plants are the favorable type in Ezypt. Parent, Large stigma B had short height (86.7 cm) while PR78 exhibited tallest (130.0 cm) in height. The hybrid PR78 / GZ 9057 scored the highest mean value (130.7 cm). The most desirable mean values towards dwarfism were recorded for the hybrids GZ 6296 / Large stigma B (99.0 cm) and G46B / Large stigma B (101.0 cm). Even when both parents are semi-dwarf, their F_1 hybrid often shows tall stature. Selection of parental lines with appropriate plant height and non-lodging characteristic is important for high yield potential hybrids; Ikehashi *et al*. (1994) and Cao and Zhan (2014).

Regarding the panicle length, the mean values of the six parents ranged from 23.7 cm for the early parent Large stigma B to 29.5 cm for the late parent PR 78 as shown in Table 2. Meanwhile, the F_1 mean values ranged from 20.2 cm to 31.2 cm for the crosses GZ 6296 / Large stigma B and PR 78 / GZ 9057, respectively. These findings indicate the presence of over dominance for long panicle over the short panicles. Concerning panicles plant^{-1}, the parents GZ 9057 and GZ 6296 showed the highest mean values of 26.7 and 23.3 panicles, respectively, while the crosses, G46B / Large stigma B, GZ 6296 / Large stigma B and GZ 6296 / PR 78 recorded the highest mean values of 45.3 and 44.3 panicles, respectively. For panicle weight trait, the two parents G46B and PR78 scored the highest mean values with 7.2 and 6.0g, respectively. On the contrary, Giza 178 and GZ 9057 recorded the lowest mean values among the parents. The hybrids, PR78 / GZ 9057, GZ 6296 / GZ 9057 and PR 78 / G46B scored the highest mean values (> 5.50 g) for this trait.

In case of 1000-grain weight, the parents Large stigma B, PR 78 and GZ 6296 recorded the highest mean values of 34.2, 30.2 and 28.7 g, respectively. On the contrary, Giza 178 and G46B parents recorded the lowest mean values for this trait. Among hybrids, PR 78 / Large stigma B and GZ 9057 / Large stigma B scored the highest mean values for 1000-grain weight with values of 33.0, 32.7 and 30.7, respectively. For spikelet fertility %, parents Giza 178, GZ 6296 and Large stigma B scored the highest mean values of spikelet fertility % with 96.0, 95.6 and 95.5%, respectively. For hybrids, Giza 178 / GZ 6296, G46B / Large stigma B and GZ 6296 / G46B recorded the highest mean values with 97.0, 96.9 and 96.5%, respectively. The highest mean values for grain yield plant^{-1} were obtained from the hybrids, GZ 9057 / Large stigma B (59.6g), PR 78 / Large stigma B (57.4g), PR 78 x G46B (56.3g), Giza 178 / Large stigma (55.3g) and GZ 6296 / G46B (54.7g). The parental genotypes GZ 9057, GZ 6296 and Giza 178 manifested highest grain yield of 44.3, 41.7 and 40.4 g plant^{-1}, respectively.

Table 3 represents the partitioning of total variance among genotypes into general and specific combining ability for studied traits. The mean square

Table 2. Mean performance of studied rice genotypes and their F_1s for the studied characteristics.

Genotypes	DH (days)	Ht (cm)	PnL(cm)	PnP	PnW(g)	TGW (g)	SFP	GYP^{-1}(g)
Giza 178	101.0	108.7	24.7	20.3	4.6	20.9	96.0	40.4
GZ 6296	91.7	103.7	24.2	23.3	5.6	28.7	95.6	41.7
PR 78	101.3	130.0	29.5	19.3	6.0	30.2	90.0	35.4
GZ 9057	92.0	107.0	24.1	26.7	4.6	27.8	93.5	44.3
G 46B	88.7	110.0	26.2	22.7	7.2	26.3	95.2	35.4
Large stigma B	77.0	86.7	23.7	13.0	4.7	34.2	95.5	32.2
Giza 178 x GZ 6296	95.0	116.3	28.2	25.3	5.5	30.7	88.6	53.0
Giza 178 x PR 78	99.7	125.7	26.0	42.0	5.3	28.3	97.0	44.6
Giza 178 x GZ 9057	94.0	122.0	27.2	31.0	5.5	26.3	86.5	51.2
Giza 178 x G 46B	90.0	116.0	25.8	38.7	6.4	25.3	95.9	46.3
Giza 178 x Large stigma B	87.0	126.7	26.2	38.3	5.3	25.3	89.8	55.3
GZ 6296 x PR 78	90.0	108.3	30.1	43.3	5.9	30.1	89.1	50.2
GZ 6296 x GZ 9057	93.0	128.0	28.0	38.3	7.1	28.2	94.5	48.3
GZ 6296 x G 46B	90.0	120.7	27.3	31.3	5.9	26.5	96.5	54.7
GZ 6296 x Large stigma B	89.0	99.0	20.2	44.3	3.9	27.8	95.1	49.1
PR 78 x GZ 9057	90.0	130.7	31.2	32.0	7.3	29.9	86.5	47.0
PR 78 x G 46B	93.0	122.7	30.3	39.0	6.8	28.8	93.7	56.3
PR 78 x Large stigma B	84.3	130.0	28.7	33.0	5.7	33.0	83.7	57.4
GZ 9057 x G 46B	93.0	118.3	27.5	36.0	6.5	29.3	94.7	54.4
GZ 9057 x Large stigma B	85.0	115.7	25.5	37.3	6.6	32.7	94.8	59.5
G 46B x Large stigma B	90.0	101.0	23.1	45.3	4.8	27.5	96.9	51.9
L.S.D. at 0.05%	1.41	2.64	0.71	3.12	0.46	0.47	3.65	2.48
at 0.01%	1.88	3.53	0.95	4.17	0.62	0.63	4.89	3.32

Abbreviations: DH, Days to heading; Ht, Plant Height; PnL, Panicle length; PnP, Panicles $plant^{-1}$; PnW, Panicle weight; TGW, Thousand-grain weight; SFP, Spikelet fertility %; GYP^{-1}, Grain yield $plant^{-1}$.

Table 3. Analysis of variance for all studied traits of the six rice parents and their F_1 hybrids.

S.O.V.	D.f.	DH(days)	Ht(cm)	PnL(cm)	PnP	PnW(g)	TGW(g)	SFP	GY/P^{-1}(g)
Rep.	2	3.06	0.43	0.18	2.11	0.01	0.03	0.14	16.58
Genotypes	20	93.98**	422.77**	21.79**	250.19**	4.11**	26.61**	47.62**	177.21**
Parents	5	242.58**	577.60**	14.49**	64.49**	3.29**	58.16**	15.44**	63.86**
Crosses	14	46.56**	285.20**	23.52**	95.36**	4.29**	16.86**	58.52**	57.19**
P vs. C (H)	1	14.93**	1574.63**	34.30**	3346.5**	5.63**	5.41**	55.86**	2423.1**
Error	40	0.73	2.58	0.19	3.577	0.079	0.08	4.91	2.269
GCA	5	93.65**	256.49**	15.54**	5.26**	2.41**	23.11**	19.77**	7.48**
SCA	15	10.56**	102.40**	4.51**	109.44**	1.02**	4.13**	14.57**	76.24**
Error	40	0.24	0.86	0.06	1.19	0.03	0.03	1.63	0.76
CA/SCA	---	1.13	0.31	0.43	0.01	0.30	0.70	0.18	0.01

*, ** significant at 0.05 and 0.01 levels, respectively. Abbreviations: DH, Days to heading; Ht, Plant Height; PnL, Panicle length; PnP, Panicles $plant^{-1}$; PnW, Panicle weight; TGW, Thousand-grain weight; SFP, Spikelet fertility %; GY/P^{-1}, Grain yield $plant^{-1}$.

estimates for these traits showed highly significant differences among genotypes (parents and crosses as well as their interaction) for all studied traits. These results clearly showed the amount of variability that does exist among the tested genotypes and hence, the ability for further development through selection in the studied genotypes as well as their segregating generations. These findings are coherent with that of Geetha *et al.,* (1994), Singh *et al.,* (2001), El-Refaee (2002), Tiwari *et al*., (2011) and Dutta *et al*., (2013).

Combining ability estimates revealed that both general and specific combining ability variances were highly significant for all studied traits, which indicate the importance of both additive and non-additive genetic variance in determining the inheritance of these traits. However, the magnitude of GCA/SCA was lower than unity in all studied traits except days to heading. The results suggest the relative importance of non-additive gene action in controlling plant height, panicle length, panicles plant^{-1}, panicle weight, 1000-grain weight, spikelets fertility % and grain yield plant^{-1}. These results suggest that selection in late generation would be effective which is in agreement with the results of Hammoud (2004) and Sedeek (2006).

General combining ability effects for studied traits are presented in Table 4. The estimated values of GCA for days to heading were highly significant and negative (desirable) for parents G46B (-0.61) and Large stigma B (-6.11). Hence, these genotypes could be considered as good combiners for early maturing. On the contrary, highly significant positive estimates (undesirable) of GCA effects were detected for the two genotypes Giza 178 (3.68), and PR 78 (2.68). These estimates could help in identifying which parental lines would give hybrids of desirable duration. Upadhyay and Jaiswal (2015) obtained similar results for different genotypes using line x tester design.

With respect to plant height, three genotypes, GZ 6296, G46B, and Large stigma B were the best combiners with their GCA estimates being negative and highly significant (desirable) with values of -3.67, -1.29, and -7.92, respectively. On the contrary, three rice cultivars showed positive highly significant (undesirable) estimates varying from 1.88 for Giza 178 to 8.54 for PR 78. The negative values of GCA effects which mean decreased plant height could be useful to breed short stature rice hybrids. Regarding panicle length, data in Table 4 revealed that the rice cultivars, PR 78, GZ 9057 and G46B showed high, significant and positive (desirable) estimates of general combining ability effects. These rice cultivars appeared to be good combiners in rice crosses for this trait. On the other hand, the rest of cultivars gave negative highly significant (undesirable) estimates of general combining effects except G46B. This means that these rice cultivars seem to be poor combiners in rice crosses.

Data in Table 4 revealed that highly significant GCA effects of either positive or negative nature for two parental genotypes with respect to panicles plant^{-1}. Positive and highly significant (desirable) value

Table 4. Estimates of general and specific combining ability effects of parents and their F_1 hybrids for all studied traits.

Parents and crosses	DH	Ht	PnL	PnP	PnW	TGW	SFP	GYP^{-1}
GCA								
Giza 178	3.68**	1.88**	-0.40**	-1.36**	-0.54**	-2.69**	0.00	-0.63*
GZ 6296	0.26	-3.67**	-0.46**	0.31	0.13*	0.17**	0.67	0.32
PR 78	2.68**	8.54**	2.42**	0.14	0.20**	1.40**	-2.46**	-1.23**
GZ 9057	0.10	2.46**	0.22**	0.14	0.12*	0.33**	-0.73	1.60**
G46B	-0.61**	-1.29**	0.07	1.10**	0.80**	-1.16**	2.30**	-0.23
Large stigma B	-6.11**	-7.92**	-1.85**	-0.32	-0.71**	1.94**	0.21	0.17
L.S.D. at 0.05%	0.32	0.60	0.16	0.71	0.10	0.11	0.83	0.57
at 0.01%	0.43	0.80	0.21	0.95	0.14	0.14	1.12	0.76
SCA								
Giza 178 x GZ 6296	-0.12	2.55**	2.48**	-6.02**	0.01	4.76**	-4.88**	5.27**
Giza 178 x PR 78	2.13**	-0.32	-2.60**	10.81**	-0.32*	1.12**	6.65**	-1.57*
Giza 178 x GZ 9057	-0.95*	2.10*	0.81**	-0.19	-0.04	0.17	-5.58**	2.18**
Giza 178 x G46B	-4.24**	-0.15	-0.41	6.52**	0.24	0.70**	0.75	-0.88
Giza 178 x Large stigma B	-1.74**	17.14**	1.87**	7.60**	0.66**	-2.38**	-3.25**	7.72**
GZ 6296 x PR 78	-4.12**	-12.11**	1.56**	10.48**	-0.33*	0.06	-1.96	3.09**
GZ 6296 x GZ 9057	1.46**	13.64**	1.70**	5.48**	0.98**	-0.73**	1.71	-1.62*
GZ 6296 x G46B	-0.83	10.05**	1.18**	-2.48*	2.01**	-1.01**	0.75	6.60**
GZ 6296 x Large stigma B	3.67**	-4.99**	-4.00**	11.93**	-1.43**	-2.81**	1.44	0.60
PR 78 x GZ 9057	-3.95**	4.10**	1.98**	-0.69	1.08**	-0.30*	-3.13**	-1.37
PR 78 x G46B	-0.24	-0.15	1.26**	5.35**	-0.14	0.09	1.08	9.74**
PR 78 x Large stigma B	-3.41**	13.80**	1.58**	0.77	0.33*	1.23**	-6.90**	10.43**
GZ 9057 x G46B	2.34**	1.60	0.67**	2.35*	-0.29	1.63**	0.31	5.00**
GZ 9057 x Large stigma B	-0.16	5.55**	0.59*	5.10**	1.30**	1.96**	2.48*	9.71**
G46B x Large stigma B	5.55**	-5.36**	-1.67**	12.14**	-1.23**	-1.71**	1.61	3.94**
L.S.D. at 0.05 %	0.88	1.66	0.44	1.95	0.30	0.29	2.29	1.55
at 0.01 %	1.18	2.22	0.59	2.61	0.39	0.39	3.10	2.10

was recorded for the genotype G46B (1.10). In this case, this cultivar could be considered as good combiner for higher panicles plant^{-1}. Data in Table 4 revealed that significant and highly significant GCA effects of either positive or negative estimates for all parental genotypes with respect to panicle weight were recorded. Results revealed that four rice cultivars namely, GZ 6296, PR 78, GZ 9057, and G46B showed positive significant and highly significant (desirable) estimates of general combining ability effects for panicle weight. These rice cultivars appeared to be good parental combiners in rice crosses for this trait. Thousand-grain weight is one of the chief yield components for which genotypes with significantly positive GCA effects are needed. Large stigma B, PR 78 and GZ 9057 had highly significant and positive (desirable) GCA values of 1.94, 1.40 and 0.33, respectively among parents. These results agreed with the results reported by Rosamma and Vijayakumar (2005), Kumar *et al*., (2007), Akter *et al*., (2010), Latha *et al*., (2013) and Aditya and Bhartiya (2015).

For spikelets fertility %, only one parent (G46B) manifested high significant positive GCA estimate of 2.30 for this trait. This genotype could be considered as good combiner for high spikelets fertility %. Swamy *et al*., (2003) identified two good combiner parents for improved fertility percentage in rice. The results in Table 4 revealed that GZ 9057 exhibited positive and highly significant (desirable) value of GCA effects for grain yield plant^{-1} with value of 1.60. The genotypes indicated positive high significant values could be used in rice crossing program as good combiners for high grain yield plant^{-1}. Similar findings have been reported by Rogbell *et al*. (1998) Swamy *et al*. (2003), Elmoghazy (2007), Petchiammal and Kumar (2007) and Saleem *et al*. (2010) for different genotypes.

Estimates of specific combining ability (SCA) effects for F_1 hybrids are shown in Table 4. For days to heading and plant height, negative specific combining ability effects were desirable where as in other traits positive specific combining ability effects were required. For SCA effects of days to heading, six hybrids showed negatively significant and highly significant desirable estimates. The values of SCA effects ranged from -0.95 to -4.24 for Giza 178 / GZ 9057 and Giza 178 x G46B, respectively. Five hybrids revealed desirable positive and highly significant SCA effects and ranged from 1.46 for GZ 6296 / GZ 9057 to 5.55 for G46B / Large stigma B. For plant height, significant and high significant negative or positive SCA effects were recorded in eleven crosses for plant height. Three hybrids showed negative values (desirable) for SCA effects. The hybrid GZ 6296 / PR 78 recorded the highest value of SCA effect (-12.11). Eight crosses showed significant and highly significant positive SCA effects. The hybrids showing significant negative SCA effects may be useful in exploitation of heterosis due to their desirable stature.

For panicle length, 14 hybrids showed desirable positive significant and highly significant estimates. The values ranged from 0.59 to 2.48. The hybrid Giza 178 / GZ 6296 recorded the highest value for SCA effects of 2.48. For panicles plant^{-1}, ten combinations (desirable) recorded positive significant and highly significant values which ranged between 2.35 for GZ 9057 / G46B and 12.14 for G46B / Large stigma B. Six hybrids recorded desirable positive significant and highly significant values of SCA effects for panicle weight which ranged from 0.33 to 2.01 for hybrids PR 78 / large stigma B and GZ 6296 / G46B, respectively. For 1000-grain weight, six hybrids recorded positive highly significant (desirable) SCA effects. Hybrid Giza 178 / GZ 6296 indicated maximum SCA value of 4.76. These results are similar with those of Rosamma and Vijayakumar (2005) and Sharma (2006) who identified various good general combiners for the improvement of 1000-grain weight in rice. Regarding spikelets fertility %, two hybrids; Giza 178 / PR 78 and GZ 9057 / Large stigma B expressed positive significant and highly significant (desirable) SCA estimates of 6.65 and 2.48, respectively. Five hybrids expressed non-preferable high significant negative SCA effects. These results are similar with those of Panwar (2005) who adjudged some best hybrids based on high SCA effects and mean performance for spikelets fertility from a half diallel experiment in rice. It is obvious that ten out of the 15 F_1 crosses showed positive highly significant estimates of SCA effects for grain yield plant^{-1}. Such estimates were maximized in the hybrids PR 78 / Large stigma B (10.43), PR 78 / G46B (9.74) and GZ 9057 / Large stigma B (9.71). These results indicated that non-additive genetic effect were predominant in these particular combinations of rice hybrids for grain yield plant^{-1}.

This part of investigation aimed to study the magnitude of the genetic variance components *i.e*. additive genetic variance ($ó^2$ A) and dominance genetic variance ($ó^2$ D) to utilize these components in estimating of heritability in broad and narrow sense for the studied traits. The results in Table 5 showed that the non-additive or dominance genetic variance as a portion of the total genetic variance was larger than the additive genetic variance for most of studied traits. Both were significant and positive for all studied traits except additive genetic variance (ó2 A) for panicles plant^{-1}. Higher estimates for non-additive or dominance genetic variance was computed for plant height, panicle length, panicles plant^{-1}, panicle weight, spikelets fertility % and grain yield plant^{-1} traits in comparison with its corresponding estimates of additive genetic variance Table 5. This result indicated that dominance genetic variance played the major role compared to the additive variance in the inheritance of these traits. These results were in general agreement with those reported by El-Refaee (2002), El-Mowafi and Abou Shosha (2003), Ahmed (2004), Hammoud (2004), Abd El-Hadi and El-Mowafi (2005), El-Mowafi *et al.*, (2005), Sedeek (2006), Awad Allah (2006), Elmoghazy (2007) and Abd Allah (2008).Heritability in narrow sense is an indicator of the efficiency of selection procedure in identifying the superior genotypes. Heritability estimates in broad sense were high for all studied traits, while heritability estimates in narrow sense were relatively low for the same traits except days to heading and 1000-grain weight (Table 5). This further suggested that a major part of the total phenotypic variance for these traits was due to dominance genetic variance and environmental effects. These findings led to conclude that selection for such traits must be done in the late generations. These results in general agreement with those reported by El-Mowafi (1994), Hammoud (1996), El-Refaee (2002), Hammoud (2004), Awad Allah (2006), Abd Allah (2008), Anis (2009) Tiwari *et al.*, (2011) and Dutta *et al.*, (2013).

The heterosis is the measure of superiority of the hybrid over its parents. It is expressed as the percentage deviation of F_1 mean performance from the better parent, mid-parent or best commercial cultivar. Estimates of heterosis over better (H_{BP}) and mid-parent (H_{MP}) for all studied traits are presented in Table 6. For days to heading, the estimates revealed that most of crosses (12 crosses) exhibited desirable significant and highly significant negative heterotic values towards earliness for better-parent. The highest negative values were recorded for the hybrids PR 78 / Large stigma B (-16.78%) and Giza 178 / Large stigma B (-13.86%). Nine hybrids showed significant and highly significant negative heterotic effects (desirable) relating to H_{MP} varying from -1.38 for the hybrid Giza 178 x GZ 6296 to -6.90 for PR 78 x GZ 9057. These findings indicated that heterosis can be used to get earliness in rice hybrids. In general the results are in agreement with those reported by El-Refaee (2002), El-Mowafi and Abou-Shousha (2003), Ahmed (2004), Hammoud (2004), El-Mowafi *et al.*, (2005), Awad-Allah (2006), Elmoghazy (2007), Abd Allah (2008), El-Diasty *et al.*, (2008) and Zhou *et al*., (2012).

For plant height, the results revealed that most of the 15 studied F_1 hybrids exhibited undesirable positive and significant heterotic values, 8 and 12 hybrids towards tallness for H_{BP} and H_{MP}, respectively except the cross combination GZ 6296 / PR 78 which exhibited negative high significant values towards shortness for H_{BP} and H_{MP}. Therefore, it could be concluded that the hybrid GZ 6296 / PR 78 could be of practical interest in rice breeding programs for the short stature plant.

Table 5. Estimates of additive ($ó^2$ A), dominance ($ó^2$ D) genetic variances, environmental variance ($ó^2$ E) and heritability in broad (h^2_b) and narrow (h^2_n) senses for all studied traits

Genetic componentsTraits	$ó^2$ A	$ó^2$ D	$ó^2$ E	Heritability	
				h^2_b %	h^2_n %
Days to heading	20.77	10.31	0.73	99.22	66.30
Plant height	38.52	101.54	2.58	99.39	27.33
Panicle length	2.75	4.44	0.19	99.13	37.93
panicles plant^{-1}	26.04-	108.25	3.58	98.59	31.22
Panicle weight	0.34	0.99	0.08	98.10	25.41
1000-grain weight	4.74	4.10	0.10	99.68	53.49
Spikelet fertility %	1.29	12.93	4.91	89.68	10.18
Grain yield plant^{-1}	17.18	75.48	2.27	98.71	29.11

Table 6. Estimates of heterosis relative to mid-parent (H_{MP}%) and better-parent (H_{BP}%) for the studied traits.

Hybrids	Days to heading		Plant height		Panicle length		Panicles plant^{-1}	
	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%
Giza 178 x GZ 6296	-1.38*	-5.94**	9.58**	7.06**	15.36**	14.19**	16.03*	8.57
Giza 178 x PR 78	-1.48*	-1.64*	5.31**	-3.33**	-4.12**	-11.98**	111.76**	106.56**
Giza 178 x GZ 9057	-2.59**	-6.93**	13.14**	12.27**	11.41**	10.14**	31.91**	16.25**
Giza 178 x G 46B	-5.10**	-10.89**	6.10**	5.45**	1.51	-1.40	79.84**	70.59**
Giza 178 x Large stigma B	-2.25**	-13.86**	29.69**	16.56**	8.28**	6.08**	130.00**	88.52**
GZ 6296 x PR 78	-6.74**	-11.18**	-7.28**	-16.67**	12.05**	1.92	103.13**	85.71**
GZ 6296 x GZ 9057	1.27	1.09	21.52**	19.63**	16.02**	15.86**	53.33**	43.75**
GZ 6296 x G 46B	-0.18	-1.82*	12.95**	9.70**	8.61**	4.46**	36.23**	34.29**
GZ 6296 x Large stigma B	5.53**	-2.91**	4.03**	-4.50**	-15.40**	-16.28**	144.04**	90.00**
PR 78 x GZ 9057	-6.90**	-11.18**	10.27**	0.51	16.29**	5.65**	39.13**	20.00**
PR 78 x G 46B	-2.11**	-8.22**	2.22*	-5.64**	8.86**	2.71*	85.71**	72.06**
PR 78 x Large stigma B	-5.42**	-16.78**	20.00**	0.00	7.96**	-2.71*	104.12**	70.69**
GZ 9057 x G 46B	2.95**	1.09	9.06**	7.58**	9.42**	5.10**	45.95**	35.00**
GZ 9057 x Large stigma B	0.59	-7.61**	19.45**	8.10**	6.77**	5.81**	88.24**	40.00**
G 46B x Large stigma B	8.65**	1.50	2.71*	-8.18**	-7.29**	-11.72**	154.21**	100.00**
L.S.D. at 0.05%	1.22	1.41	2.29	2.65	0.62	0.72	2.70	3.12
at 0.01%	1.63	1.89	3.07	3.55	0.83	0.96	3.62	4.18

Hybrids	Panicle weight		1000-grain weight		Spikelet fertility%		Grain yield plant^{-1}	
	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%	H_{MP}%	H_{BP}%
Giza 178 x GZ 6296	9.00*	-0.84	23.87**	7.09**	-7.52**	-7.68**	29.06**	27.05**
Giza 178 x PR 78	-0.50	-12.53**	10.84**	-6.19**	4.30*	1.08	17.62**	10.34**
Giza 178 x GZ 9057	18.61**	17.63**	8.01**	-5.34**	-8.67**	-9.86**	20.85**	15.56**
Giza 178 x G 46B	9.01*	-11.05**	7.27**	-3.74**	0.31	-0.10	22.18**	14.55**
Giza 178 x Large stigma B	15.39**	13.99**	-8.05**	-25.93**	-6.25**	-6.46**	52.35**	36.82**
GZ 6296 x PR 78	2.28	-1.55	2.32**	-0.22	-4.06*	-6.87**	30.23**	20.39**
GZ 6296 x GZ 9057	40.16**	28.48**	0.06	-1.51	-0.09	-1.22	12.42**	9.14**
GZ 6296 x G 46B	38.61**	22.75**	-3.70**	-7.67**	1.19	0.94	42.00**	31.21**
GZ 6296 x Large stigma B	-23.82**	-29.92**	-11.66**	-18.81**	-0.47	-0.52	32.98**	17.78**
PR 78 x GZ 9057	37.49**	21.74**	3.22**	-0.88	-5.72**	-7.45**	18.01**	6.18*
PR 78 x G 46B	2.52	-6.01	2.01**	-4.53**	1.22	-1.51	59.11**	59.01**
PR 78 x Large stigma B	7.43	-4.55	2.64**	-3.41**	-9.83**	-12.42**	69.85**	62.09**
GZ 9057 x G 46B	10.50**	-9.25**	8.26**	5.40**	0.41	-0.49	36.58**	22.83**
GZ 9057 x Large stigma B	42.39**	41.83**	5.54**	-4.39**	0.28	-0.80	55.68**	34.38**
G 46B x Large stigma B	-19.70**	-33.84**	-8.98**	-19.49**	1.66	1.47	53.72**	46.78**
L.S.D. at 0.05%	0.40	0.47	0.41	0.47	3.17	3.66	2.15	2.49
at 0.01%	0.54	0.62	0.55	0.63	4.24	4.89	2.88	3.33

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

Heterotic effect over H_{BP}% ranged from -3.33% for Giza 178 x PR 78 to 16.67% for GZ 6296 x PR 78. Similar results were obtained by Hammoud (1996), El-Refaee (2002), El-Mowafi (2001), Ahmed (2004), Hammoud (2004), Elmoghazy (2007), El-Diasty *et al.*, (2008) and Anis (2009). For panicle length, as evident from Table 6, significant and highly significant positive (desirable) heterotic effects were estimated for nine hybrids for the H_{BP}. The highest estimates were detected for the crosses GZ 6296 / GZ 9057 (15.86%) and Giza 178 / GZ 6296 (14.19%). The H_{MP} was positive significant and highly significant (desirable) in eleven hybrids. The highest H_{MP} were 16.29, 16.02 and 15.36 12.05% for the crosses, PR 78 / GZ 9057, GZ 6296 / GZ 9057 and Giza 178 / GZ 6296, respectively. For panicles plant^{-1}, data revealed that 14 hybrids had highly positive significant estimates over H_{BP} which ranged from 16.25 % for the hybrid Giza 178 / GZ 9057 to 106.56 % for the hybrid Giza 178 / PR 78. Meanwhile, positive significant and highly significant (desirable) H_{MP} recorded for all hybrids for this trait. The highest value was 144.04 % for the cross GZ 6296 / Large stigma B and the lowest value was 16.03 % for Giza 178 / GZ 6296.

For panicle weight trait data in Table 6 showed positive highly significant heterosis (desirable) were detected for six hybrids as deviation from the better parent value and ranged from 41.83% for the hybrid GZ 9057 / Large stigma B to 13.99% for hybrid Giza 178 / Large stigma B. Meanwhile, most of the hybrids had positive significant and highly significant H_{MP}. The highest values were recorded for the hybrids GZ 9057 / Large stigma B and GZ 6296 / GZ 9057 with values of 42.39 and 40.16%, respectively. For 1000-grain weight, most of the hybrids showed negative high significant (undesirable) H_{MP} for this trait. The two hybrids Giza178 / GZ 6296 and GZ 9057 / G46B showed positive high significant values for better parent with values of 7.09 and 5.40%, respectively. Ten hybrids had positive high significant H_{MP} estimates, the highest hybrid was Giza 178 / GZ 6296 with value of 23.87% and the lowest hybrid was PR 78 / G46B with value of 2.01%. With respect to spikelets fertility %**,** results revealed that six hybrids had negative highly significant estimates of H_{BP} that ranged from -6.46% for hybrid Giza 178 / Large stigma B to -12.42% for hybrid PR 78 / Large stigma B. The hybrid Giza 178 / PR 78 is the only one recorded positive significant (desirable) H_{MP} with value of 4.30%. As shown in Table 6, desirable H_{MP} was positive significant in all hybrids for grain yield plant^{-1} trait. The highest estimates were detected for PR 78 / Large stigma B (62.09 %) and PR 78 / G46B (59.01 %). Moreover, positive high significant values of H_{MP} were estimated for all hybrids. The highest value (69.85 %) was recorded for the cross PR78 / Large stigma B and the lowest value (12.42 %) for the cross GZ 6296 / GZ 9057. Positive heterosis effects for grain yield plant^{-1} have previously obtained by Attia (2001), El-Refaee (2002), and Abd Allah (2008).

The Similarity matrix based on the eight agronomic characteristics of the studied six rice genotypes (Table 7) was used to draw the phylogenetic tree for these genotypes (Figure 1). The tree divided the six genotypes into two main branches, G64B at

Table 7. Similarity matrix for the studied six rice genotypes based on eight agronomic characteristics

Genotypes	Giza 178	GZ 6296	PR 78	GZ 9057	G 46B
Giza 178	0				
GZ 6296	17.118	0			
PR 78	9.713	14.691	0		
GZ 9057	16.498	2.460	13.996	0	
G 46B	19.984	36.121	26.550	35.581	0
Large stigma B	35.236	18.807	31.627	20.133	53.773

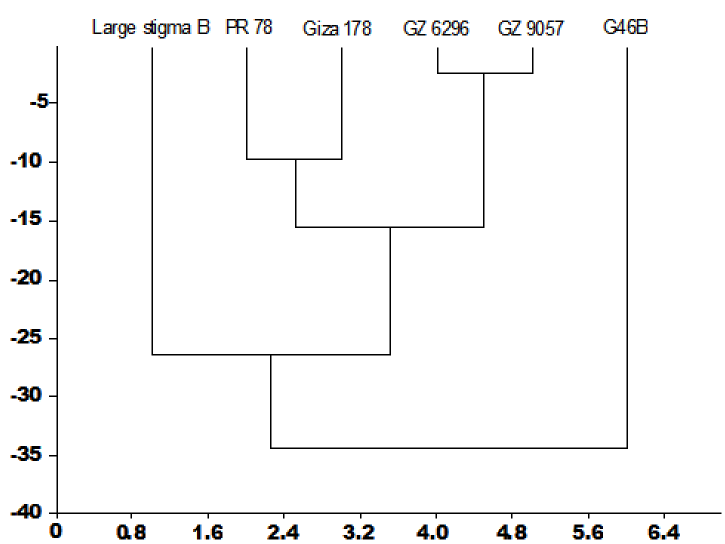

Fig. 1. Phylogenetic tree for the studied six rice genotypes classified by eight agronomic characteristics.

separate branch and the other five genotypes together at the other one. The most relative genotypes were the two promising Egyptian lines GZ 6296 and GZ 9057 and clustered together in one cluster. The other two Egyptian rice genotypes, PR 78 and Giza 178 were clustered together and were the nearest to the last cluster. Finally, the Large stigma B was clustered with the four Egyptian rice genotypes.

REFERANCES

Abd Allah RM 2008. Genetical and morphological studies on environmental genetic and cytoplasmic male sterility lines in rice. M.Sc. Thesis, Fac. of Agric. Mansoura Univ., Egypt.

Abd El-Hadi AH and El-Mowafi HF 2005. Combining ability analysis of the maintainers and restorer lines for cytoplasmic male sterile (CMS) system of hybrid rice. Egypt. J. Agric. Res., 83(5): 183-196.

Aditya JP and Bhartiya A 2015. Combining ability analysis for yield and components traits in fine grain rice of mid hills of Uttarakhand. Journal of Rice Research, 8(1): 15-22.

Ahmed ARM 2004. Genetical studies on some hybrids of rice. M.Sc Thesis, Fac. of Agric. Mansoura Univ., Egypt.

Akter A, Hasan MJ, Begum H, Kulsum MU and Hossain MK 2010. Combining ability analysis in rice (*Oryza Sativa* L.). Bangladesh J. Pl. Breed. Genet., 23(2): 07-13.

Alexandratos N and Bruinsma J 2012. World Agriculture towards 2030/2050. ESA Working Paper No. 12-03. Agricultural Development Economics Division, FAO, Rome, Italy.

Anis GB 2009. Breeding for earliness and some agronomic characters in rice (*Oryza sativa* L.). M.Sc Thesis, Fac. of Agric. Kafr El-Sheikh Univ., Egypt.

Attia KA 2001. Evaluation and RAPD analysis of photo-thermosensitive genetic male sterile lines in Indica rice (*Oryza sativa*, L.). M. Sc. Thesis, Institute of Genetics and Plant Breeding, Menoufiya Univ.

Awd-Allah MMA 2006. Application of genetic engineering tools on rice genome. M.Sc. Thesis, Genet. Dep., Fac. of Agric., Al-Azhar Univ., Egypt.

Cao L and Zhan X 2014. Chinese experiences in breeding three-line, two-line and super hybrid rice, *In*, Rice - Germplasm, Genetics and Improvement, Wengui Yan (*ed*.), 279-308.

Shi-hua C, Li-yong C, Shi-hua Y and Z. Hu-qu 2004. Forty Years' Development of Hybrid Rice: China's Experience. Rice Science, 11(5-6): 225–230.

Dingkhun M and Asch F 1999. Phenological responses of *Oryza sativa* L., *O. glaberrima* and inter-specific rice varieties on a top sequence in West Africa. Euphytica, 110: 109-126.

Dutta P, Dutta PN and Borua PK 2013. Morphological traits as selection indices in rice: A statistical view. Universal J. of Agricultural Research, 1(3): 85-96.

El-Diasty ZM, El-Mowafi HF, Hamada MS and Abdallah RM 2008. Genetic studies on photo-thermo-sensitive genic male sterility (P/TGMS) and its utilization in rice breeding. J. Agric. Sci. Mansoura Univ., 33(5): 3391-3404.

Elmoghazy AM 2007. Genetic and molecular breeding for drought tolerance in rice. Ph.D. Thesis, Fac. of Agric., Kafr El-Sheikh Univ., Egypt.

El-Mowafi HF 1994. Studies on rice breeding. Ph.D. Thesis, Fac. of Agric., Kafr El-Sheikh Tanta Univ., Egypt.

El-Mowafi HF and Abou-Shousha AA 2003. Combining ability and heterosis analysis of diverse CMS lines in hybrid rice. J. Agric. Res. Tanta Univ., 29(1): 106-127.

El-Mowafi HF Bastawisi AO, Abdel Khalek AF, Attia KA and El-Namaky RA 2009. Hybrid rice technology in Egypt. *In*, F. Xie and B. Hardy (*ed*.), Accelerating hybrid rice development, Proceedings of 5th International Symposium in Hybrid Rice, 11-15 Sept. 2008, Changsha, China, pp: 593-608.

El-Mowafi HF, Bastawisi AO, Abo-Youssef MI and Zaman FU 2005. Exploitation of rice heterosis under Egyptian conditions. Egypt. J. Agric. Res., 389 (5A): 143-166.

El-Refaee YZE 2002. Genetical and biochemical studies on heterosis and combining ability in rice. M.Sc. Thesis, Fac. of Agric., Tanta Univ., Kafr El-Sheikh, Egypt.

Geetha S, Sunderaraj APM, Giridharan S and Selvi B 1994. Association of component characters of medium duration rice genotypes. Annals of Agric. Res., 15:410-412.

Griffing B 1956. Concept of general and specific combining ability in relation to diallel mating systems. Australian j. of Biol. Sci., 9:463-493.

Hammoud SAM 1996. Breeding studies on some rice characters. M.Sc. Thesis. Fac. of Agric., Menoufiya Univ., Egypt.

Hammoud SAM 2004. Inheritance of some quantitative characters in rice (Oryza sativa, L.). Ph.D. Thesis, Fac. Agric., Minufiya Univ., Egypt.

Ikehashi H, Zau JS, Moon HP and Maru Y 1994. Wide compatibility gene(s) and Indica-Japonica heterosis in rice for temperate countries. *In*: S. S. Virmani (*Ed*.). Hybrid rice technology: New development and future prospects, pp: 21-31. IRRI, Manila, Philippines.

IRRI 2013. Standard Evaluation System (SES) for rice, 5th edition. International Rice Research Institute, Los Banos, Laguna, Philippines.

Ju L, C Liyong and C Shihua 2013. Progress in hybrid rice research and development in China. *In*: Proceedings of the 6th International Hybrid Rice Symposium, 10-12 September 2012, Hyderabad, India. Los Baños, Philippines: International Rice Research Institute, 93-102.

Khush GS 2005. What it will take to Feed 5.0 Billion Rice consumers in 2030. Plant Molecular Biology, 59: 1-6.

Kumar ST, Narasimman R, Thangavelu P, Eswaran R and Kumar CPS 2007. Combining ability analysis for yield and its component characters in rice (*Oryza sativa* L.). Int. J. Plant Sci., 2(1): 151-155

Latha S, Sharma D and Sanghera GS 2013. Combining ability and heterosis for grain yield and its component traits in rice (*Oryza sativa* L.). Not. Sci. Biol., 5(1): 90-97.

Panwar LL 2005. Line × tester of combining ability in rice (*Oryza sativa* L.). Ind. J. Genet, 65(1): 51-52.

Petchiammal KI and Kumar CRA 2007. Combining ability studies for yield and yield associated traits in rice (*Oryza sativa* L.) involving Assam rice cultures. Inter. J. Agric. Sci., 3(2): 234-236.

Rogbell JE and Subbaraman N 1998. Heterosis and combining ability analysis in rice. Crop Res. Hisar, 13(1): 143-150.

Rohlf FJ 2000. NTSYS-PC manual Exeter Software, Setauket, New York.

Rosamma CA and Vijayakumar NK 2005. Heterosis and combining ability in rice (*Oryza sativa* L.) hybrids developed for Kerala state. Ind. J. Genet., 65(2): 119-120.

RRTC 2006. National Rice Research Program: Final results of 2005 growing season. Sakha, Egypt.

Saleem, MY, Mirza JI and Haq MA 2010. Heritability, genetic advance and heterosis in line x tester crosses of basmati rice. J. of Agric. Res., (46): 18-23.

Sedeek SEM 2006. Breeding studies on rice. Ph.D. Thesis, Faculty of Agric., Kafr El-Sheikh, Tanta Univ., Egypt.

Siddiq EA 1997. Current status and future outlook for hybrid rice technology in India. *In*: Hybrid Rice: A Key to Success, pp: 1–34. Vijaya, R., Kumar and P.S.S. Murthy (eds.). Acharya N.G. Ranga Agricultural University, Agricultural Research Station, Maruteru, India.

Singh SK and Haque MF 1999. Heterosis for yield and yield components in rice (*Oryza sativa* L.). Ind. J. Genet., 52: 237–238.

Singh SK, Bhati PK, Sharma A and Sahu V 2015. Super hybrid rice in China and India: Current status and future prospects. Inter. J. Agriculture and Biology, 7(2): 221 232.

Singh SK, Sahu V, Sharma A and Bhati PK 2013. Heterosis for yield and yield components in rice (*Oryza sativa* L.). Bioinfolet, 10: 752–761.

Singh SP, Singh LR, Kumar P, Kumar R, Singh G and Singh G 2001. Estimation of gene action through triple test cross in common wheat (*Triticum aestivum* L.) Progressive Agic., 1(1): 20-23.

Sneath PH and Sokal RR 1973. *Numerical Taxonomy*. San Francisco: W.H. Freeman, USA.

Sharma RK 2006. Studies on gene action and combining ability for yield and its component traits in rice (*Oryza sativa* L.). Ind. J. Genet., 66(3): 227-228.

Swamy MH, Rao MRG and Vidhachandra B 2003. Studies on combining ability in rice hybrids involving new CMS lines. Karnataka J. Agric. Sci., 16(2): 228-230.

Tiwari DK, Pandey P, Tripathi S, Giri SP and Dwivedi JL 2011. Studies on genetic variability for yield components in rice (*Oryza sativa* L.). Advances in Agriculture & Botanics, 3(1): 76-81.

Upadhyay MN and Jaiswal HK 2015. Combining ability analysis for yield and earliness in hybrid rice (*Oryza sativa* L.). Asian Journal of Crop Science, 7: 81-86.

Yuan LP 1998. Hybrid rice breeding in China. *In*: Advances in hybrid rice technology, Virmani S.S., E.A. Siddiq and K. Muralidharan (eds.). International Rice Research Institute (IRRI), Los Banos, Laguna, Philippines. pp 27-33.

Zhang Q, Gao YJ, Saghai MA, Yang SH and Li JX 1995. Molecular divergence and hybrid performance in rice. Molecular Breeding, 11: 133-142.

Zhou G, Chen Y, Yao W, Zhang C, XieW, Hua J, Xing Y, Xiao J and Zhang Q 2012. Genetic composition of yield heterosis in an elite rice hybrid. Proceedings of National Academy of Science of the USA, 109(39): 15847-15852.