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COMBINING ABILITY AND GENE ACTION ANALYSIS IN EGYPTIAN BASMATI HYBRID RICE

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ABSTRACT

Studies on combining ability and gene action of five basmati cytoplasmic genic male sterile lines (CMS) and novel nine Egyptian basmati restorer lines (testers) were carried out using line x tester (L x T) analysis for some agronomic, yield and its component characters to get useful information for the basmati hybrid rice breeding program in Egypt. Analysis of variance for combining ability revealed significant differences among the basmati CMS lines and the novel Egyptian basmati restorers (testers) for all studied characters studied, except filled grains panicle^{-1} for CMS lines. Highly significant mean squares (MS) of all studied traits for L x T (SCA), indicated that they interacted and produced markedly different combing ability effects and this might be due to wide genetic diversity of basmati CMS lines and the novel basmati restorer lines. The expected MS values of GCA of basmati male testers were higher than female basmati (CMS) lines for all agronomic and yield characters, except plant height, spikelet fertility % and grain yield t ha^{-1} indicating that the influence of male parent is higher than that female parent. The ratio of K^2gcax K^2sca was higher than unity for plant height, panicle length, spikelets panicle^{-1}, filled grains panicle^{-1}, spikelet fertility% and 1000-grain weight, indicating that the additive gene action is playing high role in the inheritance of these traits. On the contrary the ratio of K^2gcax K^2sca was less than unity for days to maturity, panicles plant^{-1} and grain yield characters, indicating that the non-additive gene action is playing big role in the inheritance of these traits. Among the five basmati CMS and nine basmati restorer lines, the female basmati CMS lines, Sakha Basmati 12A, Sakha Basmati 13A and Sakha Basmati 14A and the male Egyptian basmati restorer lines, EBR30, EBR25, EBR24, EBR3 and Giza Basmati 201 were identified as the best general combiners for grain yield and most of studied traits. Among the 45 basmati hybrid rice combinations studied, the hybrids IR58025A x EBR10, Sakha Basmati 11A x Giza Basmati 201, Sakha Basmati 12A x EBR1, Sakha Basmati 12A x EBR17, Sakha Basmati 13A x EBR2 and Sakha Basmati 14A x EBR2 had the best SCA effects for most of yield and yield component characters.

Key words: ***Combining ability, Gene action, Basmati hybrid rice***.

INTRODUCTION

Rice (*Oryza sativa* L.) is considered as one of the most important strategic crops in the world and the main food for about a half of the world population. It occupies, annually about 0.547 to 0.630 hectars.

Hybrid rice is the only technology that is able to increase rice yield about 20-25% higher than the best commercial varieties (Virmani *et al* 1997, El-Mowafi *et al* 2005, 2018, 2021 and 2022). Currently, hybrid rice technology is used in large scale cultivation in several Asian countries. Hybrid rice covers more than 50% of total rice cultivated area in China (You *et al* 2006). The development of hybrid rice technology and the adoption of hybrid rice cultivars to Egyptian environments offer one approach to solve the problem of matching food supply to expected demand.

Due to the increasing demand of rice with the rapidly increase in population, more and more rice have to be produced on less land and with less inputs. Hybrid rice is more profitable and more sustainable for yield production, therefore utilization of hybrid rice is an important technology to meet the increasing in rice demand in the world.

Scented rice or aromatic rice is popular in Asia and it has gained wider acceptance in Europe, the United States and Gulf countries. Because of their aroma flavor and texture, aromatic varieties command a higher price in comparison with other rice varieties. The major far eastern aromatic rice variety is 'Basmati' (Weber *et al* 2000). There is a great demand for basmati rice in the local and international markets. There is a need to develop new basmati rice varieties and hybrids with high crop yield and superior quality on par with traditional basmati varieties. However, incorporating both quality trials in basmati rice makes the breeding program more complex in Egypt.

Identification of the cytoplasmic male sterile female basmati (CMS), male basmati restorer lines and best basmati hybrid rice combinations obtained through hybridization can be used for commercial production in Egypt. Developing hybrid rice with higher yield, better grain quality and multi-resistance is very important, and the key is to breed CMS and restorer lines with good combining ability in good adapted varieties.

The aim of the present study is to estimate combining ability and gene action in F_1 basmati hybrids developed by male sterility-fertility restoration system using five basmati cytoplasmic male sterile lines (CMS) and nine Egyptian basmati restorer lines identified through Egyptian basmati hybrid rice breeding programe.

MATERIALS AND METHODS

The present study was carried out at the Experimental Research Station, Kafr El-Sheikh during the two successive growing seasons of 2020 and 2021.

The genetic materials used in this study involved five cytoplasmic male sterile lines (CMS), from aromatic (basmatic) rice. The CMS lines were used as female lines, in addition, the new nine Egyptian basmatic restorers developed by the National Project to Advance the Productivity and

Marketing of Hybrid Rice and the National Project to Develop the Production of Hybrid and Super Rice Under Conditions of Water Scarcity and Climatic Changes in cooperation between the Agricultural Research Center (ARC) and the Academy of Scientific Research and Technology.

The experimental comprised hybrid progenies derived from 45 F_1 hybrid rice combinations generated through Line x tester mating design. Five exotic and Egyptian Basmatic or aromatic CMS lines viz., IR58025A, Sakha Basmati11A, Sakha Basmati12A. Sakha Basmati13A and Sakha Basmati14A were used as female lines. New basmatic restorer lines viz., EBR1, EBR2, EBR3, EBR15, EBR16, EBR20, EBR25, EBR30 and Giza Basmatic 201 were used as male parents to produce the hybrid seeds in isolation plots for hybrid rice production program (Table 1).

These materials were grown during 2020 and 2021 growing seasons in different sowing dates either in day intervals to get optimum synchronization in hybrid rice seed production program in the isolation field to obtain the hybrid seeds. The experimental hybrids among CMS lines and restorer or tester lines were attempted during the year of 2020 through basmati hybrid rice breeding and hybrid rice seed production program to produce enough amounts of hybrid rice seeds for replicated yield experiment. The F_1 hybrid rice combinations along with their respective maintainer and male parents were grown in a randomized complete block design (RCBD) with three replications at Sakha Research Station in 2021 summer seasons. Thirty-day old seedlings were transplanted with one seedling hill^{-1} adopting a spacing of 20 cm between rows and 20 cm between plants. Each entry consisted of 14 rows of 5 m length (5 x 2.8 m^2). All recommended agronomical practices were followed to raise the ideal crop stand. Observations were recorded on nine agronomic and yield traits. Observations were taken on ten plants plot^{-1} at random from each entry in each replication according to IRRI Standard Evaluation System (2014) for agronomic and yield traits. Ten guarded rows (10 m^2) were harvested from each entry in each replication to determine grain yield (tonx feddan), adjusted to grain yield tx ha.

Table 1. Exotic and Egyptian cytoplasmic male sterile lines (females) and tester lines (male parents or restorers) used in this study.

Parents	Cytoplasmic source	Aroma	Origin
CMS lines (Female lines)			
IR58025A	WA (wild abortive)	Aromatic	IRRI
Sakha Basmati11A	WA (wild abortive)	Aromatic	Egypt
Sakha Basmati12A	WA (wild abortive)	Aromatic	Egypt
Sakha Basmati13A	WA (wild abortive)	Aromatic	Egypt
Sakha Basmati14A	WA (wild abortive)	Aromatic	Egypt
Restorer or tester (male lines)			
Egyptian Basmati R1 (EBR1)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R2 (EBR2)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R3 (EBR3)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R15 (EBR15)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R16 (EBR16)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R20 (EBR20)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R25 (EBR25)	New basmatic restorer	Aromatic	Egypt
Egyptian Basmati R30 (EBR30)	New basmatic restorer	Aromatic	Egypt
Giza Basmatic 201 (released)	New basmatic restorer (released 2018)	Aromatic	Egypt

Combining ability analysis was carried out as suggested by Kempthorne model (1957). Therefore, the expected MS should be as follow:

$$K^2g\ (F) = \frac{(M.S.F - M.S.E)}{(r\,x\,M)}$$

$$K^2g\ (M) = \frac{(M.S.M - M.S.E)}{(r\,x\,F)}$$

$$K^2gca = \frac{(M-1)K^2gM + (F-1)K}{(M-1) + (F-1)}$$

$$K^2sca = \frac{M.S.FM - M.S\,Error}{r}$$

$$\text{the relative imp} = \frac{K^2gca}{K^2sca}$$

where:

M: Males, F: Females and r: Replications

MS due to lines and MS due to testers were tested against MS due to lines x testers MS due to lines x testers was tested against MS due to error.

The following characters were recorded:

1- Agronomic characters:

Days to maturity, plant height at harvesting (cm), panicle length (cm) and spikelets panicle^{-1}.

2- Yield and its component characters: panicles plant^{-1},

Filled grains panicle^{-1},

Spikelet fertility%,

1000-grain weight (g) and grain yield t ha^{-1}.

Statistical analysis

Data were analyzed by using ordinary analysis of variance to test the significance of differences among the 59 genotypes (five CMS female lines, 9 restorers as tester lines and their 45 F_1 hybrid rice combinations). If the Genotypes mean squares were found significant, there was a need to proceed for further analysis, i.e., line x tester analysis.

Line x tester analysis

The data were subjected to analysis of variance for randomized complete blocks design as suggested by Panse and Sukhatme (1954) and analysis of variance for line x tester design (Kempthorne, 1957).

The fixed model used to estimate general combining ability (GCA) and specific combining ability (SCA) effect is as follows:

$$X_{ijk} = \mu + g_i + g_j + S_{ij} + e_{ijk}$$

RESULTS AND DISCUSSION

Analysis of variances for all studied traits are presented in Table (2). Results indicated highly significant differences among the studied genotypes for all traits. The parental lines and the hybrid rice combinations showed highly significant differences for all studied traits. Parents vs. hybrids mean squares indicated that average heterosis was highly significant in all hybrids for all agronomic studied traits in this study. Analysis of variance for combining ability revealed highly significant difference among the basmati CMS lines except filled grains panicle^{-1} for CMS lines and the novel Egyptian basmati restorers (testers) for all agronomic and yield traits studied. Highly significant mean squares of all studied traits for L x T (SCA), indicated that they interacted and produced markedly different combining ability effects and this might be due to the wide genetic diversity of basmati CMS lines and the new basmati restorer lines (testers).

Combining ability

Significant differences of GCA effects were observed among the female basmati cytoplasmic male sterile lines and Egyptian basmati testers for all traits as shown in Tables (2) and (3).

The expected MS values of GCA of basmati male testers K^2 (M) were higher than female basmati lines K^2 (F) for all the studied characters except plant height, spikelet fertility % and grain yield t ha^{-1}. These values of the results mentioned in Table (2) indicated that the influence of male parents is higher than that of female parents. On the other hand, the expected MS values of female lines K^2 (F) were higher than male testers K^2g (M) plant height, spikelet fertility% and grain yield, indicating that the influence of female parents is higher than that of male parents.

Table 2. Analysis of variance and mean squares from line x testers analysis for studied characters.

SOV	df	Agronomic traits			
		Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets panicle^{-1}
Replications	2	0.446	0.43	0.017	12.226
Genotypes	58	17.46**	50.40**	11.14**	3153.944**
Parents	13	19.09**	118.39**	14.37**	6673.665**
Crosses	44	16.20**	29.01**	8.29**	1372.373**
Par. vs. crosses	1	51.78**	107.17**	94.32**	35786.7**
Lines	4	37.42**	143.18**	7.12**	1983.174*
Testers	8	36.68**	69.96**	35.35**	4197.933**
Lines x testers	32	8.43**	4.51**	1.68**	589.632**
Error	116	0.22	0.45	0.14	16.801
CV%		0.35	0.60	1.36	1.62
k^2 (f)		1.378	5.286	0.259	72.829
k^2 (M)		2.431	4.634	2.347	278.742
k^2 gca		2.080	4.851	1.651	210.104
k^2 sca		2.736	1.352	0.513	190.944
k^2 gcax k2sca		0.760	3.589	3.221	1.100

SOV	df	Yield and yield components				
		Panicles plant^{-1}	Filled grains panicle^{-1}	Grain yield t ha^{-1}	Spikelets fertility%	1000 grain weight
Replications	2	0.41	0.58	0.006	2.187	0.243
Genotypes	58	16.313**	2681.589**	10.925**	23.195**	7.001**
Parents	13	12.711**	6348.051**	7.716**	21.882**	20.139**
Crosses	44	11.992**	1149.279**	1.018**	22.259**	2.045**
Par.vs.crosses	1	253.238**	22439.25**	488.559**	81.426**	54.27**
Lines	4	30.119**	713.715	5.841**	122.462**	5.963**
Testers	8	18.907*	4458.267**	1.113**	29.939**	5.75**
Lines x testers	32	7.998**	376.477**	0.391**	7.814**	0.63**
Error	116	0.987	3.15	0.017	2.919	0.065
CV%		4.76	0.77	1.04	1.87	0.95
k^2 (f)		1.079	26.317	0.216	4.428	0.218
k^2 (M)		1.195	297.008	0.073	1.801	0.379
k^2 gca		1.156	206.778	0.121	2.677	0.325
k^2 sca		2.337	124.444	0.125	1.632	0.188
k^2 gcax k2sca		0.495	1.662	0.967	1.640	1.728

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

Table 3. Genetic parameters for studied traits.

Parameter	Agronomic				Yield and yield components				
	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets panicle^{-1}	Panicles plant^{-1}	Filled grains panicle^{-1}	1000 grain weight	Spikelets fertility %	Grain yield t ha^{-1}
Additive variance (σ^2 A)	2.957	9.499	2.446	292.166	1.547	284.610	0.539	5.721	0.250
Dominant variance (σ^2 D)	2.737	1.353	0.513	190.944	2.337	124.442	0.188	1.632	0.125
Environmental variance (σ^2 E)	0.220	0.450	0.140	16.801	0.987	3.150	0.065	2.919	0.017
Genotypic variance (σ^2 G)	5.694	10.853	2.959	483.110	3.884	409.052	0.727	7.353	0.375
Phenotypic variance (σ^2 P)	5.914	11.303	3.099	499.911	4.871	412.202	0.792	10.272	0.392
Broad sense heritability (h^2b)%	96.280	96.019	95.483	96.639	79.735	99.236	91.795	71.583	95.659
Narrow sense heritability (h^2n)%	50.003	84.045	78.921	58.444	31.753	69.046	68.021	55.698	63.828
Relative importance of GCA%*	51.935	87.530	82.655	60.476	39.823	69.578	74.101	77.809	66.725
Relative importance of SCA%**	48.065	12.470	17.345	39.524	60.177	30.422	25.899	22.191	33.275

Expected mean squares (MS) values of GCA (K^2gca) were higher than MS values of SCA (K^2sca) for plant height, panicle length, spikelets panicle^{-1}, filled grains panicle^{-1}, spikelet fertility % and 1000-grain weigh. The ratio of K^2gcax K^2sca was higher than unity for the six above-mentioned traits, indicating that the additive gene action is playing high role in the inheritance of these traits. In the contrary, the expected mean square (MS) values of SCA (K^2sca) were higher than MS values of GCA (K^2gca) for days to maturity, panicles plant^{-1} and grain yield characters. The ratio of K^2gcax K^2sca was less than unity for later mentioned traits, indicating the non-additive gene action is playing big role in the inheritance of these traits.

Genetic parameters

The estimates of genetic parameters for the agronomic and yield, traits Table (3) revealed that the additive variance (σ^2A) and relative importance of GCA % for all traits studied except panicles plant^{-1} were greater than non-additive (dominance variance) (σ^2D) and relative importance of SCA%. On the other hand, high estimates of non-additive genetic variance (dominance) and its relative magnitude of SCA were found to be more than those of the additive variances for panicles plant^{-1}. These results indicate that dominance variance played a major role in the inheritance of this character. The importance of the additive and non-additive gene action for the inheritance of these traits was in agreement with the findings of El-Mowafi *et al* (2005), Pradhan and Singh (2008), Tyagi *et al* (2008), Ghara *et al* (2012), Kumar *et al* (2015), Abd El-Hadi *et al* (2018), Chuwang *et al* (2018), Akankisho and Jaiswal (2019), Bano and Singh (2019), Kour *et al* (2019), El_Dabaawy (2021), El-Mowfi *et al* (2021), Ahmed (2022) and El-Mowafi *et al* (2022).

Concerning heritability, the results cleared that the estimated values of heritability in broad sense (h^2b) were high for all agronomic and yield characters. On the other hand, heritability values in narrow sense was relatively high for plant height, panicle length, filled grains panicle^{-1}, 1000-grain weight and grain yield t ha^{-1}, moderate for days to maturity, spikelts panicle^{-1} and spikelets fertility% and low for panicles plant^{-1} with values of (84.01%, 78.9%, 69.04%, 68%, 63.82%, 50.00%,58.44%, 55.69% and 31.75%), respectively.

The results also illustrated that a major part of the total phenotypic variance (σ^2p) was due to additive genetic variance for the five studied characters, plant height, panicle length, filled grains panicle^{-1}, 1000-grain weight and grain yield t ha^{-1}. Accordingly, it was expected that an effective phenotypic selection for these characters to improve the basmati parental lines for hybrid rice breeding programme could be achieved with a satisfactory degree of accuracy. Similar results were obtained by Kumer *et al* (2015), El-Dabaawy (2021), El-Mowafi *et al* (2021), Ahmed (2022) and El-Mowafi *et al* (2022). The case of panicles plant^{-1} character, which showed low estimate of heritability in narrow sense (h^2n) suggested that a major part of the total phenotypic variance was due to dominance genetic variance. This finding indicated that the selection for these characters should be done in the late generations. In case of days to maturity, spikelets panicle^{-1} and spikelets fertility% characters, the estimates of these parameters were moderate, indicating that a major part of total phenotypic variance was due to both additive and dominance genetic variance. Accordingly, it was expected that the effective phenotypic selection for these characters could be achieved with a satisfactory degree of accuracy. However, these results are in general agreement with those reported by El-Mowafi *et al* (2005), El-Mowafi *et al* (2012), Akankisha and Jaiswal (2019), El-Mowafi *et al* (2022) and Mahrous (2022).

GCA effects

Agronomic characters

For days to maturity, Table (4) revealed that the basmati CMS lines Sakha Basmati 12A and Sakha Basmati 13A showed highly significant and negative estimates of GCA effects with values of (-1.578±0.014) and (-0.578±0.014). These CMS lines showed earliness in days to maturity and thus can be a preferable `female parents for developing early maturing basmati hybrids and these CMS lines appeared to be good maternal combiners in basmati hybrid rice combinations for characteristics of early maturity. On the other hand, the rest three of basmati CMS lines gave highly significant and positive estimates of GCA effects. Among the testers or restorer lines, EBR1 (-3.00±0.024) and EBR2 (-0.600±0.024), EBR10 (-0.333±0.24) and EBR17 (-0.267±0.024) showed highly significant and negative (desirable) estimates of GCA effects for days to maturity. El-Mowafi *et al* (2018), El-Mowafi *et al* (2021) and El-Mowafi *et al* (2022) reported rice CMS, restorers, PTGMS and testers showing negative GCA effects.

The results in Table (4) indicated that the same female CMS lines mentioned above Sakha Basmati 12Ax B and Sakha Basmati 13Ax B were the best combiners for short stature plant by virtue of their highly significant and negative estimates (desirable) of GCA effects with the values of (-2.689±0.28) and (-2.319±0.28), respectively. Three tester or restorer lines, EBR10, EBR3 and EBR17 gave highly significant and negative estimates of GCA effects for desirable short stature plant with the values of (-4.815±0.05), (-1.548±0.05) and (-0.415±0.05), respectively. The negative GCA effects values that mean decreased plant height, could be useful to breed short stature rice hybrids, Abdallah (2013), El-Mowafi *et al* (2018), El-Dabaawy (2021), and Ahmed (2022) suggested several parents with desirable GCA effects for plant height in rice hybrids.

Table 4. General combining ability effects for each line and tester for studied characters.

Genotypes	Agronomic				Yield and yield components				
	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets panicle^{-1}	Panicles plant^{-1}	Filled grains panicle^{-1}	1000 grain weight	Spikelets fertility%	Grain yield t ha^{-1}
Lines									
IR58025A	0.089**	2.015**	0.356**	9.452**	-0.489**	6.274**	-0.593**	-0.950**	-0.770**
Sakha Basmati11A	0.496**	1.682**	-0.756**	-1.956**	-0.378**	-3.207**	0.037**	-0.637**	-0.104**
Sakha Basmati12A	-1.578**	-2.689**	0.096**	4.304**	0.511**	4.904**	0.333**	0.298**	0.341**
Sakha Basmati13A	-0.578**	-2.319**	-0.237**	1.600**	1.548**	-4.356**	0.556**	-2.177**	0.304**
Sakha Basmati14A	1.570**	1.311**	0.541**	-13.400**	-1.193**	-3.615**	-0.333**	3.465**	0.230**
LSD 5 %	0.014	0.028	0.009	1.033	0.061	0.194	0.004	0.179	0.001
1%	0.019	0.039	0.012	1.471	0.086	0.276	0.006	0.256	0.001
Testers									
EBR1	0.133**	0.519**	0.489**	-21.133**	0.941**	-22.667**	0.356**	-1.392**	-0.148**
EBR2	-0.600**	0.585**	0.556**	-8.600**	-0.593**	-14.267**	0.356**	-2.321**	-0.148**
EBR3	-3.000**	-1.548**	1.222**	-0.533	0.274**	-4.133**	0.622**	-1.368**	0.252**
EBR15	-0.333**	-4.815**	0.889**	18.400**	-1.326**	21.667**	-0.511**	1.799**	-0.415**
EBR16	-0.267**	-0.415**	-2.178**	-2.267*	-0.859**	-0.067	-0.311**	0.771**	-0.348**
EBR20	1.267**	1.785**	1.156**	-11.200**	0.074	-7.867**	-0.111**	0.929**	0.052**
EBR25	2.200**	2.452**	-1.244**	6.733**	-1.393**	9.667**	-0.711**	1.435**	0.252**
EBR30	-1.000**	0.119**	-2.444**	32.000**	1.741**	29.600**	-0.711**	0.134	0.252**
Giza Basmatic 201	1.600**	1.319**	1.556**	-13.400**	1.141**	-11.933**	1.022**	0.012	0.252**
LSD 5 %	0.024	0.050	0.015	1.859	0.109	0.349	0.007	0.323	0.002
1%	0.035	0.071	0.022	2.648	0.156	0.496	0.010	0.460	0.003

The basmati CMS line Sakha Basmati 14Ax B, IR58025Ax B and Sakha Basmati 1Ax B and the basmati tester lines Giza Basmati 201, EBR3, EBR10, EBR2 and EBR1 exhibited desirable and highly significant and positive estimates of GCA effects for panicle length with values of (0.541 ± 0.09), (0.356 ± 0.09), (0.096 ± 0.09), (1.639±0.015), (1.222±0.015), (1.222±0.015), (1.156±0.015), (0.889±0.015), (0.556±0.015) and (0.489±0.015), respectively. These basmati and basmati restorer lines appeared to be good female and male combiners in rice basmati hybrids for panicle length, El-Mowafi *et al* (2005), Abdallah (2013), El-Mowafi *et al* (2018), El-Dabaawi (2021) and Ahmed and El-Mowafi *et al* (2022) observed promising female CMS, PTGMS and male restorer lines with high GCA effects for panicle length trait. For spikelets panicle^{-1}, the estimates of GCA effects Table (4) were highly significant and positive for the female basmati CMS lines IR58025Ax B (9.452±1.033), Sakha Basmati 12Ax B (4.304±1.033) and Sakha Basmati 13Ax B (1.600±1.033) and the tester or restorer basmati lines EBR30 (32.00 ±1.859), EBR10 (18.400±1.859) and EBR25 (6.733±1.859), indicating that these basmati rice genotypes could be considered as good combiners for high number of spikelets panicle^{-1}. Among the five basmati CMS lines and nine basmati restorer lines Sakha Basmati 12Ax B and EBR10 were found as best general combiners for the Egyptian basmati hybrid rice breeding programs for improving agronomic traits, days to maturity (earliness), plant height (short stature plant), panicle length and spikelets panicle^{-1}. Similar results were reported earlier by El-Mowafi *et al* (2018), El-Dabaawy (2021), El-Mowafi *et al* (2021), Ahmed (2022) and El-Mowafi *et al* (2022).

Yield and its component traits

With respect to panicles plant^{-1}, estimates of (g^i) effects Table (4) were either highly significant positive or negative for all the five female basmati CMS lines. Sakha Basmati 13Ax B and Sakha Basmati 12Ax B showed desirable highly significant and positive effects. The values respectively were (1.548±0.061) and (0.511±0.061). Furthermore, the estimates of GCA effects of panicles plant^{-1} for the pollen parents (testers) were highly significant positive or negative for all parents, except EBR24, EBR30, Giza Basmati 201, EBR1 and EBR3 which showed significantly positive and desirable estimates, the GCA effects, were (1.741±0.109), (1.141±0.109), (0.941±0.109) and (0.274±0.109), respectively.

For filled grains panicle^{-1} trait, data in Table (4) revealed highly significant and positive values (desirable) of GCA effects were exhibited for the two basmati CMS lines, IR58025A (6.274±0.194) and EBR 12A (4.904±0.194) . On the other hand, the rest three basmati CMS lines gave highly significant and negative estimates (undesirable) of GCA effects. However, the results in Table (4) showed that the testers (restorer lines), EBR30, EBR10 and EBR25 proved to be the best combiners for highest number of filled grains panicle^{-1}, since their estimates of GCA effects were highly significant and positive (desirable) with values of (29.60±0.349), (21.667±0.349) and (9.667±0.349), respectively.

In case of spikelet fertility%, data in Table (4) indicated that the Egyptian basmati CMS lines, Sakha Basmati 14Ax B and Sakha Basmati 12Ax B had preferred highly significant and positive estimates of GCA effects of (3.465±0.179) and (0.298±0.179), respectively. EBR10, EBR25, EBR24 and EBR17 among basmati restorer lines were found as the best general combiners based on estimates of GCA effects with values of (1.799±0.323), (1.435±0.323), (0.929±0.323) and (0.771±0.323), respectively. Concerning to 1000-grain weight in Table (4), the basmati CMS lines, Sakha Basmati 13A, Sakha Basmati 12A and Sakha Basmati 11A and the basmati restorer lines, Giza Basmati 201, EBR10, EBR3, and EBR1 and EBR2 exhibited desirable and highly significant and positive estimates of GCA effects with values of (0.556±0.157), (0.333±0.157), (0.037±0.004), (1.022±0.007), (0.662±0.007), (0.356±0.007) and (0.0 ±0.007), respectively. These basmati CMS and restorer lines parents appeared to be good maternal and paternal combiners in basmati rice hybrids for 1000-grain weight.

For grain yield tx ha^{-1}, results in Table (4) revealed that CMS lines (female parents) namely Sakha Basmati 12Ax B, 13Ax B and 14Ax B expressed desirable highly significant and positive GCA effects of (0.341±0.001), (0.304±0.001) and (0.230±0.001), respectively. The new Egyptian basmati restorers (testers), EBR3, EBR25, EBR30 and EBR24 exhibited highly significant and positive GCA effects with values of (0.252±0.002), (0.252±0.002), (0.252±0.002), respectively. These genotypes are considered excellent general combiners for grain yield tx ha^{-1} in basmati hybrid rice programme in Egypt. Generally, the results indicated that the female (CMS) lines, Sakha Basmati 12Ax B, Sakha Basmati 13Ax B and Sakha Basmati 14Ax B and the male basmati restorer lines, EBR30, EBR25, EBR24, EBR3 and Giza Basmati 201 were identified as the best general combiners for grain yield and most of studied traits. However, Pradhan and Singh (2008), Salgotra *et al* (2009), Abdelkhalik (2015), Kumar *et al* (2015), El-Mowafi *et al* (2018), Kour *et al* (2019), Sharma and Jaiswal (2020), El-Dabaawy (2021), El-Mowafi *et al* (2021), Ahmed (2022) and El-Mowafi *et al* (2022) have reported positive GCA effects for agronomic and yield characters.

SCA effects

Agronomic characters

SCA effects are function of non-additive gene action. A high value of SCA effects implicates role of epistatic and dominance genetic variance in expression of characters (Sharma and Jaiswal, 2020). In the present study, 22 basmati hybrid rice combinations showed highly significant and negative SCA effects for days to maturity Table (5). IR58025AxGiza Basmati 201 (-2.822±0.122), Sakha Basmati 11AxEBR17 (-2.363±0.122), Sakha Basmati 12AxEBR1 (-2.356±0.122), Sakha Basmati 12AxEBR2 (-1.956±0.122) and Sakha Basmati 12AxEBR3 (-1.889±0.122) exhibited highest negative and highly significant SCA effects for days to maturity (earliness). Among the 45 hybrids studied, 18 hybrid rice combinations showed highly significant and negative SCA effects for plant height (short stature plant). The highest negative and significant SCA effects for plant height were observed by the basmati hybrids, Sakha Basmati 11AxGiza Basmati 201 (-2.281±0.249), IR58025AxEBR2 (-2.215±0.249), IR58025AxEBR1 (-2.143±0.249), Sakha Basmati 13AxEBR3 (-1.748±0.249) and Sakha Basmati 12AxEBR3 (-1.711±0.249). 21 basmati hybrid rice combinations showed positive and significant SCA effects for panicle length character. The hybrids Sakha Basmati 11AxEBR24 (1.326±0.077), Sakha Basmati 11AxEBR30 (1.222±0.077), IR58025AxEBR2 (1.111±0.077), Sakha Basmati 14AxEBR3 (0.926±0.077) and IR58025AxEBR1 (0.844±0.077) displayed the highest significant and positive SCA values for panicle length. Ten basmati combinations showed significant and positive SCA effects for spikelets panicle^{-1}. The highest positive and significant SCA effects for spikelets panicle^{-1} were recorded by the hybrids Sakha Basmati 11AxGiza Basmati 201 (23.622±9.297), Sakha Basmati 11AxEBR1 (21.763±9.297), Sakha Basmati 14AxEBR1 (17.133±9.297), Sakha Basmati 13AxEBR2 (16.600±9.297) and IR58025AxEBR24 (16.015±9.297).

The combinations which showed negative estimates for days to maturity and plant height characters or high positive estimates for panicle length and spikelets panicle^{-1} characters could be utilized for improvement of these characters following biparental making or recurrent selection or any approach for favoring desirable gene accumulation. In addition, the combinations showed significantly negative Sij effects for days to maturity (earliness) and plant height (short statute plant) characters and positive Sij for panicle length and spikelets panicle^{-1} characters may be useful in the exploitation of heterosis due to their desirable characters.

Yield and its component characters

The estimated values of specific combining ability effects (Sij) for yield and its component characters are presented in Table (5). The results indicated that, 15 hybrid rice combinations showed significant and positive SCA effects for panicles plant characters. The highest SCA effects were detected for the hybrids, IR58025Ax EBR25 (3.56±0.546), Sakha Basmati 12Ax EBR3 (3.56±0.546), Sakha Basmati 11Ax EBR1 (2.44±0.546), Sakha Basmati 13Ax Giza Basmati 201 (1.778±0.546). Concerning the filled grain characteristic, twenty out of the forty five hybrid rice combinations studied exhibited highly significant and positive SCA effects. The best combinations were Sakha Basmati 11Ax Giza 201 (26.341±1.743), Sakha Basmati 12Ax EBR1 (14.963±1.743), IR58025Ax EBR24 (13.126±1.743), Sakha Basmati 14Ax Giza Basmati 201 (11.415±1.743) and Sakha Basmati 14Ax EBR1 (10.148±1.743). As for fertility percentage, only four out of the 45 hybrids showed significant and positive SCA effects (desirable). The hybrids IR58025Ax EBR2 (2.871±1.615), Sakha Basmati 13Ax EBR1 (2.250±1.615), Sakha Basmati 11Ax Giza Basmati 201 (2.012±1.615) and Sakha Basmati 12Ax EBR17 (1.662±1.65) recorded highest values for spikelet fertility%.

Table 5. Estimates of specific combining ability effect for each studied character.

Genotypes	Agronomic			
	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets panicle^{-1}
IR58025AxEBR1	2.311**	-2.148**	0.844**	-2.385
IR58025AxEBR2	1.044**	-2.215**	1.111**	-21.585**
IR58025AxEBR3	-1.556**	1.585**	-0.222**	-18.319**
IR58025AxEBR15	-0.222**	0.185	-0.556**	5.748
IR58025AxEBR16	1.044**	1.785**	0.178**	9.748*
IR58025AxEBR20	0.178**	0.585**	-0.822**	16.015**
IR58025AxEBR25	1.244**	0.919**	-0.422**	5.415
IR58025AxEBR30	-1.222**	0.252*	0.444**	5.815
IR58025AxGiza Basmati201	-2.822**	-0.948**	-0.556**	-0.452
Sakha Basmati11AxEBR1	-0.430**	-0.481**	-1.044**	-29.644**
Sakha Basmati11AxEBR2	-0.696**	1.452**	-0.444**	-6.511
Sakha Basmati11AxEBR3	2.037**	0.252*	-0.111**	11.089*
Sakha Basmati11AxEBR15	1.037**	0.185	0.222**	8.156
Sakha Basmati11AxEBR16	-2.363**	-0.881**	0.289**	3.822
Sakha Basmati11AxEBR20	-0.896**	0.585**	-0.044	6.756
Sakha Basmati11AxEBR25	-1.163**	0.919**	0.356**	0.489
Sakha Basmati11AxEBR30	0.704**	0.252*	1.222**	-17.778**
Sakha Basmati11Ax Giza Basmati201	1.770**	-2.281**	-0.444**	23.622**
Sakha Basmati12AxEBR1	-2.356**	1.556**	-0.230**	21.763**
Sakha Basmati12AxEBR2	-1.956**	0.156	-0.963**	10.230*

Table 5. Cont.

Genotypes	Agronomic			
	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets panicle^{-1}
Sakha Basmati12AxEBR3	-1.889**	-1.711**	0.037	7.163
Sakha Basmati12AxEBR15	1.111**	-0.444**	-0.296**	-2.104
Sakha Basmati12AxEBR16	0.711**	-0.511**	0.437**	-0.770
Sakha Basmati12AxEBR20	1.178**	-0.378**	0.104*	-2.504
Sakha Basmati12AxEBR25	1.244**	-0.378**	0.504**	-4.437
Sakha Basmati12AxEBR30	0.444**	-0.044	-0.296**	-5.037
Sakha Basmati12Ax Giza Basmati201	1.511**	1.756**	0.704**	-24.304**
Sakha Basmati13AxEBR1	-1.689**	1.185**	0.104*	-6.867
Sakha Basmati13AxEBR2	-0.956**	0.119	0.037	16.600**
Sakha Basmati13AxEBR3	-0.556**	-1.748**	-0.630**	7.867
Sakha Basmati13AxEBR15	-0.556**	-0.481**	0.704**	-1.067
Sakha Basmati13AxEBR16	1.378**	0.119	0.770**	-8.733
Sakha Basmati13AxEBR20	0.844**	-0.081	-0.563**	-14.467**
Sakha Basmati13AxEBR25	0.244**	-0.415**	0.170**	6.933
Sakha Basmati13AxEBR30	0.444**	0.252*	-0.630**	10.333*
Sakha Basmati13Ax Giza Basmati201	0.844**	1.052**	0.037	-10.600*
Sakha Basmati14AxEBR1	2.163**	-0.111	0.326**	17.133**
Sakha Basmati14AxEBR2	2.563**	0.489**	0.259**	1.267
Sakha Basmati14AxEBR3	1.963**	1.622**	0.926**	-7.800
Sakha Basmati14AxEBR15	-1.370**	0.556**	-0.074*	-10.733*
Sakha Basmati14AxEBR16	-0.770**	-0.511**	-1.674**	-4.067
Sakha Basmati14AxEBR20	-1.304**	-0.711**	1.326**	-5.800
Sakha Basmati14AxEBR25	-1.570**	-1.044**	-0.607**	-8.400
Sakha Basmati14AxEBR30	-0.370**	-0.711**	-0.741**	6.667
Sakha Basmati14Ax Giza Basmati201	-1.304**	0.422**	0.259**	11.733*
LSD 5%	0.122	0.249	0.077	9.297
1%	0.173	0.355	0.110	13.239

Table 5. Cont.

Genotypes	Yield and yield components				
	Panicles plant^{-1}	Filled grains panicle^{-1}	1000 grain weight	Spikelets fertility%	Grain yield t ha^{-1}
IR58025AxEBR1	-0.978**	-0.741	0.126**	0.525	-0.630**
IR58025AxEBR2	-0.778**	-11.807**	-0.207**	2.871**	-0.630**
IR58025AxEBR3	0.022	-13.274**	-0.141**	1.237	-0.030**
IR58025AxEBR15	0.622*	5.259**	-1.007**	0.044	0.637**
IR58025AxEBR16	0.156	7.326**	-0.207**	-0.551	0.570**
IR58025AxEBR20	-1.111**	13.126**	0.593**	-0.629	0.170**
IR58025AxEBR25	3.356**	0.259	0.193**	-1.749*	-0.030**
IR58025AxEBR30	0.222	4.659**	0.193**	-0.041	-0.030**
IR58025AxGiza Basmati201	-1.511**	-4.807**	0.459**	-1.709*	-0.030**
Sakha Basmati11AxEBR1	2.244**	-23.926**	0.496**	1.156	-0.296**
Sakha Basmati11AxEBR2	-0.889**	-1.993*	0.496**	1.261	-0.296**
Sakha Basmati11AxEBR3	-2.422**	7.874**	-0.104**	-0.805	0.304**
Sakha Basmati11AxEBR15	0.178	5.074**	0.363**	-0.822	-0.030**
Sakha Basmati11AxEBR16	-0.289	-3.859**	0.163**	-2.907**	-0.096**
Sakha Basmati11AxEBR20	1.444**	5.274**	-0.037**	-0.352	-0.496**
Sakha Basmati11AxEBR25	-0.756*	-0.926	-0.437**	-0.528	0.304**
Sakha Basmati11AxEBR30	1.778**	-13.859**	-0.437**	0.987	0.304**
Sakha Basmati11Ax Giza	-1.289**	26.341**	-0.504**	2.012*	0.304**
Sakha Basmati12AxEBR1	0.689*	14.963**	0.200**	-1.662*	0.259**
Sakha Basmati12AxEBR2	0.222	0.896	0.200**	-3.173**	0.259**
Sakha Basmati12AxEBR3	3.356**	3.096**	-0.067**	-1.273	-0.141**
Sakha Basmati12AxEBR15	-1.378**	2.296*	0.067**	1.564	-0.474**
Sakha Basmati12AxEBR16	-1.511**	3.696**	-0.133**	1.662*	0.459**
Sakha Basmati12AxEBR20	1.222**	-2.170*	-0.333**	0.024	0.059**
Sakha Basmati12AxEBR25	-0.644*	-0.037	0.267**	1.544	-0.141**
Sakha Basmati12AxEBR30	-3.111**	0.030	0.267**	1.492	-0.141**

Table 5. Cont.

Genotypes	Yield and yield components				
	Panicles plant^{-1}	Filled grains panicle^{-1}	1000 grain weight	Spikelets fertility%	Grain yield t ha^{-1}
Sakha Basmati12Ax Giza Basmati201	1.156**	-22.770**	-0.467**	-0.179	-0.141**
Sakha Basmati13AxEBR1	0.319	-0.444	-0.022	2.250*	0.296**
Sakha Basmati13AxEBR2	0.852**	8.822**	-0.022	-1.978*	0.296**
Sakha Basmati13AxEBR3	-0.348	8.689**	-0.289**	0.538	-0.104**
Sakha Basmati13AxEBR15	-0.415	-0.111	0.844**	0.315	0.230**
Sakha Basmati13AxEBR16	0.452	-5.044**	-0.356**	0.936	-0.504**
Sakha Basmati13AxEBR20	-1.481**	-13.244**	-0.556**	-0.255	0.096**
Sakha Basmati13AxEBR25	-1.348**	6.222**	0.044**	-0.121	-0.104**
Sakha Basmati13AxEBR30	-0.148	5.289**	0.044**	-1.150	-0.104**
Sakha Basmati13Ax Giza Basmati201	2.119**	-10.178**	0.311**	-0.534	-0.104**
Sakha Basmati14AxEBR1	-2.274**	10.148**	-0.800**	-2.269*	0.370**
Sakha Basmati14AxEBR2	0.593*	4.081**	-0.467**	1.019	0.370**
Sakha Basmati14AxEBR3	-0.607*	-6.385**	0.600**	0.303	-0.030**
Sakha Basmati14AxEBR15	0.993**	-12.519**	-0.267**	-1.101	-0.363**
Sakha Basmati14AxEBR16	1.193**	-2.119*	0.533**	0.861	-0.430**
Sakha Basmati14AxEBR20	-0.074	-2.985**	0.333**	1.213	0.170**
Sakha Basmati14AxEBR25	-0.607*	-5.519**	-0.067**	0.853	-0.030**
Sakha Basmati14AxEBR30	1.259**	3.881**	-0.067**	-1.289	-0.030**
Sakha Basmati14Ax Giza Basmati201	-0.474	11.415**	0.200**	0.410	-0.030**
LSD 5%	0.546	1.743	0.036	1.615	0.009
1%	0.778	2.482	0.051	2.300	0.013

Twenty two out of 45 basmati hybrid rice combinations showed highly significant and positive SCA effects for 1000-grain weight. The highest SCA effects were detected from the hybrids, Sakha Basmati 13Ax EBR10, Sakha Basmati 14Ax EBR3, IR58025Ax EBR24, Sakha Basmati 14Ax EBR17, Sakha Basmati 11Ax EBR2 with values of (0.844±0.036), (0.600±0.036), (0.593±0.036), (0.533±0.036), (0.496±0.036) and (0.496±0.036), respectively. Eighteen out of fifty four basmati hybrid rice combinations resulted from basmati female CMS lines crossed with basmati male parents exhibited highly significant desirable SCA effects for grain yield t ha^{-1}. The most desirable basmati hybrids for grain yield were IR58025Ax EBR10 (0.637±0.009), IR58025Ax EBR17 (0.570±0.009), Sakha Basmati 12Ax EBR17 (0.459±0.009), Sakha Basmati 14Ax EBR1 (0.370±0.009) and Sakha Basmati 14Ax EBR2 (0.370±0.009).

Generally, the results revealed that the basmati hybrid rice combinations IR58025Ax EBR10, Sakha Basmati 11Ax Giza Basmati 201, Sakha Basmati 12Ax EBR1, Sakha Basmati 12Ax EBR17, Sakha Basmati 13Ax EBR2 and Sakha basmati 14Ax EBR2 recorded the best SCA effects for most of yield and its component characters.

It could be concluded that the values of the excellent hybrid combinations which showed SCA effects were obtained from crossing good by good, good by low and low by low combiners. However, it could be also concluded that GCA effects of the parental lines were generally unrelated to the SCA effects of their respective crosses. This conclusion was also reported by El-Mowafi (2001b), El-Mowafi *et al* (2005), Pradhan *et al* (2006), Salgotra *et al* (2009), Koli *et al* (2013), Aditya and Bhartiya (2015) Xiang *et al* (2016), El-Mowafi *et al* (2018) Akanksha and Jaiswal (2019) and El-Mowafi *et al* (2021).

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تحليل القدرة علي الإئتلاف والفعل الجيني للأرز الهجين المصري البسمتي

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تم تقدير دراسات القدرة علي الإئتلاف والفعل الجيني لخمس سلالات بسمتي عقيمة ذكريا سيتوبلازميا وكذلك تسعة سلالات بسمتي مصرية معيدة للخصوبة في تحليل السلالة X الكشاف لبعض الصفات الحقلية وصفات المحصول ومكوناته للحصول علي معلومات مفيدة لبرنامج تربية الأرز الهجين البسمتي في مصر. وقد أعطي تحليل التباين للقدرة علي الإئتلاف إختلافات معنوية بين سلالات العقم البسمتي وكذلك السلالات المعيدة للخصوبة لجميع الصفات الحقلية وصفات المحصول ومكوناته ماعدا صفة عدد الحبوب الممتلئة بالسنبلة لسلالات العقم الوراثي السيتوبلازمي. أعطي تحليل متوسطات المربعات معنوية عالية لجميع الصفات تحت الدراسة لتحليل السلالة x الكشاف (القدرة الخاصة علي الإئتلاف)والتي يشير التداخل بينها وجود تأثير قدرة علي الإئتلاف متباين وربما يرجع ذلك الي وجود إختلافات وراثية واسعة بين سلالات العقم البسمتي والسلالات المعيدة للخصوبة. قيم متوسطات المربعات المتوقعة للقدرة العامة علي الإئتلاف للكشافات البسمتي $K^2(M)$ كانت أعلي من سلالات العقم البسمتي $K^2(F)$ لكل الصفات الحقلية وصفات المحصول ماعدا صفات طول النبات ، النسبة المئوية لخصوبة السنيبلات ومحصول الحبوب وهذا يدل علي أن تأثير الأب أعلي من تأثير الأم. نسبة K^2sca K^2gcax كانت أكبر من الوحدة لصفات طول النبات ، طول السنبلة ، عدد السنيبلات بالسنبلة ، عدد الحبوب الممتلئة بالسنبلة ، النسبة المئوية لخصوبة السنابل ووزن الألف حبة ودل ذلك علي أن الفعل الجيني المضيف يلعب دور كبير في وراثة هذه الصفات. وعلي النقيض فإن نسبة K^2sca K^2gcax كانت أقل من الوحدة لصفات عدد الأيام حتي النضج، عدد الأشطاء في النبات ومحصول الحبوب وذلك يدل علي أن الفعل الجيني غير المضيف يلعب دور كبير في وراثة تلك الصفات. كان بين سلالات العقم البسمتي والسلالات البسمتي المعيدة للخصوبة ، السلالات العقيمة Sakha Basmati 12A, Sakha Basmati 13A , Sakha Basmati 14A و السلالات المعيدة للخصوبة EBR30, EBR25, EBR24, EBR3 , Giza Basmati 201 تم تعريفها علي أنها أفضل التراكيب في القدرة العامة علي الإئتلاف لصفة محصول الحبوب ومعظم الصفات تحت الدراسة. بين ٤٥ تركيب هجيني تم دراستها كانت الهجن IR58025Ax EBR10, Sakha Basmati 11Ax Giza Basmati 201, Sakha Basmati 12Ax EBR1, Sakha Basmati 12Ax EBR17, Sakha Basmati 13Ax EBR2 , Sakha Basmati 14Ax EBR2 هي الأفضل من حيث القدرة الخاصة علي الإئتلاف لمعظم صفات المحصول ومكوناته.