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GENETIC BASIS OF COMBINING ABILITY FOR VARIOUS QUANTITATIVE TRAITS USING CMS LINES OF RICE (*ORYZA SATIVA* L.)

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Summary: Line × Tester experiment was carried out at the Experimental Farm of Rice Research and Training Center (RRTC), Sakha, Kafrelsheikh, Egypt during three growing seasons to evaluate the performance of 21 F1 hybrids along with their parents. Three cytoplasmic male sterile lines, two wild abortive (Wild Abortive); IR69625A, IR70368A and one (Kalinga) K17A as female were tested with seven cultivars/lines as testers. The analysis of variance detected that, highly significant variations among genotypes (parental lines with their crosses) for all traits in both seasons and in their combined analysis. Two hybrid combinations; IR69625A×Giza178 and IR69625A×Giza179 were recorded the best values for grain yield under both seasons and their combined. General combining ability (GCA) and specific combining ability (SCA) effects of genotypes for the studied traits were estimated. The results indicated that, K17A (female) and Giza 179 (male) were the best combiner for early heading date and could be useful to breed early maturing rice cultivars. The CMS line IR69625A and Giza178, Giza179 gave highly significant and positive GCA value and so appeared to be good parental lines combiner in hybrid combinations for high grain yield/plant. The positive values of GCA mean increased for grain yield/plant, which could be useful in breeding programs for high yield potential rice cultivars. The hybrid combination IR69625A×Giza179 showed highly significant and positive SCA estimates under both seasons and their combined. In conclusion, it is clear that this hybrid seemed promising hybrid for earliness and high grain yield under Egyptian conditions.

Keywords: rice, combining ability, CMS, yield and yield components

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops grown in the world relative to both area and production, providing sustenance to half of the global population. Rice plays a significant role in Egypt, i.e. the country’s strategy for achieving the food self-sufficiency and increasing the overall export. The global population is expected to increase dramatically in the future, thus rice production must increase by 50% in order to meet the growing worldwide demand for this crop (Khush and Brar, 2002). Accordingly, rice breeders and producers are continuously searching for new technologies and lines which would increase rice production under changing climate conditions. The exploitation of hybrid rice technology in most of the rice-consuming countries has produced high yields, conserved land for agricultural diversification, and created rural employment opportunities during rice growing seasons. China is the leading country in hybrid rice cultivation with approximately 15 million ha or 50% of the total rice area devoted to hybrid rice varieties annually. An increase in grain yields by using hybrid rice technology can feed more than 70 million people every year. Under the same conditions, hybrid rice varieties produce 15-20% more yield than improved inbred varieties, thereby rice production is best increased by using hybrid rice. In order to obtain good hybrids, it is essential to understand the nature of gene action that controls the yield and its components. Combining ability estimation is a powerful tool available to select the desirable parents and crosses for the exploitation of heterosis. General combining ability (GCA) effects largely involve additive gene effects,

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whereas specific combining ability (SCA) effects represent only the non-additive gene action including dominance. The presence of non-additive genetic variance offers the scope for heterosis exploration (Yadav et al., 1999). The parents with good GCA and SCA could be used to produce good hybrids (Yang et al., 2000). Furthermore, the heterosis and combining ability of hybrid rice were studied by Zhang et al. (2002). Analyses of line x tester models provide information about GCA and SCA effects on the studied rice genotypes, which is helpful in estimating various types of gene actions (Rashid et al., 2007). The identification of suitable parents using a line x tester rice analysis in rice has been studied by Singh and Kumar (2004). Hybrid rice cultivars can produce higher yields than conventional cultivars by at least 15% under the same input conditions. Hence, this technology can be used to break the current yield plateau in rice, where yield levels of conventional cultivars reached stable levels (El-Mowafi et al., 2005).The main objective of this investigation was to estimate the GCA and SCA effects on rice traits, as well as to identify promising parental lines that can be combined in high-yielding early rice hybrids.

MATERIALS AND METHODS

The research in this paper was conducted at the experimental farm of the Rice Research and Training Center (RRTC), Sakha, KafrElsheikh, Egypt, during three growing seasons. A total of three cytoplasmic male-sterile (CMS) lines, *viz.* IR69625A and IR70368A, K17A as a female line, seven rice cultivars/lines *viz.*, Giza 178, Giza 179, Giza 181, Giza 182, Sakha 105, HR195, and the promising line GZ6296-12-1-2-1-1 were planted as testers on different sowing dates in 2014. In the same season, the hybridization of the selected parental lines was performed, using a line x tester mating design, to obtain the 21 F_1 hybrid seed. These 21 F_1 hybrids and their parents were evaluated in a randomized complete block design (RCBD) with three replications at the experimental farm of the Rice Research and Training Center during the 2015 and 2016 seasons. The following data were recorded: days to heading, number of fertile tillers per plant, panicle length (cm), seed set (%),1000–grain weight (g) and grain yield/plant (g) as recommended by (IRRI,1996). The days to heading, panicle length (cm) and seed set % were recorded using the A-line (CMS line), whereas the number of fertile tillers per plant, 1000–grain weight and grain yield per plant were recorded using the correspondent self-fertile B-lines (maintainer line). A combining ability analysis was carried out on the basis of the Kempthorne method (1957).

The estimates of GCA effects: GCA effects of each line were calculated according to the following equation:

$$g_i = \frac{Y_{i..}}{tr} - \frac{Y..}{Ltr}$$

where

$Y_{i..}$ = total of the i^{th} line over testers,

Y.. = grand total,

L, t and r = number of lines, testers and replications, respectively.

The GCA effects of testers were calculated as follows:

$$g_j = \frac{\sum Y.j.}{Lr} - \frac{Y..}{Ltr}$$

where

Y. j. = total of the i^{th} tester over lines.

The estimates of SCA effects: The values of SCA effects were determined as follows:

$$Sij = \frac{Yij.}{r} - \frac{Yi..}{rt} - \frac{Y.j.}{rL} + \frac{Y..}{L+r}$$

where

Yij. = value of the i^{th} line with the i^{th} tester

The estimates of standard error (S.E) pertaining to the GCA effects of lines and testers, and the SCA effect of different combinations were calculated as follows:

$$SE\ (GCA\ for\ lines) = \sqrt{\frac{Me}{rt}}$$

SE (GCA for testers) = $\sqrt{\dfrac{Me}{rL}}$

SE (SCA effects for combinations) = $\sqrt{\dfrac{Me}{r}}$

LSD = $t_{\substack{0.05\\0.01}}$ x SE

RESULTS AND DISCUSSION

Analysis of variance**:** The analysis of variance revealed that variations between the genotypes analyzed (parental lines and their crosses) were highly significant for all the studied characters in both seasons and in their combined analyses (Tables 1 and 2). The parents, crosses and their interaction (parents vs. crosses) showed significant or highly significant mean squares for all the traits studied, except for the number of fertile tillers per plant and P *vs.* Cr in grain yield /plant in the parents which were non-significant in the second season. The mean square values of lines, testers and line x tester (Tables 1 and 2) also showed significant or highly significant mean squares for all the studied characters in both seasons and their combined analyses, except for testers' number of fertile tillers per plant in the second season, line x tester for number of fertile tillers per plant in both seasons, and line x tester for 1000-grain weight in the second season. The significance of the mean squares due to lines and testers indicated a prevalence of additive variance. Several studies reported the prevalence of dominant gene action for a majority of the yield traits (Peng and Virmani, 1990;Ramaligan et al., 1993;Stayanarayana et al., 1998), which was also reported by EL-Mowafi, 2001; Singh and Kumar, 2004; EL-Mowafi et al., 2005;Abd EL-Hadi and EL-Mowafi, 2005.

Table 1. Mean squares (MS) from the ANOVA for the days to heading, panicle length and seed set % traits during the 2015 and 2016 seasons and their combined data

S. O. V.	DF		Days to heading			Panicle length			Seed set %		
	Single	Comb.	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
Years (Y.)	-	1	-	-	12.90	-	-	31.57**	-	-	20.03
Reps/ Y.	-	4	-	-	9.78	-	-	0.83	-	-	3.28
Genotypes (G)	(30)	(30)	100.14**	98.24**	195.46**	17.69**	15.05**	30.80**	2896.40**	2910.71**	5803.39**
Parents (P)	9	9	111.83**	108.10**	217.37**	9.37**	7.12**	13.50**	4626.23**	4610.20**	9234.49**
Parents vs. crosses	1	1	425.29**	455.01**	880.05**	13.30*	33.34**	44.39**	2381.46**	2543.04**	4923.12**
Crosses (Cr)	20	20	78.62**	75.96**	151.37**	21.65**	17.71**	37.91**	2143.71**	2164.32**	4303.40**
Lines (L)	2	2	72.82**	55.82**	127.62**	15.36**	15.37**	29.49**	178.91**	61.71**	225.35**
Testers (T)	6	6	174.10**	156.21**	327.86**	38.36**	28.30**	65.77**	7033.59**	7139.66**	14168.24**
L x T	12	12	31.84**	39.19**	67.09**	14.34**	12.80**	25.39**	26.24**	27.09**	50.66**
G x Y.	-	(30)	-	-	2.92	-	-	1.93	-	-	3.72*
P xY	-	9	-	-	2.57	-	-	3.00	-	-	1.96
P vs. Cr x Y.	-	1	-	-	0.25	-	-	2.27	-	-	1.32
Cr x Y.	-	20	-	-	3.21	-	-	1.44	-	-	4.63**
L x Y.	-	2	-	-	1.02	-	-	1.23	-	-	15.27**
T x Y.	-	6	-	-	2.45	-	-	0.90	-	-	5.01*
L x T x Y.	-	12	-	-	3.95	-	-	1.75	-	-	2.67
Error	60	120	2.21	2.78	2.49	2.08	1.67	1.88	2.24	2.24	2.24

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

Table 2.Mean squares (MS) from the ANOVA for the number of fertile tillers / plant, 1000-grain weight and grain yield/plant traits during the 2015 and 2016 seasons and their combined data

S.O.V.	DF		No. of fertile tillers / plant			1000-grain weight			Grain yield/plant		
	Single	Comb.	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
Years (Y.)	-	1	-	-	35.27*	-	-	0.58	-	-	0.375
Reps/ Y.	-	4	-	-	3.45	-	-	2.83	-	-	16.17
Genotypes (G)	(30)	(30)	17.90**	3.73*	13.94**	6.43**	5.34**	11.01**	233.62**	202.89**	428.24**
Parents (P)	9	9	30.13**	2.22	17.94**	4.29**	2.50**	6.30**	80.25**	70.23**	145.68**
Parents vs. crosses	1	1	52.02**	9.16*	52.42**	72.75**	76.07**	148.83**	87.85**	7.02	72.28**
Crosses (Cr)	20	20	10.70**	4.13*	10.21**	4.08**	3.08**	6.23**	309.92**	272.37**	573.18**
Lines (L)	2	2	66.33**	13.28**	67.52**	15.24**	17.90**	33.09**	226.42**	195.57**	420.72**
Testers (T)	6	6	8.96**	1.94	3.95*	3.96**	2.72**	6.12**	871.32**	788.36**	1653.61**
L x T	12	12	2.29	3.71	3.80*	2.28**	0.78	1.81*	43.14**	27.18**	58.38**
G x Y.	-	(30)	-	-	7.69**	-	-	0.76	-	-	8.27
P x Y.	-	9	-	-	14.41**	-	-	0.49	-	-	4.81
P vs. Cr x Y.	-	1	-	-	6.07	-	-	0.01	-	-	22.60
Cr x Y.	-	20	-	-	4.61**	-	-	0.92	-	-	9.11
L x Y.	-	2	-	-	12.09**	-	-	0.05	-	-	1.26
T x Y.	-	6	-	-	6.95**	-	-	0.56	-	-	6.07
L x T x Y.	-	12	-	-	2.20	-	-	1.25	-	-	11.95
Error	60	120	1.59	1.89	1.74	0.75	0.76	0.75	8.73	6.97	7.85

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

Mean performances: The mean performances of three CMS (female parent) lines and seven testers as male parents, as well as their F_1 hybrid combinations (the agronomic traits of 21 line x tester hybrids such as the heading date, panicle length (cm) and seed set % during the 2015 and 2016 seasons observed singly and in combination) are shown in Table 3. The results obtained indicate that the mean performances of the agronomic traits analyzed vary significantly between the genotypes. The earlier CMS K17 line was a female parental line in heading (85.67 days) with substantial differences (13-15 days) compared to the other CMS lines (90.50 days were recorded for the earlier restorer line Giza 179). The lowest mean value (82 days) was obtained for the combination K17A × Giza 179, whereas the hybrid IR70368A × Giza 181 exhibited the latest heading date. The mean values of the panicle length recorded for the female and male parents Giza 181 and HR195 ranged from 20.89 to 25.50 cm respectively, whereas the F_1 mean values ranged from 17.48 to 29.40 cm for the hybrids IR70368A × Sakha 105 and K17A × HR195 respectively. The tester line HR195 produced the longest panicles (25.50 cm). Furthermore, the F_1 hybrid combination K17A × HR195 exhibited the highest mean panicle length (29.40 cm). The mean values of the panicle length obtained for this hybrid combination exceeded the longest panicle value of the corresponding parents. The seed set (%) of CMS lines (female parent) was based on outcrossing, thus these three lines were male sterile and built grains were obtained through cross-pollination. Therefore, they showed a low seed set (%) ranging from 11.89% for IR 70368A to 13.67% for K17A. Moreover, the tester lines Giza 179, Giza 178 and Sakha 105 exhibited the highest mean seed set values among the parental lines with the means of 97.31, 95.36 and 95.30 %, respectively. Consequently, the hybrid combinations IR69625A × HR195, K17A × HR195 and K17A × Giza 179 showed the highest mean seed set values (97.03%, 96.57% and 96%, respectively). However, the lowest mean seed set values were recorded in the hybrid combinations IR69625A × Sakha 105, IR70368A × Sakha 105 and K17A × Sakha 105 ranging from 17.17 to 17.82%, which indicates that the cross between pure *Indica* (Female) and pure *Japonica* (male) exhibited a complete to partial sterility in F_1 generation.

Table 3.The mean values of rice lines, testers and F_1 hybrids for the days to heading, panicle length and seed set percentage traits during the 2015 and 2016 seasons observed solely and in combination

Genotypes	Days to heading (days)			Panicle length (cm)			Seed set %		
	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
CMS lines (female):									
IR69625A	99.33	101.67	100.50	24.00	23.83	23.92	12.40	13.83	13.12
IR70368A	99.00	98.67	98.83	22.00	24.87	23.43	11.78	12.00	11.89
K17A	85.33	86.00	85.67	22.17	23.70	22.93	13.67	13.67	13.67
Testers (Males):									
Giza 178	98.67	97.67	98.17	20.67	22.67	21.67	95.36	95.35	95.36
Giza 179	91.00	90.00	90.50	23.33	22.00	22.67	97.05	97.57	97.31
GZ 6296	93.00	94.67	93.83	23.55	22.33	22.94	93.43	96.13	94.78
Giza 181	103.67	103.33	103.50	20.11	21.67	20.89	89.63	88.16	88.89
Giza 182	92.33	95.00	93.67	21.47	21.10	21.28	91.65	92.76	92.21
Sakha 105	91.00	92.00	91.50	25.00	24.83	24.92	95.19	95.42	95.30
HR195	104.00	104.67	104.33	25.33	25.67	25.50	94.26	93.63	93.95
Hybrid combinations :									
IR69625A × Giza 178	91.67	92.67	92.17	24.67	26.00	25.33	95.75	93.25	94.50
IR69625A × Giza 179	89.67	89.67	89.67	22.00	22.67	22.33	91.16	92.35	91.76
IR69625A × GZ 6296	90.33	91.00	90.67	22.90	24.00	23.45	89.11	90.56	89.83
IR69625A × Giza 181	99.33	99.00	99.17	24.33	26.00	25.17	93.30	92.04	92.67
IR69625A × Giza 182	92.33	95.00	93.67	24.07	25.67	24.87	91.79	93.60	92.70
IR69625A × Sakha 105	87.00	87.00	87.00	25.73	26.67	26.20	18.39	16.55	17.47
IR69625A × HR195	98.67	97.67	98.17	26.87	27.57	27.22	96.91	97.15	97.03
IR70368A × Giza 178	90.00	92.33	91.17	21.97	23.77	22.87	92.67	94.54	93.60
IR70368A × Giza 179	86.33	89.00	87.67	21.67	24.07	22.87	89.28	89.97	89.63
IR70368A × GZ 6296	98.00	97.33	97.67	24.20	24.00	24.10	82.78	88.60	85.69
IR70368A × Giza 181	102.67	101.67	102.17	25.00	26.67	25.83	91.80	91.97	91.88
IR70368A × Giza 182	90.33	89.67	90.00	23.33	24.07	23.70	76.48	79.81	78.14
IR70368A × Sakha 105	85.67	85.67	85.67	15.83	19.13	17.48	16.67	17.67	17.17
IR70368A× HR195	88.67	87.33	88.00	26.67	25.40	26.03	88.84	90.96	89.90
K17A × Giza 178	89.00	89.33	89.17	19.73	20.00	19.87	94.37	94.19	94.28
K17A × Giza 179	81.67	82.33	82.00	22.63	23.33	22.98	95.77	96.22	96.00
K17A × GZ 6296	92.00	95.67	93.83	23.53	24.00	23.77	90.68	91.08	90.88
K17A × Giza 181	94.00	95.33	94.67	24.67	25.10	24.88	92.14	92.55	92.35
K17A × Giza 182	86.67	84.67	85.67	24.00	25.33	24.67	83.80	83.92	83.86

K17A × Sakha 105		87.67	89.00	88.33	22.40	22.07	22.23	17.26	18.38	17.82
K17A × HR195		92.67	93.00	92.83	28.80	30.00	29.40	96.65	96.48	96.57
LSD	0.05	2.425	2.726	1.787	2.356	2.115	1.551	2.444	2.444	1.694
	0.01	3.225	3.625	2.344	3.134	2.841	2.035	3.250	3.251	2.221

The mean performances of the three CMS (female parent) lines and seven testers as male parents, as well as their F_1 hybrid combinations (the number of fertile tillers/plant, 1000-grain weight and grain yield/plant of 21 line x tester hybrids observed solely and in combination during the period 2011-2012) are presented in Table 4. Relative to the number of fertile tillers/plant, the highest mean values among all the parental lines (males and females) were recorded for IR70368A, Giza 178 and HR195 (20.83, 22.67 and 24.17 tillers respectively). Moreover, the largest number of fertile tillers/plants was recorded in the hybrid combinations IR69625A × GZ6296-12-1-2-1-1 (23.83), IR69625A × Giza 178 (23.00) and IR69625A × Giza 182 (22.67). With regard to the 1000-grain weight, the results obtained indicated that the parental lines IR70368A, Giza 179, Sakha 105 and GZ 6296 had the heaviest grains with the means of 23.83, 24.48, 24.00 and 23.93 g, respectively. The hybrid combinations K17A × HR195, IR69625A × Giza 179, IR70368A × Gz6296 and K17A × Giza 178 exhibited the heaviest grains with the means of 27.52, 26.27, 25.90 and 25.88 g, respectively. However, the lowest mean 1000-grain weight values of 22.63 and 21.01 g were recorded in the tester line Giza 178 and the hybrid combination IR69625A × Giza 181, respectively. Highly significant differences were recorded in the grain yield/plant traits analyzed. IR69625A showed the highest mean value (14.00 g) as a female line, whereas the male parent tester Giza 179 exhibited the highest mean value (50.33 g) for grain yield/plant. The most desirable mean values were recorded for the hybrid rice combinations IR69625A × Giza 178 (51.67g), IR69625A × Giza 179 (51.67g), K17A × Giza 178 (45.33g) and IR69625A × HR195 (45.17g) (although significant differences were recorded between the hybrid combination IR69625A × 178 and IR69625A × Giza 179).

Table 4. The mean values of rice lines, testers and F_1 hybrids for the no. of fertile tillers / plant, 1000-grain weight and grain yield/plant traits during the 2015 and 2016 seasons observed solely and in combination

Genotypes	No. of fertile tillers / plant			1000-grain weight (g)			Grain yield/plant (g)		
	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
CMS lines (female):									
IR69625A.	16.00	20.33	18.17	23.47	23.04	23.25	35.49	35.53	35.51
IR70368A.	21.33	20.33	20.83	23.50	24.17	23.83	38.63	38.23	38.43
K17A	18.67	21.33	20.00	23.58	23.28	23.43	34.28	32.98	33.63
Testers (Males):									
Giza 178	24.33	21.00	22.67	20.29	21.72	21.01	40.00	40.00	40.00
Giza 179	22.00	22.67	22.33	24.61	24.34	24.48	52.33	48.33	50.33
GZ 6296	24.67	20.00	22.33	23.83	24.03	23.93	40.67	41.00	40.83
Giza 181	25.33	21.00	23.17	22.33	22.00	22.17	38.33	36.67	37.50
Giza 182	24.00	20.67	22.33	23.27	23.07	23.17	40.67	38.67	39.67
Sakha 105	23.67	21.33	22.50	24.00	24.00	24.00	38.33	40.00	39.17
HR195	26.00	22.33	24.17	22.61	22.67	22.64	34.33	30.67	32.50
Hybrid combinations :									
IR69625A × Giza 178	25.00	21.00	23.00	24.60	23.67	24.13	51.00	52.33	51.67
IR69625A × Giza 179	21.33	20.00	20.67	26.20	26.33	26.27	51.67	51.67	51.67
IR69625A × GZ 6296	23.67	24.00	23.83	24.00	24.00	24.00	43.33	41.33	42.33
IR69625A × Giza 181	21.33	22.00	21.67	22.67	22.60	22.63	43.33	42.67	43.00
IR69625A × Giza 182	24.67	20.67	22.67	23.80	24.60	24.20	35.33	41.00	38.17
IR69625A × Sakha 105	21.67	20.00	20.83	24.53	24.63	24.58	14.33	15.67	15.00
IR69625A × HR195	23.00	20.33	21.67	25.13	25.07	25.10	47.33	43.00	45.17
IR70368A × Giza 178	22.00	20.33	21.17	25.67	26.07	25.87	43.00	41.33	42.17
IR70368A × Giza 179	20.33	21.33	20.83	26.00	25.20	25.60	38.67	39.67	39.17
IR70368A × GZ 6296	21.00	20.00	20.50	26.00	25.80	25.90	35.00	39.33	37.17
IR70368A × Giza 181	20.00	21.00	20.50	24.33	25.43	24.88	36.00	38.33	37.17
IR70368A × Giza 182	20.33	19.33	19.83	25.07	24.80	24.93	40.00	38.33	39.17
IR70368A × Sakha 105	20.00	21.00	20.50	23.67	24.14	23.90	20.00	18.33	19.17
IR70368A × HR195	20.33	21.00	20.67	25.40	26.20	25.80	40.67	39.33	40.00
K17A × Giza 178	21.00	19.33	20.17	25.73	26.03	25.88	46.33	44.33	45.33
K17A × Giza 179	18.67	20.33	19.50	24.53	25.53	25.03	40.00	39.67	39.83

K17A × GZ 6296	18.00	19.67	18.83	25.43	25.13	25.28	36.33	34.67	35.50
K17A × Giza 181	19.67	18.33	19.00	25.50	25.33	25.42	32.33	35.00	33.67
K17A × Giza 182	20.33	19.00	19.67	25.07	24.87	24.97	34.00	36.00	35.00
K17A × Sakha 105	18.00	20.00	19.00	24.22	26.33	25.28	15.33	18.33	16.83
K17A × HR195	20.67	20.33	20.50	28.30	26.73	27.52	37.78	39.67	38.73
LSD 0.05	2.064	2.246	1.495	1.417	1.424	0.984	4.929	4.180	3.167
0.01	2.740	2.988	1.960	1.885	1.340	1.290	6.556	5.562	4.153

General combining ability effects (GCA): Significant differences of GCA were observed between the CMS lines for the traits analyzed as shown in Table 5. The female parents (CMS) showed significant GCA values for days to heading. The results indicated that K17A was the best combiner for early heading with highly significant and negative estimates of GCA effects. Conversely, IR69625A showed highly significant and positive estimates of GCA. Among the tester lines, the tester lines Giza 179 and Sakha 105 showed highly significant and negative values for days to heading. These lines proved to be good combiners for earliness, and could be use for breeding early-maturing rice cultivars. The line IR69625A appeared to be a good combiner with new hybrid combinations for panicle length, whereas K17A exhibited non-significant and negative estimates of GCA effects. Among the testers, HR195 and Giza181 had significant and positive estimates for panicle length, whereas Sakha 105 was the poorest combiner with significant and negative estimates. Relative to the seed set (%), IR69625A and K17A as female parents showed significant GCA estimates, whereas the tester lines HR195, Giza178 and Giza179 displayed highly significant and positive values. Swamy et al., (2003) identified two good combiner parents for improved fertility percentage in rice. The results of EL-Mowafi (2001), Alam et al., (2004), Abd EL-Hadi and EL-Mowafi et al., (2005) were consistent with the present results.

Table 5. GCA estimates of rice lines and testers for days to heading, panicle length and seed set percentage traits during the 2015 and 2016 seasons observed solely and in combination

Genotypes		Days to heading(days)			Panicle length (cm)			Seed set %		
		2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
Lines	IR69625A	1.55**	1.50	1.53**	0.79*	0.96**	0.87**	2.07**	1.17**	1.62**
	IR70368A	0.50	0.22	0.36	-0.90**	-0.67*	-0.79**	-3.33**	-1.96**	-2.65**
	K17A	-2.06**	-1.73**	-1.89**	0.11	-0.28	-0.08	1.25**	0.79*	1.02**
Testers	Giza 178	-0.93	-0.19	-0.56	-1.44**	-1.29**	-1.37**	13.99**	12.95**	13.47**
	Giza 179	-5.27**	-4.63**	-4.95**	-1.47**	-1.19**	-1.33**	11.80**	11.80**	11.80**
	GZ 6296	2.28**	3.03**	2.65**	-0.02	-0.54	-0.28	7.25**	9.04**	8.14**
	Giza 181	7.50**	7.03**	7.27**	1.09*	1.37**	1.23**	12.14**	11.14**	11.64**
	Giza 182	-1.38**	-1.85**	-1.61**	0.22	0.47	0.35	3.75**	4.73**	4.24**
	Sakha 105	-4.38**	-4.41**	-4.39**	-2.24**	-1.92**	-2.08**	-62.82**	-63.50**	-63.16**
	HR195	2.17**	1.03	1.60**	3.87**	3.10**	3.49**	13.86**	13.82**	13.84**
LSDL	0.05	0.64	0.72	0.47	0.62	0.56	0.41	0.65	0.65	0.45
	0.01	0.86	0.96	0.62	0.83	0.75	0.54	0.86	0.86	0.59
LSDT	0.05	0.99	1.11	0.72	0.96	0.86	0.63	0.97	0.97	0.69
	0.01	1.31	1.48	0.95	1.27	1.14	0.83	1.28	1.28	0.90

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

The estimated values of GCA for the each line and tester relative to fertile tillers/plant, 1000-grain weight (g) and grain yield/plant (g) are presented in Table 6. According to fertile tillers/plants, the data obtained showed that IR69625A as a female line and Giza178 as a male line were the best combiners with significant and positive estimates of GCA effects. However, K17A was the poorest combiner with highly significant and negative values. The values of GCA for fertile tillers/plant are in accordance with the results reported by Mehla et al., (2000), Rosamma and Vijayakumar, (2005) and Kumar et al., (2007). The lines K17A and IR70368A showed highly significant and positive values for 1000-grain weight GCA estimates, as well as the HR195 tester. For grain yield/plant, the IR69625A line exhibited highly significant and positive GCA values, thus proving to be a good parental combiner in hybrid combinations for grain yield/plant. On the other hand, Giza178, Giza179 and Giza181 as testers showed highly significant and positive estimates of GCA. The positive values of the GCA mean increased for the grain yield/plant values, which could be useful in programs for breeding potentially high-yielding rice cultivars.

Table 6. GCA estimates of rice lines and testers for the number of fertile tillers / plant, 1000-grain weight and grain yield/plant traits during the 2015 and 2016 seasons observed solely and in combination

Genotypes		No. of fertile tillers / plant			1000-grain weight (g)			Grain yield/plant (g)		
		2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
Lines	IR69625A	1.95**	0.71*	1.33**	-0.98**	-1.06**	-1.02**	3.67**	3.47**	3.57**
	IR70368A	-0.42	0.14	-0.14	0.48*	0.52**	0.50**	-1.03	-1.23*	-1.13*
	K17A	-1.52**	-0.85**	-1.19**	0.50*	0.54**	0.52**	-2.64**	-2.23**	-2.43**
Testers	Giza 178	1.66**	-0.20	0.73*	0.29	0.09	0.19	9.55**	8.38**	8.96**
	Giza 179	-0.88**	0.12	-0.38	-0.30	-0.20	-0.25	6.21**	6.04**	6.13**
	GZ 6296	-0.11	0.79*	0.34	0.10	-0.18	-0.043	0.99	0.82	0.91
	Giza 181	-0.66	0.01	-0.32	-0.87*	-0.71*	-0.79**	-0.01	1.04	0.52
	Giza 182	0.77	-0.76*	0.01	-0.39	-0.41	-0.40**	-0.78	0.82	0.02
	Sakha 105	-1.11*	-0.09	-0.60	-0.05	0.60	0.27	-20.67**	-20.17**	-20.42**
	HR195	0.33	0.12	0.23	1.23**	0.83**	1.03**	4.70**	3.04**	3.87**
LSDL	0.05	0.55	0.18	0.39	0.37	0.38	0.26	1.31	1.11	0.84
	0.01	0.73	0.79	0.52	0.50	0.50	0.34	1.75	1.48	1.11
LSDT	0.05	0.84	0.60	0.61	0.57	0.58	0.40	1.96	1.67	1.29
	0.01	1.11	0.79	0.80	0.76	0.77	0.52	2.58	2.19	1.69

*, ** Significant at 0.05 and 0.01 levels, respectively

Specific combining ability effects (SCA)*: The* estimates of SCA effects for each F_1 hybrid combination for days to heading, panicle length and seed set (%) are shown in Table (7). Relative to days to heading, a total of seven crosses out of 21 hybrid combinations were found to show negatively significant or highly significant SCA effects. The useful negatively significant values of SCA effects are desirable in some hybrid combinations. The best hybrids were IR70368A × HR195 and IR69625A × GZ 6296. Relative to the panicle length, a total of seven cross combinations exhibited highly significant positive SCA effects, whereas K17A x HR195 exhibited the highest significant SCA effects compared to other hybrid combinations. With regard to the seed set percentage, the data obtained indicated that the five cross combinations IR69625A × Giza 182, K17 x Giza 179, IR70368A x Sakha 105, IR70368A x Giza 181 and IR70368A x Giza 178 displayed highly significant and positive SCA estimates. Similar results were reported by EL-Mowafi (2001) and Abd El-Hadi et al. (2013).

The estimates of SCA for each F_1 hybrid combination relative to the number of fertile tillers/plants, 1000-grain weight (g) and grain yield/plant (g) are presented in Table 8. With regard to the number of fertile tillers/plant, the hybrid combination IR69625A x GZ6296 (out of all 21 hybrids) showed positively significant SCA effects. According to the 1000-grain weight, the cross combination K17A x HR195 showed significant and positive SCA effects. Relative to the grain yield/plant value, three cross combinations IR69625A x Giza 179, IR70368A x Giza 181 and K17A x Sakha 105 combination showed positive or highly significant SCA estimates. In conclusion, it is clearly evident that the hybrid combination IR69625A × Giza 179 shows the potential for earliness and high grain yield.

Table 7. SCA estimates of the rice F_1 hybrids for days to heading, panicle length and seed set % traits during the 2015 and 2016 seasons observed observed solely and in combination

Genotypes	Days to heading(days)			Panicle length (cm)			Seed set %		
	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
IR69625A× Giza 178	-0.11	-0.28	-0.19	1.74*	1.78*	1.76**	-0.59	-1.91*	-1.25*
IR69625A× Giza 179	2.22*	1.15	1.69**	-0.89	-1.65*	-1.27**	-2.98**	-1.67	-2.32**
IR69625A× GZ 6296	-4.66**	-5.17**	-4.92**	-1.44	-0.96	-1.20**	-0.49	-0.70	-0.59
IR69625A× Giza 181	-0.88	-1.17	-1.03	-1.12	-0.88	-1.00**	-1.19	-1.32	-1.25*
IR69625A× Giza 182	1.00	3.71**	2.35**	-0.52	-0.31	-0.42	5.69**	6.65**	6.17**
IR69625A× Sakha 105	-1.33	-1.73	-1.53*	3.61**	3.08**	3.34**	-1.12	-2.15**	-1.64**
IR69625A× HR195	3.77**	3.49**	3.63**	-1.37	-1.05	-1.21**	0.69	1.11	0.90
IR70368A× Giza 178	-0.73	0.66	-0.03	0.74	1.18	0.96**	1.74*	2.51**	2.12**
IR70368A× Giza 179	-0.06	1.77	0.85	0.47	1.38	0.92**	0.54	-0.91	-0.18
IR70368A× GZ 6296	4.04**	2.44*	3.24**	1.56	0.67	1.11**	-1.40	0.48	-0.45
IR70368A× Giza 181	3.49**	2.77**	3.13**	1.23	1.42	1.32**	2.72**	1.74*	2.23**
IR70368A× Giza 182	0.04	-0.33	-0.14	0.43	-0.27	0.07	-4.20**	-4.00**	-4.10**
IR70368A× Sakha 105	-1.61	-1.77	-1.69**	-4.58**	-2.81**	-3.69**	-2.56**	2.10	2.33**
IR70368A× HR195	-5.17**	-5.55**	-5.36**	0.12	-1.57*	-0.72*	-1.95*	-1.93*	-1.94**
K17A × Giza 178	0.84	-0.38	0.23	-2.49**	-2.97**	-2.73**	-1.14	-0.59	-0.87
K17A × Giza 179	-2.15*	-2.93**	-2.54**	0.42	0.26	0.34	2.44	2.58**	2.51**
K17A × GZ 6296	0.61	2.73**	1.67**	-0.12	0.28	0.08	1.89*	0.21	1.05
K17A × Giza 181	-2.60**	-1.60	-2.10**	-0.11	-0.53	-0.32	-1.52	-0.42	-0.97
K17A × Giza 182	-1.04	-3.38**	-2.21**	0.09	0.59	0.34	-1.48	-2.65**	-2.06**
K17A × Sakha 105	2.95**	3.50**	3.23**	0.96	-0.27	0.34	-1.43	0.05	-0.69
K17A × HR195	1.39	2.06**	1.73	1.24	2.63**	1.93**	1.26	0.82	1.04
LSD 0.05	1.71	1.92	1.26	1.66	1.49	0.61	1.72	1.69	1.19

0.01	2.27	2.56	1.65	2.21	1.98	0.80	2.29	2.22	1.57

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

Table 8. SCA estimates of the rice F_1 hybrids for the number of fertile tillers / plants, 1000-grain weight and grain yield/plant traits during the 2015 and 2016 seasons observed solely and in combination

Genotypes	No. of fertile tillers / plant			1000-grain weight (g)			Grain yield/P (g)		
	2015	2016	Comb.	2015	2016	Comb.	2015	2016	Comb.
IR69625A× Giza 178	0.38	0.06	0.22	0.24	-0.52	-0.13	0.54	2.85	1.70
IR69625A× Giza 179	-0.73	-1.27	-1.00	-0.08	0.24	0.08	4.54**	4.52**	4.53**
IR69625A× GZ 6296	0.82	2.06	1.44**	-0.16	0.08	-0.03	1.43	-0.58	0.42
IR69625A× Giza 181	-0.95	0.84	-0.05	-0.51	-0.78	-0.65	2.43	0.52	1.47
IR69625A× Giza 182	0.93	0.28	0.61	0.13	0.91	0.52	-4.78**	-0.92	-2.85**
IR69625A× Sakha 105	-0.17	-1.04	-0.61	0.53	-0.06	0.23	-5.89**	-5.25**	-5.57**
IR69625A× HR195	-0.28	-0.93	-0.61	-0.16	0.13	-0.01	1.72	-1.14	0.29
IR70368A× Giza 178	-0.23	-0.03	-0.13	-0.14	0.29	0.07	-2.74	-3.42*	-3.08**
IR70368A× Giza 179	0.65	0.63	0.64	0.78	-0.28	0.25	-3.74*	-2.76	-3.25**
IR70368A× GZ 6296	0.54	-1.36	-0.41	0.37	0.29	0.33	-2.18	2.12	-0.02
IR70368A× Giza 181	0.09	0.41	0.25	-0.31	0.45	0.06	-0.18	0.90	0.36
IR70368A× Giza 182	-1.01	-0.47	-0.74	-0.06	-0.47	-0.27	4.59**	1.12	2.86*
IR70368A× Sakha 105	0.54	0.52	0.53	0.73	0.04	0.38	-38.93**	-40.73**	-39.81**
IR70368A× HR195	-0.57	0.30	-0.13	-1.36**	-0.32	-0.84*	-0.22	-0.09	-0.16
K17A × Giza 178	-0.14	-0.03	-0.08	-0.10	0.23	0.06	2.19	0.57	1.38
K17A × Giza 179	0.07	0.63	0.35	-0.70	0.03	-0.33	-0.80	-1.76	-1.28
K17A × GZ 6296	-1.36	-0.69	-1.03	-0.21	-0.38	-0.29	0.75	-1.54	-0.39
K17A × Giza 181	0.85	-1.25	-0.19	0.83	0.33	0.58	-2.24	-1.42	-1.83
K17A × Giza 182	0.07	0.19	0.13	-0.07	-0.43	-0.25	0.19	-0.20	-0.01
K17A × Sakha 105	-0.36	0.52	0.07	-1.26**	0.02	-0.62	1.41	3.12*	2.27*
K17A × HR195	0.85	0.63	0.74	1.52**	0.19	0.85*	-1.50	1.23	-0.13
LSD 0.05	1.46	1.58	1.05	1.01	1.00	0.69	3.48	2.95	2.23
0.01	1.94	2.11	1.38	1.33	1.33	0.91	4.63	3.93	2.93

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

CONCLUSION

Developing new high-yielding rice hybrids with superior grain quality is of paramount importance to improving food security and meeting consumer demands. Two hybrid combinations IR69625A × Giza178 and IR69625A × Giza179 exhibited the best values of grain yields in the 2015 and 2016 seasons observed solely and in combination. The CMS line K17A and restorer line Giza 179 were the best combiners for early heading date and could be used for breeding early-maturing rice cultivars. Highly significant and positive GCA values were recorded in the genotypes IR69625A, Giza 178 and Giza 179, rendering them favorable parental lines combiners in hybrid combinations for high grain yield/plant. The positive values of GCA mean increased for the grain yield/plant trait, which could be useful in programs for breeding potentially high-yielding rice cultivars. The hybrid combination IR69625A × Giza179 showed highly significant and positive SCA estimates in both seasons observed solely and in combination. In conclusion, it is clearly evident that this hybrid has considerable potential for earliness and high grain yield under Egyptian conditions.

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