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COMBINING ABILITY STUDIES FOR DEVELOPING NEW BASMATI RICE HYBRIDS IN EGYPT

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ABSTRACT

Combining ability studies on some agronomic and grain yield and its components were done via Line x Tester analysis of 60 hybrids produced by crossing five basmati and one un-basmati CMS lines and ten basmati restorer lines including the un-basmati restorer variety Giza 178. The results indicated that plant height, panicle weight, filled grains panicle^{-1}, spikelet fertility %, 1000-grain weight and grain yield (t/ha) were mainly controlled by additive gene action, while, days to maturity (earliness) and panicles plant^{-1} were mainly governed by dominance gene action (non-additive). Egyptian Pusa basmati 12A/B, 13A/B and 14A/B were general combiners among the female parents for most of the studied traits. The male parents Giza basmati 201, EPR30 and EPR25 were the best general combiners for most of the studied traits. Twenty seven out of the sixty hybrid rice combinations resulted from Basmati female and male parents exhibited significant desirable SCA effects for grain yield. The most desirable hybrids were IR58025A/EPR15, Pusa14A/EPR25, IR58025A/EPR16, Pusa13A/EPR1 and Pusa14A/EPR1.

Key words: ***Hybrid Rice, Basmati, GCA, SCA, Gene action.***

INTRODUCTION

Rice is an important food crop. Besides, it is the most extensively grown cereal in the tropical and subtropical regions of the world. In addition, rice has special position as a source of providing over 75% of Asian population and more than three billion of world populations meal which represents more than 50% of their daily calorie intake (Khush 2005 and Amirjani 2011).

The fine grains of Basmati rice varieties are considered as high quality that achieves high price in the national and international trade (Rashid *et al* 2007). Aromatic races constitute a small but an important sub group of rice. Aromatic races are rated best in quality and fetch much higher price than high quality non-aromatic rice in international market (Singh *et al* 1997).

Hybrid rice technology might be considered as a big breakthrough that can further increase rice production leading to food security and reduction of poverty in Egypt. Hybrid rice combinations can out yield conventional cultivars by 20-25% under the same input levels (El-Mowafi *et al* 2005).

The parents with good GCA can be used to obtain a hybrid with high heterosis in all the hybrids developed from them, which is a function of such the two parents of a hybrid (El-Mowafi *et al* 2005). Several methods such as per se performance, genetic diversity, combining ability and others, have been attempted to select the parents. Among them combining ability analysis offers a powerful tool for estimating the value of a parent to produce superior hybrid combinations. The combining ability studies provide information which helps in the selection of better parents (Salgotra *et al* 2009 and Hasan *et al* 2013). Thus, the present investigation was carried out to study the combining ability in order to identify good Basmati combiners and superior Basmati hybrid combinations.

MATERIALS AND METHODS

The present study was carried out at the Experimental Research Station, Kafr El-Sheikh during the three successive growing seasons of 2017, 2018 and 2019. The genetic materials used in this investigation involved six cytoplasmic male sterile lines (CMS), five of them were aromatic (basmatic) and one was unaromatic rice. The CMS lines were as a wild abortive cytoplasmic male sterility source (WA) with three lines system (A, B and R lines). The CMS lines were used as female lines. The new nine Egyptian basmatic restores developed by hybrid rice breeding program in Egypt, along with one non-aromatic (Giza 178) were used as male parents (testers).

The experimental comprised 48 F_1 derived from combinations generated from Line x tester mating design. Five basmatic or aromatic CMS lines viz., IR58025A, Pusa11A, Pusa12A. Pusa13A and IR68902A and one unaromatic CMS line, Sakha1A Possessing wild abortive (WA) type were used as female lines. New basmatic restorer lines *viz*., EPR1, EPR2, EPR3, EPR15, EPR16, EPR20, EPR25, EPR30, Giza Basmatic 201 and the non-basmati variety Giza178 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 2017 and 2018 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 make the hybrids among the parental lines and to obtain the hybrid seeds. The experimental hybrids among CMS lines and tester lines were attempted during the years 2017 and 2018 through hybrid rice breeding and seed production program (A X R) to produce enough amounts of hybrid rice seeds for replicated yield experiment. The F_1 hybrid rice combinations along with their respective parents were grown in a randomized complete block design with four replications at Sakha Research Station in 2019 summer season. Thirty-day old seedling was 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 and 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 ten agronomic and yield characters. Observations were taken on ten plants $plot^{-1}$ at random from each entry in each replication according to IRRI Standard Evaluation System (SES) 2014 for agronomic and yield characters.

Table 1. Cytoplasmic male sterile lines (females) and tester lines (male parents or restorers) used in the study

Genotype	Cytoplasmic source	Aroma	Origin
CMS lines (Female lines)			
1- IR58025A	WA (wild abortive)	Aromatic	IRRI
2- Pusa11A	WA (wild abortive)	Aromatic	Egypt
3- Pusa12A	WA (wild abortive)	Aromatic	Egypt
4- Pusa13A	WA (wild abortive)	Aromatic	Egypt
5- Pusa14A	WA (wild abortive)	Aromatic	IRRI-Egypt
6- Sakha1A/B	WA (wild abortive)	Unaromatic	IRRI-Egypt
Restorer/tester lines			
Egyptian PusaR1 (EPR1)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR2 (EPR2)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR3 (EPR3)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR15 (EPR15)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR16 (EPR16)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR20 (EPR20)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR25 (EPR25)	New basmatic restorer	Aromatic	Egypt
Egyptian PusaR30 (EPR30)	New basmatic restorer	Aromatic	Egypt
Giza Basmatic 201	New basmatic restorer	Aromatic	Egypt
Giza 178	Commercial Restorer	Unaromatic	Egypt

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

RESULTS AND DISCUSSION

Mean performance

Mean performance of 16 basmati and unbasmati parental lines (six CMS and ten restorer lines) and their 60 hybrid rice combinations of line x tester for ten agronomc and yield characters are presented in table (2).

Table 2. Mean performance of parents and their F_1 hybrid for studied characters.

Genotype	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Tillers plant^{-1}
Female					
IR58025 A	138.00	110.23	24.73	220.24	18.60
Pusa 11A	138.45	109.30	24.63	198.59	15.48
Pusa 12A	136.78	96.16	24.15	189.42	16.75
Pusa 13A	137.70	96.95	24.58	182.17	16.98
Pusa 14A	136.43	110.93	22.83	161.80	16.32
Sakha 1A/B	134.43	99.08	22.60	158.15	18.56
Male					
EPR 1	134.73	114.65	27.58	221.93	19.75
EPR 2	134.30	117.04	27.53	194.83	20.42
EPR 3	133.78	110.91	28.05	197.42	20.20
EPR 15	130.15	104.74	27.55	284.48	19.09
EPR 16	132.38	109.75	23.38	257.22	19.55
EPR 20	132.95	111.32	28.83	251.49	19.15
EPR 25	136.43	112.81	25.30	262.31	17.99
EPR 30	131.00	110.33	22.13	331.98	21.37
Giza Basmati 201	134.48	116.44	28.50	206.00	23.02
Giza 178	135.10	103.34	23.48	175.20	22.32
Hybrid					
IR58025 A x EPR 1	136.08	111.52	29.45	245.49	20.84
EPR 2	133.70	111.23	29.73	234.16	19.43
EPR 3	128.45	113.32	29.05	252.70	21.05
EPR 15	132.50	108.37	28.38	294.04	20.51
EPR 16	134.65	114.94	25.80	277.54	20.64
EPR 20	135.18	116.17	28.25	276.12	22.29
EPR 25	137.43	117.05	26.23	281.74	20.09
EPR 30	131.70	113.83	25.60	305.95	23.39
Giza Basmati 201	132.95	113.88	29.23	253.48	20.35
Giza 178	133.95	105.88	25.75	217.03	23.24
Pusa 11A x EPR 1	133.38	112.28	26.53	209.83	23.93
EPR 2	132.38	114.99	26.43	243.90	19.64
EPR 3	133.43	112.10	27.30	269.22	21.01
EPR 15	134.83	108.09	28.10	285.52	18.75
EPR 16	131.05	111.27	25.13	260.45	20.15
EPR 20	134.30	115.39	27.90	254.22	22.27
EPR 25	135.30	116.58	25.95	265.56	19.15
EPR 30	131.85	113.15	25.35	272.11	23.23
Giza Basmati 201	137.53	112.11	27.75	265.48	20.89
Giza 178	135.00	108.35	25.43	236.50	19.48

Table 2. Cont.

Genotype	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Tillers plant^{-1}
Pusa 12A x EPR 1	129.38	110.28	27.50	261.91	23.19
EPR 2	129.00	109.69	27.33	264.76	22.11
EPR 3	126.85	105.40	28.58	270.54	25.40
EPR 15	131.78	103.21	28.25	278.35	19.45
EPR 16	132.05	108.25	26.03	261.99	19.59
EPR 20	134.38	110.28	28.50	249.34	23.36
EPR 25	135.18	110.67	27.00	266.51	19.75
EPR 30	131.40	108.88	25.03	291.98	20.88
Giza Basmati 201	134.80	110.98	29.83	225.10	24.27
Giza 178	130.93	105.75	25.33	263.67	21.21
Pusa 13A x EPR 1	131.13	111.18	27.85	231.13	23.98
EPR 2	130.85	110.08	27.75	254.08	23.30
EPR 3	129.18	105.88	27.95	269.70	22.45
EPR 15	131.40	103.77	28.60	276.10	21.59
EPR 16	133.90	108.81	25.70	250.32	22.73
EPR 20	134.05	110.71	27.38	238.37	21.70
EPR 25	135.75	111.01	25.63	274.31	20.32
EPR 30	131.90	109.36	25.38	303.74	24.43
Giza Basmati 201	134.65	111.47	28.08	233.14	26.50
Giza 178	132.00	106.23	25.58	238.44	25.79
Pusa 14A x EPR 1	136.95	113.13	28.95	239.58	19.41
EPR 2	136.43	113.63	29.00	238.17	20.84
EPR 3	132.43	112.35	30.13	236.92	19.63
EPR 15	132.68	108.50	28.03	252.12	19.96
EPR 16	133.93	111.61	24.28	240.58	21.12
EPR 20	134.90	113.14	30.23	228.99	20.58
EPR 25	134.85	114.26	26.10	243.66	18.62
EPR 30	133.05	112.16	24.83	284.04	23.54
Giza Basmati 201	135.38	114.11	29.70	244.32	21.02
Giza 178	131.85	105.06	25.78	200.89	26.93
Sakha 1A x EPR 1	131.18	111.10	27.63	225.37	23.35
EPR 2	131.08	114.75	27.33	222.34	24.87
EPR 3	129.43	108.27	28.50	219.78	23.89
EPR 15	130.83	107.23	26.80	244.55	21.41
EPR 16	131.65	110.09	24.90	240.05	22.05
EPR 20	131.88	109.59	27.20	231.25	20.56
EPR 25	135.08	111.62	24.88	241.06	20.76
EPR 30	131.85	111.08	23.88	286.88	25.14
Giza Basmati 201	129.38	113.40	28.90	218.37	25.98
Giza 178	134.68	110.46	25.68	215.06	22.57

Table 2. Cont.

Genotype	Panicle weight	Filled grains panicle	Grain yield (t/ha)	Spikelets fertiliety%	1000-grain weight
Female					
IR58025 A	4.38	189.32	8.00	85.96	23.17
Pusa 11A	4.15	177.23	6.95	89.23	23.38
Pusa 12A	4.26	172.83	8.32	91.28	24.68
Pusa 13A	4.13	168.18	8.38	92.42	24.64
Pusa 14A	3.31	146.10	6.99	90.29	22.58
Sakha 1A/B	3.58	149.05	9.40	94.19	23.87
Male					
EPR 1	5.52	198.74	10.17	89.57	28.77
EPR 2	5.26	179.12	10.17	91.94	28.78
EPR 3	5.60	187.30	10.49	94.87	29.68
EPR 15	6.55	269.15	10.74	94.61	24.31
EPR 16	6.23	247.03	10.75	96.03	24.74
EPR 20	6.42	242.93	10.84	96.59	26.47
EPR 25	6.28	242.28	10.63	92.37	25.14
EPR 30	6.98	308.25	10.80	92.84	22.63
Giza Basmati 201	5.65	189.60	10.70	91.99	29.84
Giza 178	3.67	163.43	10.56	93.29	22.35
Hybrid					
IR58025 A x EPR 1	5.84	219.75	12.15	89.52	26.59
EPR 2	5.68	214.42	12.23	91.57	26.46
EPR 3	6.10	223.92	12.56	88.60	27.20
EPR 15	6.83	269.20	12.80	91.55	25.36
EPR 16	6.58	250.79	12.71	90.37	26.23
EPR 20	6.68	247.37	12.72	89.59	26.98
EPR 25	6.58	251.70	12.89	89.34	26.15
EPR 30	7.28	276.44	13.00	90.37	26.35
Giza Basmati 201	6.43	224.64	13.13	88.62	28.25
Giza 178	4.94	192.01	12.89	88.47	25.38
Pusa 11A x EPR 1	5.57	183.03	12.89	87.37	27.84
EPR 2	5.96	216.53	13.04	88.79	27.53
EPR 3	6.45	235.10	13.41	87.32	27.44
EPR 15	6.93	256.32	13.21	89.78	27.02
EPR 16	6.16	227.87	13.01	87.49	27.01
EPR 20	6.23	228.83	13.28	90.01	27.15
EPR 25	6.30	242.31	13.50	91.25	25.98
EPR 30	6.44	245.92	13.63	90.37	26.20
Giza Basmati 201	6.74	245.77	13.68	92.58	27.44
Giza 178	5.13	206.64	13.68	87.42	24.91

Table 2. Cont.

Genotype	Panicle weight	Filled grains panicle	Grain yield (t/ha)	Spikelets fertiliety%	1000-grain weight
Pusa 12A x EPR 1	6.42	233.29	13.58	89.09	27.52
EPR 2	6.27	227.52	13.59	85.96	27.60
EPR 3	6.70	237.25	13.67	87.70	28.23
EPR 15	7.28	265.11	12.95	95.25	27.46
EPR 16	6.69	245.99	13.48	93.90	27.19
EPR 20	6.32	230.21	13.57	92.34	27.44
EPR 25	6.76	251.44	13.77	94.35	26.87
EPR 30	7.23	270.20	13.77	92.55	26.78
Giza Basmati 201	5.77	203.70	13.71	90.49	28.24
Giza 178	6.37	245.45	13.73	93.10	25.76
Pusa 13A x EPR 1	5.71	203.18	13.58	87.90	27.82
EPR 2	6.22	224.79	13.25	88.52	27.72
EPR 3	6.65	235.11	13.58	87.18	28.25
EPR 15	6.96	252.70	13.36	91.53	27.52
EPR 16	6.17	224.01	13.18	89.50	27.35
EPR 20	5.73	209.47	13.47	87.88	27.42
EPR 25	6.66	246.72	13.66	89.95	26.88
EPR 30	7.17	266.84	13.69	87.85	26.81
Giza Basmati 201	6.12	208.46	13.75	89.45	29.27
Giza 178	5.76	222.46	13.80	93.31	26.02
Pusa 14A x EPR 1	5.88	219.26	13.60	91.52	26.49
EPR 2	5.68	220.29	13.65	92.50	25.75
EPR 3	6.12	220.38	13.69	93.02	27.74
EPR 15	6.26	236.48	13.39	93.80	26.45
EPR 16	6.11	228.67	13.20	95.05	26.71
EPR 20	6.06	219.70	13.41	95.95	27.31
EPR 25	6.27	231.49	13.57	95.00	26.29
EPR 30	6.97	263.31	13.82	92.70	26.44
Giza Basmati 201	6.45	231.05	13.86	94.57	27.79
Giza 178	5.06	185.23	13.54	92.21	26.54
Sakha 1A x EPR 1	5.92	207.44	13.59	92.05	28.49
EPR 2	5.83	203.53	13.56	91.54	28.61
EPR 3	6.22	205.40	13.63	93.46	30.39
EPR 15	6.29	225.83	13.30	92.35	27.84
EPR 16	6.02	219.26	13.31	91.34	27.32
EPR 20	5.87	215.81	13.51	93.33	27.20
EPR 25	6.03	224.38	13.68	93.08	26.61
EPR 30	6.93	268.57	13.79	93.62	26.16
Giza Basmati 201	6.23	201.77	13.75	92.39	30.83
Giza 178	5.18	191.73	13.74	89.17	26.93

Complete to over dominance was observed in most hybrid rice combinations for early maturity (49 hybrids), taller parents for plant height (20 hybrids), longest panicle length (43 hybrids), high number of spikelets panicle^{-1} (38 hybrids), high number of panicles plant^{-1} (43 hybrids), heavier grain weight (43 hybrids), high number of filled grains panicle^{-1} (35 hybrids) and heavier 1000-grain weight. As revealed in Table (2), there existed complete to over dominance for low rate or high rate of spikelet fertility percentage. All hybrid rice combinations exhibited dominance effects towards higher grain yield (the 60 hybrids). Some hybrids exhibited dominance effect towards the lower parents for lower number of spikelets panicle^{-1} (two hybrids), spikelet fertility% (19 hybrids). The rest of hybrid rice combinations showed intermediate mean values between the two parents involved for days to maturity (11 hybrid), plant height (40 hybrids), panicle length (17 hybrids), spikelets panicle $^{-1}$ (20 hybrids), panicles plant^{-1} (17 hybrids), panicle weight (17 hybrids), filled grains panicle^{-1} (25 hybrids), spikelet fertility% (33 hybrids) and 1000-grain weight (21 hybrids), indicating additive or no-dominance effects.

Analysis of variance

The analysis of variance (Table 3 showed highly significant differences among the 76 genotypes (16 parents and 60 F_1 hybrids) which were tested for all studied agronomic and yield. Parents *vs* hybrids mean squares indicated that average heterosis was highly significant in all hybrids for all agronomic and yield studied traits under this investigation.

The analysis of variance for combining ability given in Table (3) showed highly significant differences among CMS and restorer (tester) lines (GCS) of basmati and unbasmati rice genotypes. The highly significant mean squares of lines x testers (SCA) for all studied traits, indicated that interaction produced markedly different combining ability effects and this might be due to the wide genetic diversity of basmati CMS and basmati restorer lines.

The estimated values of variance due to GCA were higher than due to SCA for plant height, panicle length, spikelets panicle^{-1}, panicle weight, filled grains panicle^{-1}, spikelet fertility%, 1000-grain weight and grain yield (t/ha) traits and suggesting greater importance of additive genetic variance for these traits (Table 3).

Table 3. Mean square estimates of ordinary analysis of variance for ten agronomic and yield studied characters.

SOV	df	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Tillers plant^{-1}
Replications	3	0.426	2.481**	0.379	14.314	2.76
Treatments	75	24.564**	69.483**	14.747**	4436.867**	22.574**
Parents	15	24.15**	169.485**	20.939**	9122.056**	17.894**
Crosses	59	22.094**	40.205**	10.676**	2312.424**	17.374**
Par. *vs*. crosses	1	176.489**	296.863**	162.042**	59501.16**	399.618**
Lines	5	56.527**	134.549**	11.005**	5921.714**	43.236**
Testers	9	53.242**	138.857**	54.023**	8219.292**	37.247**
Lines x testers	45	12.038**	9.992**	1.971**	730.018**	10.525**
Residual	225	0.458	0.635	0.288	18.197	1.223
CV%		0.51	0.72	2.01	1.74	5.19
SOV	**df**	**Panicle weight**	**Filled grains panicle**	**Grain yield (t/ha)**	**Spikelets fertiliety%**	**1000- grain weight**
Replications	3	0.006	7.027	0.003	0.64	0.023
Treatments	75	2.898**	3786.673**	11.640**	26.244**	11.269**
Parents	15	5.708**	8590.462**	7.953**	29.745**	26.909**
Crosses	59	1.139**	1967.957**	0.626**	24.131**	4.573**
Par. *vs*. crosses	1	64.54**	39034.07**	716.773**	98.392**	171.731**
Lines	5	1.491**	3016.749**	4.801**	128.604**	12.945**
Testers	9	4.866**	7982.636**	0.879**	25.177**	15.96**
Lines x testers	45	0.354**	648.489**	0.112**	12.314**	1.366**
Residual	225	0.005	15.836	0.002	1.873	0.04
CV%		1.16	1.78	0.35	1.50	0.75

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

The analysis of variance for combining ability showed highly significant mean squares due to both GCA and SCA. Therefore, it seemed that both additive and non-additive were operative with greater importance of additive genetic variance (GCA) for most of traits studied. Similar results were reported by El-Mowafi (2001), El-Mowafi *et al* (2005), El-Daisty *et al* (2008), Alam *et al* (2007), El-Mowafi *et al* (2015), Abdelkhalik (2015), Abd El-Hadi *et al* (2018), El-Mowafi *et al* (2018) and El-Mowafi *et al* (2021).

Genetic Parameters

The estimates of genetic parameters for the ten agronomic and yield studied traits are presented in table (4). Line x Tester mating design was developed to partition genetic variance into its components. The total genetic variance was divided into lines, testers and line x tester interaction components. The first portion of variance, i.e., line and tester estimate the additive genetic variance while the second portion, line x tester interaction estimates the non-additive genetic variance including dominance.

The results indicated that the additive genetic variance (σ^2 A) that insure the relative importance of general combining ability percentage (GCA%) was for plant height, panicle length, spikelets panicle^{-1}, panicle weight, filled grains panicle^{-1}, spikelet fertility%, 1000-grain weight and Grain yield (t/ha) were greater than dominance variance (σ^2 D). The data also showed the relative importance of SCA%, respectively for the previous traits. On the other hand, non additive or dominance (σ^2 D) and the relative importance of SCA% for days to maturity and panicles plant^{-1} was greater than additive variance and relative importance of GCA%. The importance of the additive and non additive gene action for the inheritance of the studied traits is in agreement with the findings of El-Mowafi and Abou Shousha (2003), El-Mowafi *et al* (2005), Abd El-Hadi and El-Mowafi (2005), Abdallah (2013), El-Mowafi *et al* (2015), El-Mowafi *et al* (2019) and El-Mowafi *et al* (2021).

Concerning heritability estimates (Table 4) in broad sense (h^2_b %), the results revealed that the h^2_b was high for all agronomic and yield studied traits and ranged from 76.37% for spikelet fertility% to 98.88% for grain yield (t/ha).

Table 4. Genetic parameters estimates of ordinary analysis for ten agronomic and yield studied characters.

SOV	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Tillers plant^{-1}
Parameter					
Additive variance (σ^2 A)	2.83	8.48	2.39	441.85	1.93
Dominant variance (σ^2 D)	2.90	2.34	0.42	177.96	2.33
Environmental variance (σ^2 E)	0.46	0.64	0.29	18.20	1.22
Genotypic variance ($\sigma 2_g$)	5.72	10.82	2.82	619.80	4.26
Phenotypic variance ($\sigma^2{}_p$)	6.18	11.46	3.10	638.00	5.48
Broad sense heritability ($h^2{}_b$) %	92.59	94.46	90.72	97.15	77.68
Narrow sense heritability ($h^2{}_n$)%	45.76	74.04	77.16	69.26	35.24
Relative importance of gca%*	49.42	78.39	85.06	71.29	45.37
Relative importance of sca%**	50.58	21.61	14.94	28.71	54.63
SOV	**Panicle weight**	**Filled grains panicle**	**Grain yield (t/ha)**	**Spikelets fertiliety %**	**1000-grain weight**
Parameter					
Additive variance (σ2 A)	0.22	364.80	0.15	3.44	0.90
Dominant variance (σ2 D)	0.09	158.16	0.03	2.61	0.33
Environmental variance (σ2 E)	0.01	15.84	0.00	1.87	0.04
Genotypic variance (σ2 g)	0.30	522.96	0.18	6.05	1.23
Phenotypic variance (σ2 p)	0.31	538.80	0.18	7.93	1.27
Broad sense heritability (h^2b) %	98.38	97.06	98.88	76.37	96.85
Narrow sense heritability (h^2n)%	70.11	67.71	83.49	43.44	70.73
Relative importance of gca%*	71.27	69.76	84.44	56.88	73.03
Relative importance of sca%**	28.73	30.24	15.56	43.12	26.97

However, heritability in the narrow sense ($h^2{}_n$%) was low or medium for panicles plant$^{-1,}$ spikelet fertility% and days to maturity (35.24, 43.44 and 45.76%, respectively) and high for plant height (74.04%), panicle length (77.16%), spikelets panicle^{-} (69.26%), panicle weight (70.11%), filled grains panicle^{-1} (67.71%), 1000-grain weight (70.73%) and grain yield (83.49%). These results were in general agreement with those reported by

El-Mowafi *et al* (2005), Abd El-Hadi *et al* (2018), El-Mowafi *et al* (2019) and El-Mowafi *et al* (2021).

Estimates of combining ability effects:

General combining ability effects (GCA):

GCA effects of five aromatic or basmati CMS or their maintainer (A/B) lines (IR58025A, Pusa Basmati 11A/B, Pusa Basmati 12A/B, Pusa Basmati 13A/B and Pusa Basmati 14A/B and only one un-aromatic CMS (Sakha 1A/B) and ten restorer lines (testers), nine of them were aromatic or basmati rice (Egyptian Pusa Basmati Restorers (EPR) and un-aromatic restorer Giza 178 were tested for ten agronomic and yield traits and the results are presented in Tables (5 and 6).

Estimates of GCA effects for each CMS and restorer line for days to maturity (earliness) and plant height (short stature plant) are presented in Tables (5 and 6). Since negative and significant values of GCA effects would be of interest for early maturity and short stature plant, the Pusa CMS line Pusa Basmati 12A/B followed by the commercial CMS line Sakha1A/B then Pusa 13A/B were considered the best among the female CMS lines in hybrid rice breeding program.

Among the restorer lines, the Egyptian Pusa Restorers EPR3 and EPR15 recorded highly significant and negative estimates of GCA effects for days to maturity and plant height traits. These aromatic Pusa Basmati restorer lines proved to be good combiners for earliness and short stature plant. El-Mowafi *et al* (2005), Abdelkhalik (2015), El-Mowafi *et al* (2015), El-Mowafi *et al* (2018) and El-Mowafi *et al* (2021) observed rice genotypes showing negative GCA effects for days to maturity and plant height characters. The Pusa Basmati CMS line Pusa12A/B was the best combiner for days to maturity, plant height, panicle length, spikelets panicle^{-1}, panicle weight, 1000-grain weight. Besides, it was also good combiner for grain yield. Pusa 13A/B was the best combiner for earliness, short stature plant, spikelets panicle^{-1}, panicles plant^{-1}, panicle weight and 1000-grain weight, Pusa 14A/B was good combiner for panicle length, spikeket fertility% and grain yield and the un-aromatic CMS lines Sakha 1A/B was a good combiner for panicles plant^{-1}, spikelet fertility%, 1000-grain weight and grain yield (Table5).

Table 5. GCA effects of the lines for studied traits in rice

Lines	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Panicles plant^{-1}
IR58025 A	0.67**	1.82**	0.59**	11.18**	-0.73**
Pusa 11A	1.14**	1.63**	-0.57**	3.64**	-1.06**
Pusa 12A	-1.36**	-2.46**	0.18**	10.77**	0.01
Pusa 13A	-0.42**	-1.95**	-0.17*	4.29**	1.37**
Pusa 14A	1.27**	1.00**	0.55**	-11.71**	-0.75**
Sakha 1A/B	-1.30**	-0.04	-0.59**	-18.17**	1.15**
LSD 5%	0.18	0.21	0.14	1.12	0.29
LSD 1%	0.25	0.30	0.20	1.59	0.41
Lines	**panicle weight**	**filled grains panicle**	**Grain yield (t/ha)**	**spikelets fertiliety%**	**1000 grain weight**
IR58025 A	0.04**	7.32**	-0.68**	-1.15**	-0.67**
Pusa 11A	-0.06**	-0.87	-0.05**	-1.71**	-0.31**
Pusa 12A	0.33**	11.32**	0.20**	0.53**	0.15**
Pusa 13A	0.06**	-0.33	0.15**	-1.64**	0.35**
Pusa 14A	-0.17**	-4.11**	0.19**	2.69**	-0.41**
Sakha 1A/B	-0.20**	-13.33**	0.20**	1.29**	0.88**
LSD 5%	0.02	1.04	0.01	0.36	0.05
LSD 1%	0.03	1.49	0.02	0.51	0.07

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

Among the testers or restorer lines (Table 6), Giza Basmati 201 was the best general combiner for panicle length, panicles plant^{-1}, panicle weight, 1000-grain weight and grain yield. EPR30 was the best general combiner for days to maturity, spikelets panicle^{-1}, panicles palnt^{-1}, panicle weight, filled grains panicle^{-1} and grain yield (t/ha). Giza 178 was the best combiner for short stature plant, panicles plant^{-1} and grain yield. EPR25 was the best combiner for spikelets panicles $^{-1}$, spikelet fertility % and grain yield. However, the Egyptian Pusa restorer line EPR3 was the best combiner for days to maturity, plant height, panicle length, panicle weight, 1000-grain weight and grain yield.

Table 6. GCA effects of the testers for studied traits in rice.

Lines	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	Panicles $plant^{-1}$
PR 1	0.06	0.78**	0.83**	-17.09**	0.54**
PR 2	-0.65**	1.60**	0.77**	-9.74**	-0.21
PR 3	-3.01**	-1.24**	1.43**	0.50	0.33
PR 15	-0.36**	-4.27**	0.87**	19.14**	-1.63**
PR 16	-0.21	0.03	-1.85**	2.51**	-0.86**
PR 20	1.31**	1.75**	1.09**	-6.26**	-0.12
PR 25	2.54**	2.73**	-1.19**	9.50**	-2.13**
PR 30	-0.93**	0.61**	-2.15**	38.14**	1.52**
Giza Basmati 201	1.13**	1.86**	1.76**	-12.66**	1.26**
Giza 178	0.11	-3.84**	-1.57**	-24.04**	1.29**
LSD 5 %	0.23	0.27	0.18	1.45	0.37
LSD 1%	0.33	0.38	0.26	2.06	0.53
Lines	**panicle weight**	**filled grains panicle**	**Grain yield (t/ha)**	**spikelets fertiliety%**	**1000 grain weight**
PR 1	-0.36**	-18.71**	-0.15**	-1.37**	0.30**
PR 2	-0.31**	-11.85**	-0.16**	-1.13**	0.12**
PR 3	0.12**	-3.51**	0.04**	-1.40**	1.05**
PR 15	0.50**	21.24**	-0.22**	1.43**	-0.22**
PR 16	0.04**	3.07**	-0.24**	0.33	-0.19**
PR 20	-0.11**	-4.47**	-0.06**	0.57*	0.09*
PR 25	0.18**	11.64**	0.13**	1.21**	-0.69**
PR 30	0.75**	35.51**	0.23**	0.30	-0.70**
Giza Basmati 201	0.04**	-10.47**	0.26**	0.41	1.48**
Giza 178	-0.85**	-22.45**	0.18**	-0.33	-1.24**
LSD 5 %	0.02	1.35	0.02	0.46	0.07
LSD 1%	0.03	1.92	0.02	0.66	0.10

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

Specific combining ability effects (SCA)

The data of the SCA effects are given in Table (7). They revealed that there are some superior basmati combinations that could be useful in the hybrid rice breeding program for basmati rice. With respect to days to maturity and plant height, 24 and 14 hybrids showed significant effects and negative in the desired direction for the two traits, respectively.

Table 7. SCA effects of agronomic and yield traits in Basmati hybrid rice.

Hybrids	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	panicles $plant^{-1}$
IR58025 A x PR 1	2.446**	-1.885**	0.875**	-1.245	-0.886
PR 2	0.738*	-2.985**	1.208**	-19.927**	-1.539**
PR 3	-2.183**	1.948**	-0.125	-11.628**	-0.464
PR 15	-0.783*	0.020	-0.242	11.075**	0.956*
PR 16	1.021**	2.288**	-0.096	11.204**	0.325
PR 20	0.925**	1.806**	-0.583*	18.552**	1.223**
PR 25	0.846**	1.698**	-0.329	8.414**	1.036**
PR 30	-1.312**	0.603	0.000	3.987*	0.682
Giza Basmati 201	-1.925**	-0.600	-0.279	2.317	-2.095**
Giza 178	0.225	-2.893**	-0.429	-22.749**	0.762
Pusa 11A x PR 1	-0.641*	-0.929*	-0.890**	-29.365**	2.541**
PR 2	-1.125**	0.961**	-0.932**	-2.638	-0.996*
PR 3	2.080**	0.916*	-0.715**	12.443**	-0.169
PR 15	2.880**	-0.072	0.643**	10.103**	-0.467
PR 16	-2.716**	-1.189**	0.389	1.660	0.160
PR 20	-1.262**	1.210**	0.227	4.203*	1.533**
PR 25	-1.491**	1.416**	0.556*	-0.217	0.429
PR 30	-0.575*	0.106	0.910**	-22.312**	0.852
Giza Basmati 201	2.013**	-2.182**	-0.594*	21.858**	-1.220**
Giza 178	0.838**	-0.237	0.406	4.266*	-2.663**
Pusa 12A x PR 1	-2.341**	1.158**	-0.665**	15.586**	0.725
PR 2	-1.825**	-0.239	-0.782**	11.090**	0.400
PR 3	-1.845**	-1.697**	-0.190	6.624**	3.149**
PR 15	0.680*	-0.860*	0.043	-4.203*	-0.836
PR 16	0.634*	-0.119	0.539*	-3.942*	-1.469**
PR 20	1.313**	0.194	0.077	-7.811**	1.554**
PR 25	1.159**	-0.400	0.856**	-6.406**	-0.045
PR 30	0.725*	-0.070	-0.165	-9.581**	-2.562**
Giza Basmati 201	2.113**	0.780*	0.731**	-25.656**	1.089*
Giza 178	-0.612*	1.253**	-0.444	24.300**	-2.004**
Pusa 13A x PR 1	-1.309**	1.544**	0.033	-8.711**	0.162
PR 2	-0.942**	-0.368	-0.009	6.885**	0.227
PR 3	-0.463	-1.724**	-0.468*	12.266**	-1.156**
PR 15	-0.713*	-0.811*	0.741**	0.030	-0.059
PR 16	1.566**	-0.068	0.562*	-9.132**	0.315
PR 20	0.670*	0.110	-0.701**	-12.301**	-1.462**
PR 25	0.291	-0.571	-0.172	7.879**	-0.828
PR 30	0.283	-0.101	0.533*	8.669**	-0.378
Giza Basmati 201	1.170**	0.766*	-0.672**	-11.131**	1.965**
Giza 178	-0.555	1.224**	0.153	5.545**	1.215**

Table 7. Cont.

Hybrids	Days to maturity (day)	Plant height (cm)	Panicle length (cm)	Spikelets/ panicle	panicles plant^{-1}
Pusa 14A x PR 1	2.604**	0.555	0.420	15.745**	-2.292**
PR 2	2.770**	0.237	0.528*	6.981**	-0.115
PR 3	1.425**	1.804**	0.995**	-4.513*	-1.863**
PR 15	-1.125**	0.979**	-0.547*	-7.945**	0.422
PR 16	-0.196	-0.215	-1.576**	-2.858	0.816
PR 20	-0.642*	-0.400	1.437**	-5.680**	-0.469
PR 25	-1.721**	-0.271	-0.409	-6.763**	-0.420
PR 30	-0.280	-0.248	-0.730**	4.975*	0.848
Giza Basmati 201	0.008	0.454	0.241	16.050**	-1.399**
Giza 178	-2.842**	-2.896**	-0.359	-15.992**	4.471**
Sakha 1A x PR 1	-0.759*	-0.444	0.228	7.989**	-0.249
PR 2	0.383	2.394**	-0.014	-2.392	2.023**
PR 3	0.987**	-1.247**	0.503*	-15.191**	0.503
PR 15	-0.938**	0.744*	-0.639**	-9.060**	-0.015
PR 16	-0.309	-0.696*	0.182	3.068	-0.146
PR 20	-1.005**	-2.920**	-0.456*	3.037	-2.378**
PR 25	0.916**	-1.872**	-0.502*	-2.906	-0.172
PR 30	1.158**	-0.289	-0.548*	14.264**	0.556
Giza Basmati 201	-3.380**	0.781*	0.573*	-3.438	1.659**
Giza 178	2.945**	3.549**	0.673**	4.630*	-1.781**
LSD 5 %	0.562	0.661	0.445	3.541	0.918
1%	0.800	0.942	0.634	5.042	1.307

Table 7. Cont.

Hybrids	Panicle weight	Filled grains panicle	Grain yield $(t/ha)^{-1}$	Spikelets fertiliety%	1000 grain weight
IR58025 A x PR 1	-0.086**	1.435	-0.404**	1.087	-0.202*
PR 2	-0.304**	-10.751**	-0.308**	2.907**	-0.158
PR 3	-0.316**	-9.598**	-0.184**	0.203	-0.344**
PR 15	0.029	10.939**	0.311**	0.326	-0.921**
PR 16	0.251**	10.702**	0.239**	0.237	-0.075
PR 20	0.490**	14.813**	0.069**	-0.781	0.394**
PR 25	0.108**	3.039	0.057**	-1.674**	0.348**
PR 30	0.238**	3.904*	0.058**	0.274	0.556**
Giza Basmati 201	0.099**	-1.916	0.161**	-1.581*	0.276**
Giza 178	-0.510**	-22.568**	0.002	-0.998	0.126
Pusa 11A x PR 1	-0.261**	-27.094**	-0.293**	-0.495	0.687**
PR 2	0.084**	-0.445	-0.127**	0.682	0.560**
PR 3	0.141**	9.773**	0.041*	-0.519	-0.460**
PR 15	0.234**	6.252**	0.091**	-0.889	0.388**
PR 16	-0.069*	-4.027*	-0.088**	-2.077**	0.351**
PR 20	0.142**	4.471*	0.010	0.209	0.205*
PR 25	-0.074*	1.835	0.037*	0.796	-0.178*
PR 30	-0.499**	-18.423**	0.066**	0.839	0.050
Giza Basmati 201	0.516**	27.405**	0.089**	2.942**	-0.895**
Giza 178	-0.215**	0.253	0.173**	-1.488*	-0.708**
Pusa 12A x PR 1	0.205**	10.986**	0.155**	-1.015	-0.085
PR 2	0.005	-1.640	0.171**	-4.378**	0.173*
PR 3	-0.003	-0.257	0.047*	-2.371**	-0.130
PR 15	0.198**	2.850	-0.415**	2.349**	0.368**
PR 16	0.070*	1.910	0.133**	2.100**	0.071
PR 20	-0.159**	-6.339**	0.048*	0.297	0.038
PR 25	-0.003	-1.213	0.063**	1.664**	0.257**
PR 30	-0.101**	-6.330**	-0.040*	0.779	0.170*
Giza Basmati 201	-0.848**	-26.850**	-0.130**	-1.390*	-0.545**
Giza 178	0.636**	26.883**	-0.033	1.965**	-0.315**
Pusa 13A x PR 1	-0.245**	-7.489**	0.204**	-0.034	0.016
PR 2	0.220**	7.268**	-0.120**	0.343	0.092
PR 3	0.220**	9.240**	0.014	-0.728	-0.304**
PR 15	0.138**	2.088	0.041*	0.790	0.229*
PR 16	-0.178**	-8.427**	-0.111**	-0.131	0.033
PR 20	-0.482**	-15.436**	-0.003	-1.995**	-0.173*
PR 25	0.164**	5.710**	0.002	-0.568	0.070
PR 30	0.106**	1.950	-0.074**	-1.755**	0.006
Giza Basmati 201	-0.236**	-10.440**	-0.046*	-0.257	0.286**
Giza 178	0.293**	15.535**	0.091**	4.336**	-0.254**

Table 7. Cont.

Hybrids	panicle weight	filled grains panicle	*Grain yield (t/ha)*$^{-1}$	spikelets fertiliety%	1000 grain weight
Pusa 14A x PR 1	0.158**	12.381**	0.178**	-0.736	-0.565**
PR 2	-0.092**	6.557**	0.242**	0.004	-1.119**
PR 3	-0.087**	-1.698	0.078**	0.788	-0.060
PR 15	-0.332**	-10.345**	0.035	-1.264*	-0.082
PR 16	-0.010	0.020	-0.139**	1.090	0.149
PR 20	0.081*	-1.419	-0.104**	1.746**	0.463**
PR 25	0.005	-5.740**	-0.126**	0.148	0.235**
PR 30	0.132**	2.215	0.018	-1.227*	0.393**
Giza Basmati 201	0.325**	15.935**	0.026	0.534	-0.437**
Giza 178	-0.181**	-17.905**	-0.208**	-1.083	1.023**
Sakha 1A x PR 1	0.229**	9.781**	0.159**	1.193*	0.149
PR 2	0.087**	-0.988	0.142**	0.443	0.452**
PR 3	0.044	-7.460**	0.004	2.627**	1.299**
PR 15	-0.268**	-11.783**	-0.064**	-1.313*	0.017
PR 16	-0.066*	-0.178	-0.033	-1.219*	-0.529**
PR 20	-0.072*	3.908*	-0.021	0.525	-0.928**
PR 25	-0.199**	-3.631*	-0.033	-0.366	-0.731**
PR 30	0.124**	16.684**	-0.029	1.090	-1.173**
Giza Basmati 201	0.144**	-4.135*	-0.101**	-0.249	1.315**
Giza 178	-0.024	-2.198	-0.025	-2.732**	0.129
LSD 5 %	0.059	3.303	0.037	1.136	0.166
1%	0.084	4.704	0.053	1.618	0.236

For panicle length, 17 hybrids had superior SCA effects, 27 hybrids for spikelets panicle^{-1}, 11 for panicles plant^{-1}, 27 hybrids for panicle weight, 21 for filled grains panicle^{-1}, ten for spikelet fertility %, 22 for 1000- grain weight and 27 hybrid rice combinations for grain yield (t/ha) were superior in SCA effects. The hybrid IR58025A/EPR15 excelled others with significantly higher SCA effects for days to maturity, spikelets panicle^{-1}, panicles plant^{-1}, filled grains panicle^{-1} and grain yield (t/ha). It was followed by Pusa14A/EPR2 for panicle length, spikelets panicle^{-1}, filled grains panicle^{-1} and grain yield, IR58025A/EPR16 for spikelets panicle^{-1}, panicle weight and filled grains panicle^{-1} and grain yield (t/ha), Pusa13A/EPR1 for days to maturity and grain yield then Pusa14A/EPR1 for spikelets panicle^{-1}, panicle weight, filled grains panicle^{-1} and grain yield (t/ha).

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دراسات القدرة علي الإئتلاف لتطوير هجن أرز بسمتي جديدة في مصر

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تم تقدير القدرة علي الإئتلاف لبعض الصفات الحقلية وصفات المحصول ومكوناته الناتجة من تحليل السلالة x الكشاف لعدد ٦٠ هجين ناتجة بإستخدام التهجين بين خمسة سلالات عقم ذكري وراثي سيتوبلازمي بسمتي وسلالة واحدة غير بسمتي مع عشر سلالات معيدة للخصوبة (٩ سلالات بسمتي بالإضافة الي السلالة المعيدة للخصوبة جيزة ١٧٨). أظهرت النتائج أن صفات طول النبات، وزن السنبلة، عدد الحبوب الممتلئة بالسنبلة، النسبة المئوية لخصوبة السنيبلات، وزن الـ ١٠٠٠ حبة ومحصول الحبوب (طن/هكتار) يتحكم في وراثتها بشكل أساسي الفعل الجيني المضيف. بينما كانت صفات التبكير وعدد الأشطاء بالنبات يتحكم بها الفعل السيادي (غير المضيف). أظهرت السلالات Egyptian basmati 12A/B, 13A/B, 14A/B أفضل نتائج التوافق العام بين سلالات الأمهات لمعظم الصفات المدروسة، بينما كانت السلالات جيزة بسمتي ٢٠١ ، EPR30، EPR25 هي الأفضل بين سلالات الآباء لمعظم الصفات تحت الدراسة. أظهر ٢٧ هجين من بين الـ٦٠ تركيب هجيني تفوق معنوي بالنسبة لتقدير القدرة الخاصة علي الإئتلاف وكانت أفضل الهجن هي IR58025A/EPR15, Pusa14A/EPR25, Pusa14A/EPR1. IR58025A/EPR16, Pusa13A/EPR1

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