www.fagr.bu.edu.eg

Annals of Agricultural Science, Moshtohor (ASSJM)
https://assjm.journals.ekb.eg/

ISSN:1110-0419

Original Article Vol. 63(3) (2025), 17 – 32 DOI: 10.21608/assjm.2025.404844.1386

Genetical Improvement of Some Morphophysiological, Yield and Grain Quality Characteristics in Rice Crosses

Taalab[1], N.A.I, M.E.M. El-Badawy[1], A.A.A. El-Hosary[1], M.I. Abo Yousef[2] and S.A. Sedhom[1]
[1] Fac. of Agric., Benha Univ., Egypt.
[2] Rice Res. & Training Centre (RRTC), Field Crops Res. Inst., ARC, Giza, Egypt.
E-mail address: Sedhom.mansour@fagr.bu.edu.eg
https://orcid.org/0000-0002-5394-1184

Abstract

The genetic behavior of thirteen morphophysiological, yield and quality traits in rice was studied using L x T model. Six parent varieties, namely, SK104, SK106, GZ11332, SK108, SK109, SK101 and four testers Viz., IHL17, IHL65, IHL175, SR303 of Oryza sativa were used in this study in 2023 and 2024. The resultant twenty-four crosses were scrutinized in RCBD design with three replications. Results indicated that mean squares due to all crosses were significant for morphophysiological, yield and quality characteristics. The cross SK109xSR303 exhibited the best mean values for plant height, panicle length, panicle weight, grain yield plan-1, harvest index and hulling%. Non-additive gene action was responsible for the inheritance of all traits studied. The parent SK109 was the best general combiner for seven out of the thirteen traits, while the tester SR303 expressed significant and desirable GCA effects for eight out of the thirteen crosses. The cross SK109xSR303 elucidated the best SCA effects for days to 50% heading, chlorophyll content and No. of panicle plant-1, whereas the cross SK106xIHL175 expressed the most desirable SCA effects for grain yield plant-1. The cross SK109xSR303 exhibited the best desirable mid-parent and better-parent heterosis for panicle length and grain shape, as well as mid-parent heterosis for grain yield plant-1 and harvest index.

Keywords: Rice, combining ability, quality traits, heterosis

Introduction

Rice (*Oryza sative* L.) (2n=24) is considered one of the important cereal crops in Egypt and the world. It ranks third after wheat and corn in Egypt and the world in cultivated area. In Egypt, the rice cultivated area is 670.000 ha which produced 3.900.000 tons of milled rice and 5.652.000 tons of rough rice with an average of 8.44 t/ha in 2025. Rice is used to Feed most of the world's population and its cultivation is concentrated in Southeast Asia and Egypt. **(USDA,2025)**.

Selecting the best parents for the hybridization process is crucial to the success of any plant breeding program. Since it offers some crucial genetic information about the attributes under study, combining ability is a useful tool for rice breeders. Finding the impacts of both types of combining ability (GCA and SCA) is a common usage for the line tester analysis approach, which also aids in choosing advantageous parents and hybrids. General combining ability refers to additive gene action, while specific combining ability explicates non-additive genetic variance. Non-additive genetic variance was reported to govern rice grain yield, its contributing traits and quality characteristics (**Bayoumi *et al*, 2022; El-Gammaal *et al*., 2022; Abd-Aty *et al*., 2023; Santhiya *et al*., 2023; Thakur et al., 2023; Abo-Youssef *et al*., 2024; Das *et al*., 2024; Kumar *et al*., 2024; Vennila, 2024; Singh *et al*., 2025**). On the other hand, some other researchers mentioned the importance of additive gene action in governing several traits (**Kumar *et al*., 2024 and Modarresi *et al*., 2024** for plant height; **Das *et al*., 2023** for kernel L/B; and **Kushal *et al*., 2023** for 1000 kernel weight and No. of filled grains panicle^{-1}).

Exploiting the concept of heterosis in crop improvement programs became a must to develop new varieties with higher yield potentiality and better quality. From a breeder's point of view, Positive heterosis is applicable for grain yield, while negative heterotic effects are preferred for earliness. Therefore, many attempts have been made to study heterosis in rice, either mid-parent or better-parent heterosis. Among these workers are **El-Gammaal *et al*., (2022),**

Kushal *et al*., (2023), El-Naem *et al*., (2024), and Sing *et al*., (2025). Therefore, this work aimed at estimating gene action and heterosis for some morphophysiological, yield and its related traits, as well as quality traits in some top crosses of rice.

Materials and Methods

The plant materials of the present study involved ten parents, six of them represented the line parents, i.e SK104, SK106, GZ11332, SK108, SK109, SK101 and 4 testers Viz. IHL17, IHL65, IHL175, SR303 of Oryza sativa. The genetic resources of this work were obtained from Rice, Res. And the training cent. (RRTC) in Egypt. The names, pedigree, origin and type of parents are presented in Table (1).

Table 1. Names, pedigree, and type of selected rice parents.

NO	Name	Pedigree	Origin	Type
1	Sakah104	GZ4096-8-1/GZ4100-9	Egypt	Japonica
2	Sakha 106	(Giza 177 / Hexi 30)	Egypt	Japonica
3	Sakha 101	(Giza 176 / Milyang 79)	Egypt	Japonica
4	GZ11332	GZ 8455-9-1-1-2/ SKC 23819-192-2-2-2-1-1-2-2-1-2// HUA 565	Egypt	Japonica
5	Sakha 108	(Sakha101/ HR5824-B-3-2-3// Sakha 101)	Egypt	Japonica
6	Sakha 109	Sakha 105 x Sakha 101	Egypt	Japonica
7	IHL17	Unknow	IRRI	Japonica
8	IHL65	Unknow	IRRI	Japonica
9	IHL175	Unknow	IRRI	Japonica
10	SR303	Unknow	Egypt	Japonica

Experimental work

In the 2023 summer season, the grains of the ten parental varieties were sown. One-month-old seedlings were transplanted into the permanent field in two rows, 5 meters long, with a spacing of 20 x 20 between rows and plants. At flowering time, top crossing has been done between the six males and the four testers to develop 24 crosses using bulk emasculation according to **Butany (1961).**

In the 2024 growing season, the ten parents along with their 24 F1 crosses, were planted on 30th May. Thirty days after sowing, the seedlings of 34 genotypes of rice were transplanted and set in a randomized complete block design (RCBD) with three replications. Each genotype was represented by three plants with plant spacing 20 x 20 cm and 5 m long for each row. All cultural practices were applied properly as recommended for the rice crop.

Data was recorded for days to 50% heading, plant height, chlorophyll content, number of panicles/ plants, panicle length, panicle weight, 1000 grain weight, grain yield/ plant, harvest index, hulling%, milling% %, head rice recovery and grain shape. The ordinary analysis of variance for data was performed according to **Steel and Torrie (1980).** General and specific combining analyses were estimated for all studied attributes according to line x tester model proposed by **Kempthorne (1957).** Heterosis percentage relative to mid- parent and better parent was estimated according to **Mather and Jinkes (1982).**

Results and Discussion

The present study involved important information about days to 50% heading, plant height, chlorophyll content, number of panicles/ plants, panicle length, panicle weight, 1000 grain weight, grain yield/ plant, harvest index, hulling%, milling %, head rice recovery and grain shape, which can be presented as follows:

Analysis of variance and mean performance

Data on the analysis of variance of the thirteen traits studied in rice are shown in Table 2. It is obvious that mean squares due to all genotypes (crosses, lines and testers), were significant for all attributes. These results explicate the great diversity among crosses regarding morphophysiological, yield and its contributing traits as well as quality characteristics. The diversity among rice genotypes for the studied traits was previously reported by many researchers. Among those are (**Abo-Yousef *et al*, 2020; Gaballah *et al*., 2021; Ayuba *et al*., 2022; Bayoumi *et al*., 2022; El-Gammal *et al*., 2022; El-Sharnobi *et al*., 2022; Al-Daej, 2023, Abo-Yousef *et al*., 2024; and El-Naem *et al*., 2024**).

The mean performance of the thirteen traits studied is presented in Table 3. For the three morphophysiological traits, namely, days to 50% heading, plant height and chlorophyll content, the parents SK106, IHL65 and SK101 expressed the lowest mean values, being 88.67, 88.33 and 43.02 days, respectively. Moreover, the most desirable crosses SK108x IHL65 (81.00 days), SK101xSR303 (95.33) and SK109xSR303 (47.67) exhibited the best values for the respective traits. Regarding yield and its related traits, the parents SK104, SK108 and SR303 gave the best mean values for No. of panicles plant^{-1}. Moreover, the best mean value for this trait was recorded for the cross SK109xSR303, being (28.00 cm). For panicle length, the best mean performance was detected for the parent SK104 (26.08) and the cross SK109xSR303 (28.52). The parent SR303 and the cross SK109xSR303 gave the best results for panicle weight. As for 1000 grain weight, the best mean values were obtained by the variety IHL65 (30.33 g) and the cross SK108x IHL175 (32.60 g). Concerning grain yield plant^{-1}, the most desirable mean values were detected for the variety IHL175 and Sk109XSR303, recording 41.17 and 52.27 g, respectively. The same previous genotypes gave the best values for harvest index, being 46.27 and 58.43, respectively. For quality traits studied, the best mean performance for hulling% was detected by IHL65 (80.50%) and the two crosses SK104xIHL65 (82.00%) and SK106xSR303 (81.58%). Again, the variety IHL65 and the cross SK104xIHL65 exhibited the best values for milling%, being 72.70 and 73.55%, respectively. For head rice recovery, the most desirable mean values were detected by the variety SK104 and the cross Sk104xIHL175. Two varieties, viz, SK106 and IHL175 as well as the cross GZ11332xSR303 gave the best values for grain shape, being 2.04, 2.04, and 2.85, respectively. From such results, it could be concluded that the cross SK109xSR303 was the best among all studied crosses since it elucidates the best mean values for grain yield plant^{-1} and six other studied traits.

Combining ability analysis

Table (2) shows the analysis of combining ability for three morphophysiological traits, six yield and its related traits, as well as four quality traits. For all studied attributes, mean squares due to specific combining ability were much higher than those of general combining ability, revealing that the non-additive gene action was responsible for the inheritance of these traits. Similar results were obtained by **Singh *et al*., (2019), Abde El-Aty *et al*., (2020), Abo-Yousef *et al*., (2020), Kumar and Pandy (2023), Das et al., (2024), Thang (2024) and Singh *et al* (2025).** However, a number of researchers have found that additive gene activity is a significant factor in the inheritance of the traits under investigation. These include **Aamer and Ibrahin (2020), Savi et al. (2021), El-Gammal *et al*. (2022),** and **Lingaiah *et al*. (2024).**

Estimates of GCA effects for the thirteen traits studied are shown in Table 4 and Figures 1-13. Data vindicated that the parent variety SK104 exhibited the most desirable GCA effects for earliness, hulling%, milling% and head rice recovery. The line GZ11332 seemed to be the best combiner for chlorophyll content. Parent SK101 gave the most desirable and significant GCA effects for plant height. Moreover, the line SK109 gave significant and positive GCA effects for No. of panicle plant^{-1}, panicle length, panicle weight, 1000 grain weight, grain yield plant^{-1} and harvest index. The tester IHL17 displayed the desirable GCA effects for earliness and panicle length (Table 4). Also, the tester IHL65 was distinguished for hulling% and milling%. The tester P68 was the best among all testers since it gave the most desirable GCA effect for eight traits, including grain yield plant^{-1}.

Concerning SCA effects, significant and desirable values were detected in six, four, four, five, nine, four, three, nine, nine, five, seven, nine and eight for days to 59% flowering, plant height, chlorophyll content, No. of panicle plant^{-1}, panicle length, 1000 grain weight, grain yield plant^{-1}, harvest index, hulling%, milling%, had rice recovery and grain shape, respectively (Table5). However, the best effects were detected for the crosses SK104xP66 for days to 50% heading, chlorophyll content and number of panicle plant^{-1}; SK101xSR303 for plant height; SK106xIHL175 for panicle length; GZ11332xIHL17 for panicle weight; SK108xSR303 for 1000 grain weight and harvest index; SK106xIHL175 for grain yield plant^{-1} and milling%; sK108xIHL17 for hulling%; SK108xIHL65 for head rice recovery; and GZ11332xSR303 for grain shape.

Heterosis

The effects of mid-parent (MP) and better-parent (BP) heterosis for all attributes are shown in Table 6. Significant and negative heterotic values were detected for days to 50% heading in eighteen and nineteen crosses relative to mid-parent and better-parent heterosis, respectively. However, the best values were detected for the cross SK104xIHL17 (MP) and SK108xIHL65 (BP). For plant height, only two crosses, namely, SK104xSR303 and sK101xSR303, expressed desirable MP heterosis. Regarding chlorophyll content, twenty and eighteen crosses exhibited significant values for MP and BP, respectively. However, the cross SK108xIHL65 exhibited the best values for both types of heterosis. The best heterotic effects relative to MP and BP heterosis were detected for the crosses SK109xIHL175 for No. of panicle plant-1; SK109xSR303 for panicle length; Sk108xIHL175 for panicle weight, Sk106x IHL65for 1000 grain weight. For grain yield plant-1, eighteen and fourteen crosses gave the best effects relative to MP and BP, respectively. However, the most practical heterosis effects were given by the cross SK109xSR303 (MP) and SK109xIHL17 (BP), recording 37.93** and 35.57**, respectively. The best heterotic effects relative to mid-parent and better-parent were detected by the crosses SK109xSR303 for harvest index; SK106xSR303 for hulling%; SK109xIHL65 for head rice recovery; and GZ11332 xSR303 for grain shape. Regarding milling%, nineteen and fifteen crosses expressed the best heterosis effects relative to MP and BP, respectively. However, the best values were obtained by the crosses SK108xSR303 relative to mid-parent and SK109xSR303relative to better parent heterosis (Table 6). The results are in line with those obtained by **Singh *et al*. (2019), Abo-Yousef *et al*. (2020), El-Badawy *et al*., (2022), El-Gammal *et al*., (2022), Kushal *et al*., (2023), Kumar and Pandy (2023), El-Naem *et al*., (2024), Lingaiah *et al*., (2024), Santhiya *et al*., (2023) and Thang (2024).**

In conclusion, the cross SK109xSR303 followed by the cross SK109x IHL17 seemed to be the best crosses among all studied crosses since they expressed the highest yield potentiality for grain yield and some other contributing traits. Consequently, these materials are prospective and could be used in further rice breeding programs.

Table 2. Mean squares for some morphophysiological, yield and quality traits in rice.

		Morphophysiological traits			Yield and its related traits						Quality traits			
S.O. V	**Df**	**Days to 50% heading (days)**	**Plant height (cm)**	**Chlorophyll content**	**No. of panicles/ plant**	**Panicle length (cm)**	**Panicle weight (g)**	**1000 grain weight (g)**	**Grain yield/ plant (g)**	**Harvest index %**	**Hulling %**	**Milling %**	**Head rice recovery**	**Grain shape**
Reps	2	6.48	0.64	1.97	0.16	0.20	0.05	1.07	0.81	1.11	0.41	0.05	0.13	0.023
Entries	33	232.81 **	78.48 **	31.67 **	20.21 **	5.83 **	1.09 **	8.90 **	66.51 **	84.92 **	4.18 **	4.26 **	73.43 **	0.273 **
Parents	9	262.30 **	85.72 **	32.74 **	17.27 **	3.87 **	0.71 **	7.79 **	20.55 **	73.30 **	2.66 **	4.11 **	116.25 **	0.100 **
Crosses	23	174.05 **	33.72 **	12.84 **	11.28 **	4.95 **	0.90 **	5.26 **	57.41 **	56.24 **	3.96 **	2.74 **	27.07 **	0.270 **
P vs C	1	1318.84 **	1042.80 **	455.20 **	252.05 **	43.64 **	8.87 **	102.68 **	689.61 **	849.19 **	22.86 **	40.58 **	754.43 **	1.904 **
Lines	5	380.36 **	91.13 **	19.94 **	26.23 **	8.11 **	1.35 **	15.07 **	124.15 **	142.28 **	3.59 **	3.21 **	67.86 **	0.219 **
Testers	3	151.27 **	46.37 **	21.98 **	7.02 **	8.51 **	2.96 **	3.41 **	103.51 **	17.75 **	6.43 **	5.30 **	34.62 **	0.455 **
Line x Tester	15	109.84 **	12.05 **	8.65 **	7.15 **	3.18 **	0.34 **	2.36 **	25.94 **	35.25 **	3.60 **	2.07 **	11.97 **	0.249 **
Error	66	2.73	1.34	2.05	0.45	0.06	0.02	0.59	0.95	1.03	0.42	0.17	0.05	0.008
GCA		1.62	0.55	0.11	0.10	0.04	0.01	0.07	0.79	0.53	0.01	0.02	0.38	0.001
SCA		35.70	3.57	2.20	2.23	1.04	0.11	0.59	8.33	11.41	1.06	0.64	3.97	0.081

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

Table 3. Mean performance of the studied genotypes for morphophysiological, yield and quality traits of rice.

	Morphophysiological traits			Yield and its related traits						Quality traits			
Genotype	**Days to 50% heading**	**Plant height (cm)**	**Chlorophyll content**	**No. of panicles/ plant**	**Panicle length (cm)**	**Panicle weight (g)**	**1000 grain weight (g)**	**Grain yield/ plant (g)**	**Harvest index %**	**Hulling %**	**Milling %**	**Head rice recovery**	**Grain shape**
Sk104	107.33	106.00	39.33	24.00	26.08	4.59	25.37	36.53	42.00	79.06	71.80	70.30	1.65
SK106	88.67	103.00	39.62	21.33	24.87	4.15	26.43	35.73	47.51	77.15	70.00	69.11	2.04
GZ11332	89.33	100.67	40.67	18.67	23.33	4.03	30.03	36.86	43.37	79.64	70.66	66.40	1.87
Sk101	89.33	95.00	43.02	23.00	25.24	4.79	27.53	39.66	42.83	78.55	70.38	68.58	1.99
Sk108	103.67	100.00	31.00	24.00	25.08	4.06	28.33	33.67	33.67	79.34	68.25	60.27	2.09
Sk109	92.67	102.33	36.81	19.67	23.05	4.42	28.96	35.19	32.96	78.47	70.07	53.35	2.02
IHL17	110.33	96.00	39.67	22.67	25.69	4.08	27.12	36.01	40.85	79.68	70.44	57.22	1.53
IHL65	110.67	88.33	35.76	19.67	23.28	3.77	30.33	34.33	44.51	80.50	72.70	54.64	1.95
IHL175	102.67	92.33	38.62	17.67	24.57	3.42	28.00	41.17	46.27	79.00	70.07	65.66	2.04
SR303	89.67	98.00	40.29	24.00	23.18	5.05	29.64	40.59	37.93	78.08	70.20	65.10	1.96
Sk104x IHL17	81.67	109.00	44.15	25.67	26.50	4.77	28.60	37.97	42.48	80.01	73.11	70.39	2.01
Sk104x IHL65	83.67	109.00	44.33	25.33	27.00	4.65	29.04	38.27	46.98	82.00	73.55	69.71	2.33
Sk104x IHL175	82.67	110.00	39.76	24.67	26.21	4.82	28.38	41.51	47.40	79.95	71.03	75.71	2.61
Sk104xSR303	87.33	102.67	43.70	25.33	26.52	5.56	28.77	40.00	44.53	80.10	72.27	70.06	2.15
Sk106x IHL17	89.67	107.67	44.21	24.33	25.50	4.52	29.80	36.32	48.99	80.24	71.60	70.54	2.16
Sk106x HL65	91.00	106.67	41.80	25.00	23.52	4.70	30.83	37.43	48.80	80.47	70.44	69.77	1.64
Sk106x IHL175	85.67	108.00	40.07	26.67	26.21	4.84	31.97	45.74	51.16	79.56	71.68	72.59	2.08
Sk106xSR303	90.67	109.00	42.54	24.33	23.70	5.55	30.03	42.33	47.63	81.58	70.04	70.02	2.03
GZ11332x IHL17	90.00	104.00	45.06	23.00	26.21	3.78	30.38	43.82	48.99	76.65	71.66	72.05	1.75
GZ11332x IHL65	89.33	105.00	42.75	22.67	25.35	4.63	31.67	43.24	47.10	81.14	73.00	70.18	2.05
GZ11332x	85.67	104.33	45.18	23.00	24.26	3.88	30.79	44.46	46.49	80.35	70.35	69.87	2.09
GZ11332xSR303	87.67	103.00	45.05	23.67	25.61	4.93	31.50	45.05	43.93	79.82	71.75	68.65	2.85
Sk101x IHL17	90.67	103.27	41.93	25.00	26.43	4.81	28.87	34.67	44.18	79.40	71.10	68.46	2.31
Sk101x IHL65	99.33	104.17	41.20	24.00	23.60	3.95	30.03	40.18	44.37	80.55	72.65	68.54	1.87
Sk101x IHL175	111.67	98.94	39.36	23.67	25.35	4.80	29.00	40.44	40.85	79.42	71.07	68.52	2.16
Sk101xSR303	100.67	95.33	42.18	22.67	26.20	5.48	30.20	43.59	43.29	77.67	72.95	63.08	2.78
Sk108x IHL17	85.33	106.53	42.73	24.33	26.24	4.86	29.40	44.81	46.57	80.46	72.00	64.19	2.41
Sk108x IHL65	81.00	106.00	43.77	24.67	25.80	4.75	30.53	44.37	44.83	80.00	72.40	70.16	2.12
Sk108x IHL175	100.33	108.00	44.37	23.00	26.06	5.27	29.30	44.15	44.94	79.03	70.84	64.30	2.05
SK108xSR303	89.67	104.00	43.33	27.33	27.44	5.50	32.60	48.51	54.21	79.66	72.26	62.28	2.18
Sk109x IHL17	90.00	105.00	46.17	28.00	27.54	5.67	32.33	48.82	54.73	79.87	72.37	69.56	2.21
Sk109x IHL65	95.67	105.20	40.37	24.00	24.20	4.47	30.50	38.11	45.42	80.59	71.62	70.03	2.48
Sk109x IHL175	102.00	106.97	43.07	26.67	26.92	5.25	32.00	48.32	54.21	79.59	71.33	69.94	2.14
SK109xSR303	81.67	102.67	47.67	31.00	28.52	5.77	32.53	52.27	58.43	81.57	73.12	68.12	2.67
Overall mean	92.86	103.12	41.75	23.90	25.45	4.69	29.73	41.00	45.66	79.68	71.43	67.27	2.13
LSD 5%	2.69	1.88	2.33	1.09	0.41	0.22	1.26	1.58	1.65	1.05	0.663	0.37	0.14
LSD 1%	3.58	2.50	3.10	1.45	0.54	0.30	1.67	2.10	2.20	1.40	0.881	0.49	0.19

Table 4. Effects of general combining ability effects for some morphophysiological, yield and quality traits in rice.

	Morphophysiological traits				Yield s its related traits					Quality traits			
Genotypes	**Days to 50% heading (day)**	**Plant height (cm)**	**Chloro phyll content**	**No. of panicles / plant**	**Panicle length (cm)**	**Panicle weight (g)**	**1000 grain weight (g)**	**Grain yield/ plant (g)**	**Harvest index %**	**Hulling %**	**Milling %**	**Head rice recover y**	**Grain shape**
Lines													
Sk104	-6.71 **	2.48 **	-0.13	0.33	0.69 **	0.07	-1.68 **	-3.24 **	-2.17 **	0.53 **	0.65 **	2.44 **	0.06 *
SK106	-1.29 **	2.65 **	-0.96 *	0.17	-1.14 **	0.02	0.28	-2.23 **	1.62 **	0.47 *	-0.90 **	1.70 **	-0.24 **
GZ11332	-2.38 **	-1.10 **	1.40 **	-1.83 **	-0.51 **	-0.58 *	0.71 **	1.46 **	-0.89 **	-0.50 *	-0.15	1.16 **	-0.03
Sk101	10.04 **	-4.76 **	-1.95 **	-1.08 **	-0.48 **	-0.12 *	-0.85 **	-2.96 **	-4.35 **	-0.73 **	0.10	-1.88 **	0.07 *
Sk108	-1.46 **	0.95 **	0.44	-0.08	0.51 **	0.21 *	0.08	2.78 **	0.12	-0.20	0.03	-3.80 **	-0.02
Sk109	1.79 **	-0.22	1.20 **	2.50 **	0.92 **	0.40 *	1.46 **	4.20 **	5.67 **	0.42 *	0.27 *	0.38 **	0.16 **
LSD gi5%	0.95	0.666	0.825	0.387	0.145	0.08	0.44	0.56	0.59	0.37	0.23	0.13	0.05
LSD gi1%	1.27	0.885	1.096	0.514	0.193	0.11	0.59	0.75	0.78	0.50	0.31	0.18	0.07
LSDgi-gi	1.35	0.94	1.17	0.55	0.21	0.11	0.63	0.79	0.83	0.53	0.33	0.19	0.07
Testers													
IHL17	-2.65 **	0.73 **	0.93 **	0.14	0.53 **	-0.15 **	-0.48 *	-1.61 **	0.14	-0.55 **	0.13	0.17 **	-0.07 **
IHL65	-0.54	0.82 **	-0.74 *	-0.64 **	-0.96 **	-0.36 **	0.06	-2.41 **	-1.27 **	0.81 **	0.44 **	0.70 **	-0.13 **
IHL175	4.13 **	0.86 **	-1.15 **	-0.31	-0.04	-0.07 *	-0.14	1.42 **	-0.01	-0.34 *	-0.79 **	1.13 **	-0.03
SR303	-0.93 *	-2.41 **	0.96 **	0.81 **	0.46 **	0.58 **	0.56 **	2.61 **	1.15 **	0.08	0.22 *	-2.00 **	0.23 **
L.S.D gi5%	0.778	0.544	0.674	0.316	0.119	0.07	0.36	0.46	0.48	0.31	0.19	0.11	0.04
L.S.D gi 1%	1.03	0.72	0.89	0.41	0.15	0.09	0.48	0.61	0.64	0.41	0.25	0.14	0.06
LSD gi-gi	1.10	0.77	0.95	0.45	0.17	0.09	0.51	0.65	0.68	0.43	0.27	0.15	0.06

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

Table 5. Estimates of specific combining ability for some morphophysiological, yield and quality traits in rice.

	Morphophysiological traits			Yield ant its related traits						Quality traits			
Genotypes	Days to 50% heading (days)	Plant height (cm)	Chlorophyll content	No. of panicles/ plant	Panicle length (cm)	Panicle weight (g)	1000 grain weight (g)	Grain yield/ plant (g)	Harvest index %	Hulling %	Milling %	Head rice recovery	Grain shape
Sk104x IHL17	0.49	0.61	0.24	0.28	-0.59 **	-0.03	0.38	0.14	-3.01 **	0.04	0.49 *	-1.24 **	-0.20 **
Sk104x IHL65	0.38	0.51	2.09 *	0.72	1.40 **	0.06	0.28	1.25 *	2.91 **	0.68	0.63 **	-2.46 **	0.19 **
Sk104x IHL175	-5.29 **	1.48 *	-2.08 *	-0.28	-0.31 *	-0.06	-0.18	0.65	2.07 **	-0.23	-0.67 **	3.12 **	0.36 **
Sk104xSR303	4.43 **	-2.59 **	-0.25	-0.72	-0.50 **	0.03	-0.49	-2.04 **	-1.96 **	-0.50	-0.44	0.59 **	-0.35 **
Sk106x IHL17	3.07 **	-0.89	1.13	-0.89 *	0.23	-0.23 **	-0.38	-2.52 **	-0.29	0.32	0.53 *	-0.36 **	0.25 **
Sk106x HL65	2.29 *	-1.99 **	0.39	0.56	-0.25	0.15	0.12	-0.61	0.92	-0.80 *	-0.93 **	-1.66 **	-0.20 **
Sk106x IHL175	-7.71 **	-0.69	-0.94	1.89 **	1.51 **	0.01	1.45 **	3.86 **	2.03 **	-0.56	1.53 **	0.73 **	0.13 *
Sk106xSR303	2.35 *	3.57 **	-0.58	-1.56 **	-1.49 **	0.07	-1.19 **	-0.73	-2.66 **	1.04 **	-1.12 **	1.28 **	-0.18 **
GZ11332x IHL17	4.49 **	-0.81	-0.38	-0.22	0.32 *	-0.38 **	-0.22	1.29 *	2.23 **	-2.29 **	-0.16	1.69 **	-0.36 **
GZ11332x IHL65	1.71	0.10	-1.02	0.22	0.95 **	0.69 **	0.53	1.52 **	1.74 **	0.85 *	0.87 **	-0.71 **	-0.01
GZ11332x IHL175	-6.63 **	-0.61	1.82 *	0.22	-1.06 **	-0.35 **	-0.16	-1.10	-0.12	1.19 **	-0.55 *	-1.44 **	-0.07
GZ11332xSR303	0.43	1.32	-0.42	-0.22	-0.21	0.04	-0.15	-1.70 **	-3.85 **	0.25	-0.17	0.46 **	0.44 **
Sk101x IHL17	-7.26 **	2.11 **	-0.16	1.03 **	0.50 **	0.20 *	-0.18	-3.44 **	0.87	0.69	-0.97 **	1.14 **	0.11 *
Sk101x IHL65	-0.71	2.92 **	0.78	0.81 *	-0.84 **	-0.45 **	0.45	2.87 **	2.47 **	0.48	0.27	0.69 **	-0.28 **
Sk101x IHL175	6.96 **	-2.34 **	-0.66	0.14	-0.01	0.11	-0.39	-0.70	-2.31 **	0.50	-0.08	0.25	-0.10
Sk101xSR303	1.01	-2.69 **	0.05	-1.97 **	0.34 *	0.14	0.11	1.26 *	-1.03	-1.67 **	0.78 **	-2.07 **	0.27 **
Sk108x IHL17	-1.10	-0.33	-1.74 *	-0.64	-0.68 **	-0.09	-0.58	0.97	-1.20 *	1.22 **	-0.01	-1.21 **	0.29 **
Sk108x IHL65	-7.54 **	-0.95	0.96	0.47	0.38 *	0.01	0.02	1.32 *	-1.53 *	-0.59	0.09	4.23 **	0.07
Sk108x IHL175	7.13 **	1.01	1.96 *	-1.53 **	-0.29	0.25 **	-1.02 *	-2.73 **	-2.69 **	-0.42	-0.25	-2.06 **	-0.12 *
SK108xSR303	1.51	0.27	-1.18	1.69 **	0.59 **	-0.18 *	1.58 **	0.44	5.42 **	-0.21	0.17	-0.96 **	-0.24 **
Sk109x IHL17	0.32	-0.69	0.92	0.44	0.21	0.53 **	0.97 *	3.55 **	1.40 *	0.01	0.13	-0.02	-0.09
Sk109x IHL65	3.88 **	-0.58	-3.21 **	-2.78 **	-1.64 **	-0.46 **	-1.40 **	-6.36 **	-6.51 **	-0.62	-0.93 **	-0.08	0.24 **
Sk109x IHL175	5.54 **	1.16	-0.10	-0.44	0.16	0.03	0.30	0.02	1.03	-0.48	0.01	-0.60 **	-0.21 **
SK109xSR303	-9.74 **	0.11	2.39 **	2.78 **	1.26 **	-0.10	0.13	2.78 **	4.08 **	1.08 **	0.78 **	0.70 **	0.06
Sij 5%	1.90	1.33	1.65	0.77	0.29	0.16	0.89	1.12	1.17	0.74	0.46	0.26	0.10
Sij 1%	2.53	1.77	2.19	1.02	0.38	0.21	1.18	1.49	1.56	0.99	0.62	0.35	0.13
Sij-SKI	2.69	1.88	1.30	1.09	0.41	0.23	1.26	1.59	1.66	1.06	0.66	0.38	0.14

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

Table 6. Heterosis values relative to mid parent and better parent for some morphophysiological, yield and quality traits in rice.

Genotypes	Morphophysiological traits						Grain Yield and its related traits							
	Days to%50 heading(days)		Plant height (cm)		Chlorophyll content		No. of panicles/ plant		Panicle length (cm)		Panicle weight (g)		1000 grain weight (g)	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Sk104x IHL17	-24.96**	-25.98**	7.92**	2.83**	11.78**	11.30**	10.00**	6.94**	2.39**	1.63**	10.16**	4.02**	8.97**	5.44**
Sk104x IHL65	-23.24**	-24.40**	12.18**	2.83**	18.08**	12.73**	16.03**	5.56**	9.41**	3.53**	11.30**	1.35**	4.26**	-4.27**
Sk104x IHL175	-21.27**	-22.98**	10.92**	3.77**	2.02	1.10	18.40**	2.78**	3.50**	0.50*	20.41**	5.06**	6.37**	1.37*
Sk104xSR303	-11.34**	-18.63**	0.65	-3.14**	9.78**	8.47**	5.56**	5.56**	7.70**	1.70**	15.38**	10.10**	4.59**	-2.95**
Sk106x IHL17	-9.88**	-18.73**	8.21**	4.53**	11.52**	11.45**	10.61**	7.35**	0.87**	-0.75**	9.77**	8.75**	11.28**	9.87**
Sk106x HL65	-8.70**	-17.77**	11.50**	3.56**	10.90**	5.50**	21.95**	17.19**	-2.29**	-5.42**	18.58**	13.08**	8.63**	1.65*
Sk106x IHL175	-10.45**	-16.56**	10.58**	4.85**	2.43*	1.14	36.75**	25.00**	6.04**	5.40**	27.94**	16.61**	17.45**	14.17**
Sk106xSR303	1.68	1.12	8.46**	5.83**	6.47**	5.59**	7.35**	1.39*	-1.34**	-4.70**	20.54**	9.83**	7.12**	1.33*
GZ11332x IHL17	-9.85**	-18.43**	5.76**	3.31**	12.18**	10.80**	11.29**	1.47**	6.93**	2.02**	-6.74**	-7.26**	6.31**	1.17
GZ11332x IHL65	-10.67**	-19.28**	11.11**	4.30**	11.87**	5.12**	18.26**	15.25**	8.78**	8.64**	18.83**	14.97**	4.92**	4.40**
GZ11332x IHL175	-10.76**	-16.56**	8.12**	3.64**	13.97**	11.10**	26.61**	23.21**	1.29**	-1.25**	4.28**	-3.64**	6.12**	2.53**
GZ11332xSR303	-2.05	-2.23	3.69**	2.32*	11.30**	10.78**	10.94**	-1.39*	10.15**	9.77**	8.52**	-2.44**	5.58**	4.90**
Sk101x IHL17	-9.18**	-17.82**	8.13**	7.57**	1.43	-2.53*	9.49**	8.70**	3.80**	2.87**	8.37**	0.25*	5.63**	4.84**
Sk101x IHL65	-0.67	-10.24**	13.64**	9.65**	4.59**	-4.23**	12.50**	4.35**	-2.70**	-6.48**	-7.74**	-17.62**	3.80**	-0.99
Sk101x IHL175	16.32**	8.77**	5.63**	4.15**	-3.58**	-8.52**	16.39**	2.90**	1.80**	0.46*	16.89**	0.11	4.44**	3.57**
Sk101xSR303	12.48**	12.27**	-1.21	-2.72**	1.27	-1.94	-3.55**	-5.56**	8.24**	3.82**	11.40**	8.58**	5.64**	1.89**
Sk108x IHL17	-20.25**	-22.66**	8.71**	6.53**	20.94**	7.73**	4.29**	1.39*	3.36**	2.12**	19.47**	19.23**	6.03**	3.76**
Sk108x IHL65	-24.42**	-26.81**	12.57**	6.00**	31.11**	22.38**	12.98**	2.78**	6.72**	2.89**	21.36**	17.00**	4.09**	0.66
Sk108x IHL175	-2.75*	-3.22*	12.31**	8.00**	27.45**	14.88**	10.40**	-4.17**	4.99**	3.93**	40.95**	29.80**	4.02**	3.41**
SK108xSR303	-7.24**	-13.50**	5.05**	4.00**	21.57**	7.56**	13.89**	13.89**	13.74**	9.43**	20.75**	8.91**	12.47**	9.99**
Sk109x IHL17	-11.33**	-18.43**	5.88**	2.61**	20.73**	16.39**	32.28**	23.53**	13.00**	7.19**	33.34**	28.11**	15.30**	11.65**
Sk109x IHL65	-5.90**	-13.55**	10.35**	2.80**	11.24**	9.66**	22.03**	22.03**	4.47**	3.97**	9.14**	1.06**	2.88**	0.55
Sk109x IHL175	4.44**	-0.65	9.90**	4.53**	14.19**	11.51**	42.86**	35.59**	13.08**	9.59**	33.91**	18.69**	12.36**	10.50**
SK109xSR303	-10.42**	-11.87**	2.50**	0.33	23.65**	18.32**	41.98**	29.17**	23.39**	23.06**	21.75**	14.19**	11.04**	9.76**

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

Table 6. Cont.

Genotypes	Grain Yield and its related traits (Cont.)				Quality traits							
	Grain yield/ plant (g)		Harvest index %		Hulling %		Milling %		Head rice recovery		Grain shape	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Sk104x IHL17	4.68**	3.93**	2.55**	1.15	0.81	0.41	2.79**	1.82**	10.41**	0.13	26.21**	21.62**
Sk104x IHL65	8.02**	4.77**	8.62**	5.56**	2.78**	1.86**	1.80**	1.17**	11.60**	-0.83**	29.51**	19.45**
Sk104x IHL175	6.84**	0.82	7.41**	2.45**	1.17*	1.13*	0.14	-1.07**	11.37**	7.70**	41.41**	27.99**
Sk104xSR303	3.73**	-1.46	11.43**	6.04**	1.95**	1.32*	1.79**	0.65	3.49**	-0.33	19.30**	9.86**
Sk106x IHL17	1.25	0.86	10.89**	3.11**	2.32**	0.69	1.97**	1.65**	11.68**	2.08**	20.93**	5.89**
Sk106x HL65	6.84**	4.75**	6.05**	2.70**	2.08**	- 0.04	-1.27**	-3.10**	12.77**	0.97**	-17.63**	-19.31**
Sk106x IHL175	18.95**	11.09**	9.10**	7.67**	1.90**	0.71	2.35**	2.30**	7.73**	5.04**	2.13**	2.13**
Sk106xSR303	10.91**	4.27**	11.49**	0.24	5.11**	4.48**	-0.09	-0.23	4.34**	1.32**	1.58**	-0.33**
GZ11332x IHL17	20.27**	18.89**	16.35**	12.97**	-3.79**	-3.81**	1.58**	1.42**	16.56**	8.50**	3.24**	-6.07**
GZ11332x IHL65	21.49**	17.33**	7.19**	5.82**	1.34**	0.80	1.83**	0.41	15.96**	5.69**	7.16**	4.78**
GZ11332x IHL175	13.95**	7.98**	3.74**	0.49	1.29**	0.88	- 0.02	- 0.44	5.81**	5.22**	6.92**	2.45**
GZ11332xSR303	16.32**	10.97**	8.07**	1.29	1.22*	0.22	1.86**	1.53**	4.41**	3.38**	49.13**	45.58**
Sk101x IHL17	-8.37**	-12.58**	5.60**	3.17**	0.36	-0.35	0.98**	0.94**	8.84**	-0.18	31.44**	16.25**
Sk101x IHL65	8.61**	1.32	1.60*	-0.32	1.28**	0.06	1.55**	-0.07	11.25**	-0.06	-5.33**	-6.20**
Sk101x IHL175	0.07	-1.77*	-8.31**	-11.71**	0.82	0.53	1.21**	0.98**	2.08**	-0.09	7.12**	5.89**
Sk101xSR303	8.64**	7.38**	7.22**	1.09	-0.83	-1.12*	3.79**	3.66**	-5.63**	-8.02**	40.59**	39.53**
Sk108x IHL17	28.62**	24.44**	25.00**	14.01**	1.19*	0.98	3.82**	2.21**	9.27**	6.50**	32.97**	15.15**
Sk108x IHL65	30.48**	29.22**	14.70**	0.73	0.10	-0.62	2.73**	-0.42	22.12**	16.42**	5.03**	1.59**
Sk108x IHL175	17.98**	7.23**	12.43**	-2.87**	-0.18	-0.40	2.42**	1.10**	2.12**	-2.07**	-0.81**	-2.07**
SK108xSR303	30.63**	19.49**	51.42**	42.91**	1.20*	0.40	4.39**	2.94**	-0.64**	-4.33**	7.49**	4.15**
Sk109x IHL17	37.13**	35.57**	48.31**	33.99**	1.00*	0.23	3.01**	2.74**	25.83**	21.57**	24.51**	9.41**
Sk109x IHL65	9.63**	8.29**	17.26**	2.04*	1.40**	0.12	0.33	-1.49**	29.71**	28.18**	24.83**	22.77**
Sk109x IHL175	26.55**	17.37**	36.85**	17.17**	1.08*	0.74	1.81**	1.81**	17.54**	6.52**	5.67**	5.24**
SK109xSR303	37.93**	28.76**	64.84**	54.03**	4.21**	3.95**	4.25**	4.15**	15.03**	4.64**	34.00**	32.01**

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

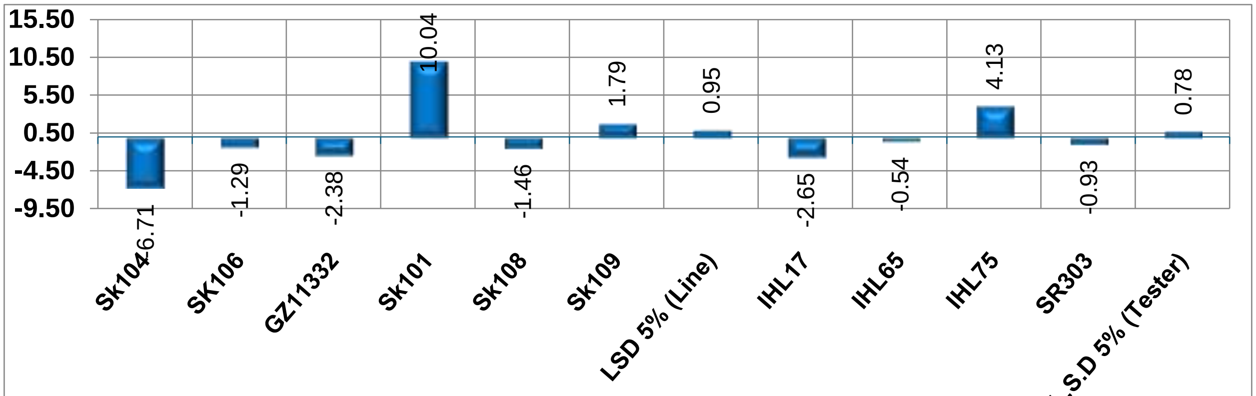

Fig. (1): GCA effects for days to 50% heading

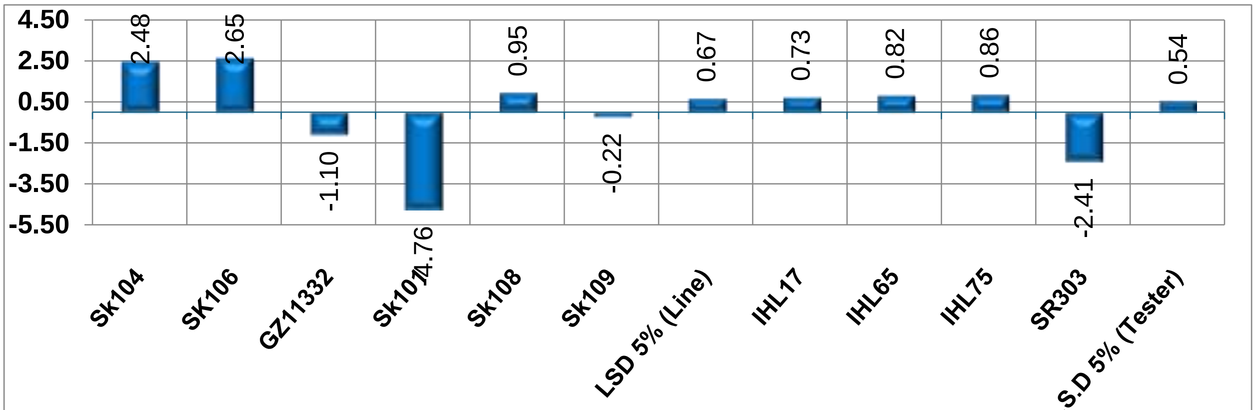

Fig. (2): GCA effects for plant height

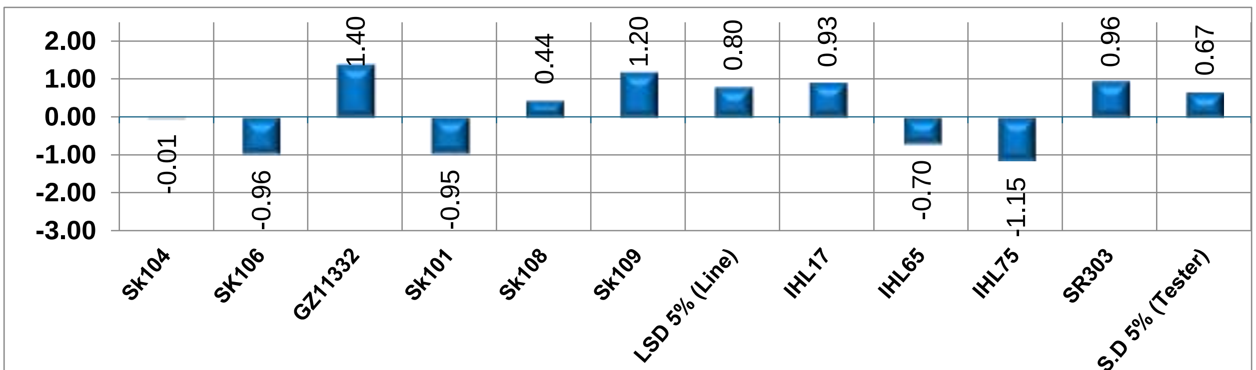

Fig. (3): GCA effects for chlorophyll content

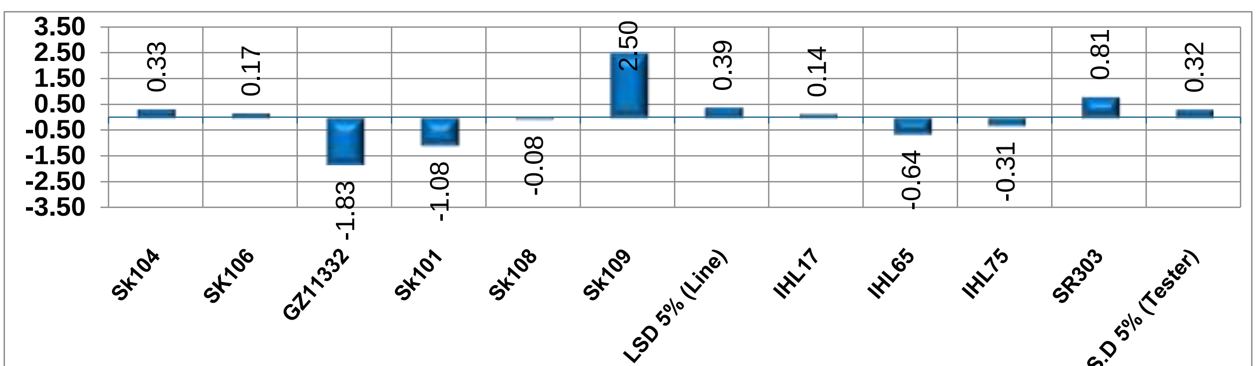

Fig. (4): GCA effects for No. of panicle/ plant

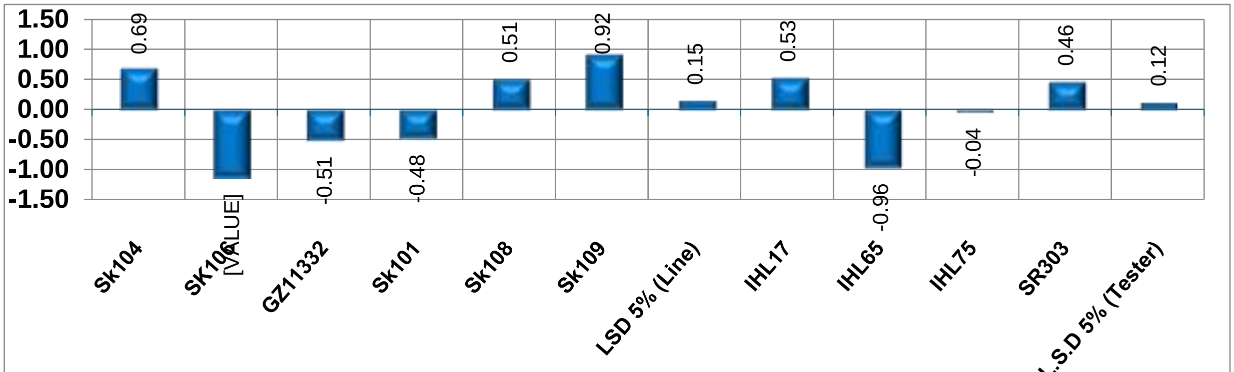

Fig. (5): GCA effects for panicle length

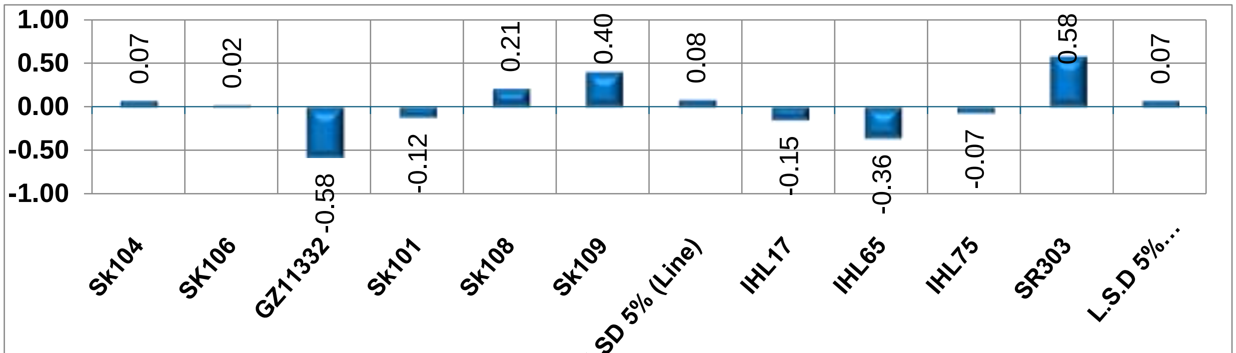

Fig. (6): GCA effects for panicle weight

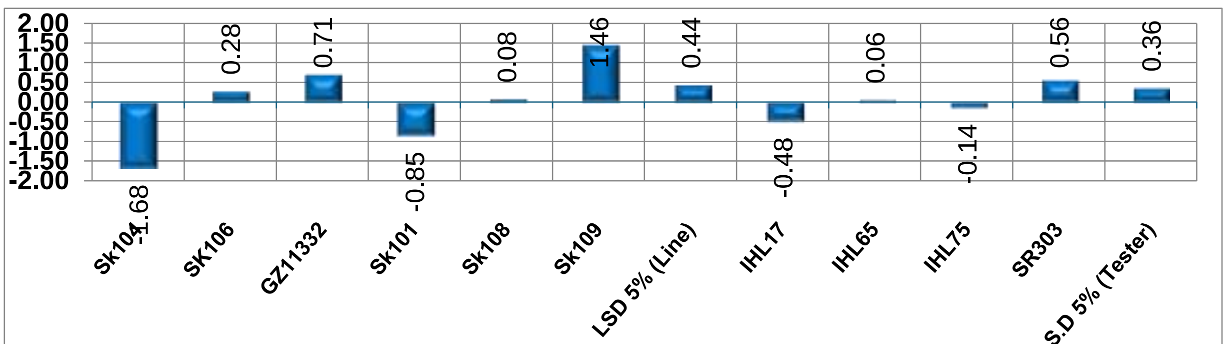

Fig. (7): GCA effects for 1000 grain weight

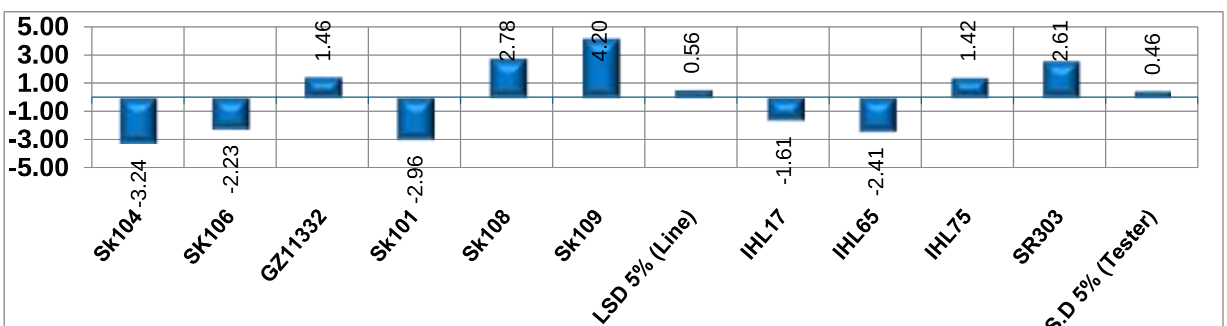

Fig. (8): GCA effects for grain yield/ plant

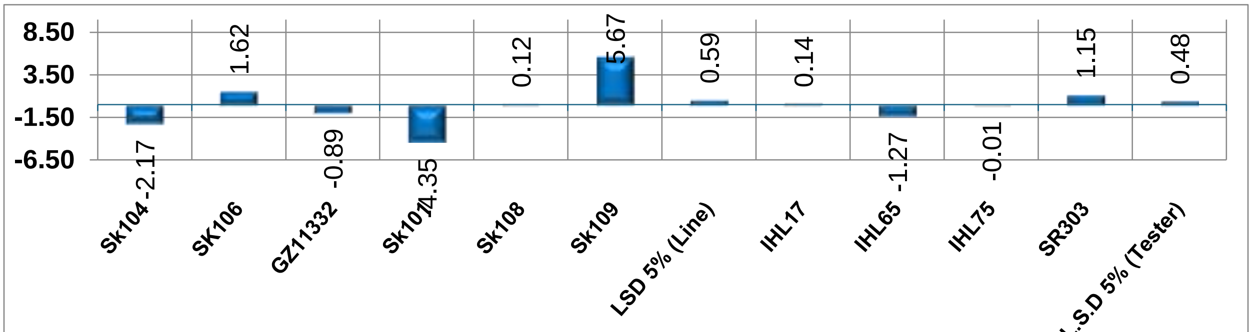

Fig. (9): GCA effects for harvest index

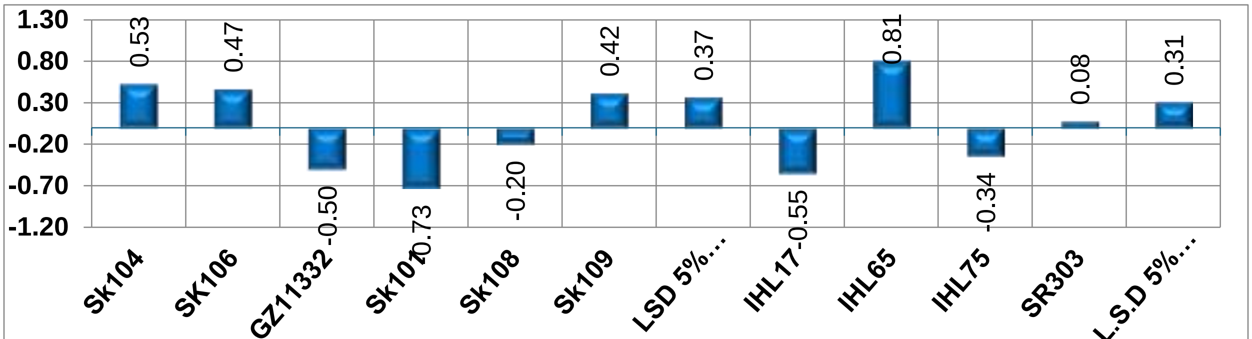

Fig. (10): GCA effects for hulling%

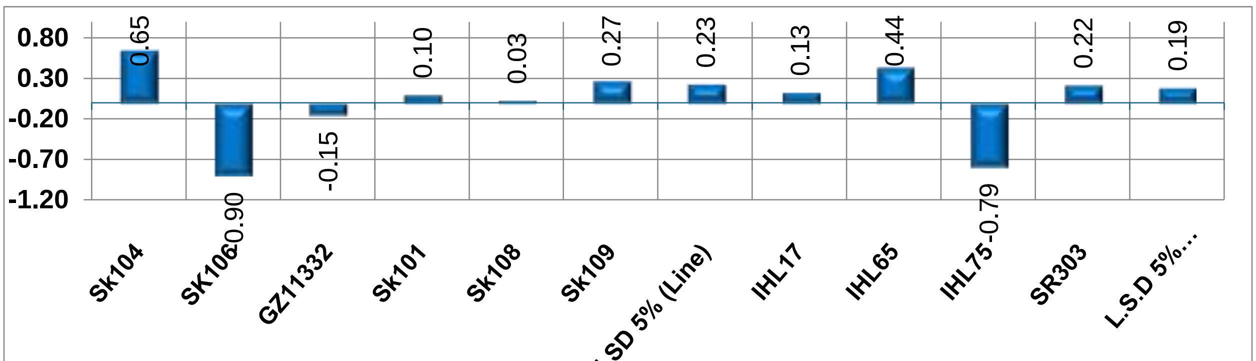

Fig. (11): GCA effects for milling%

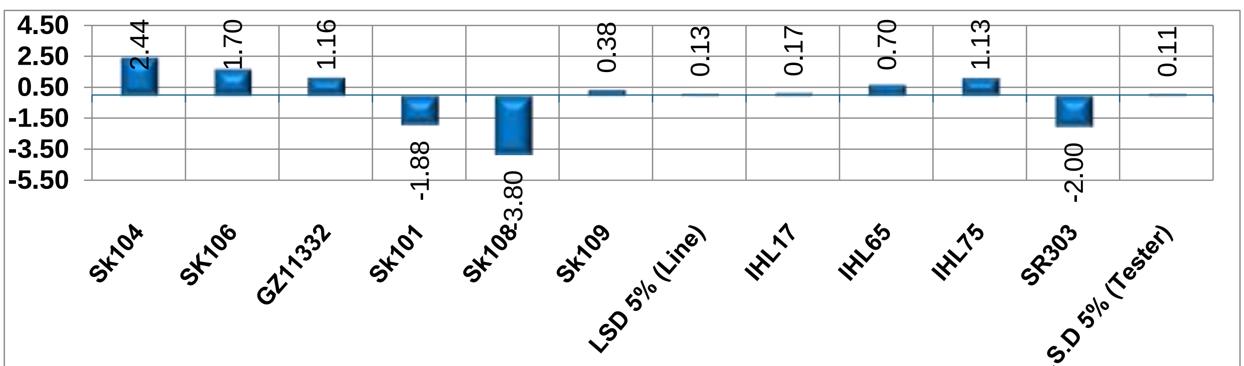

Fig. (12): GCA effects for head rice recovery

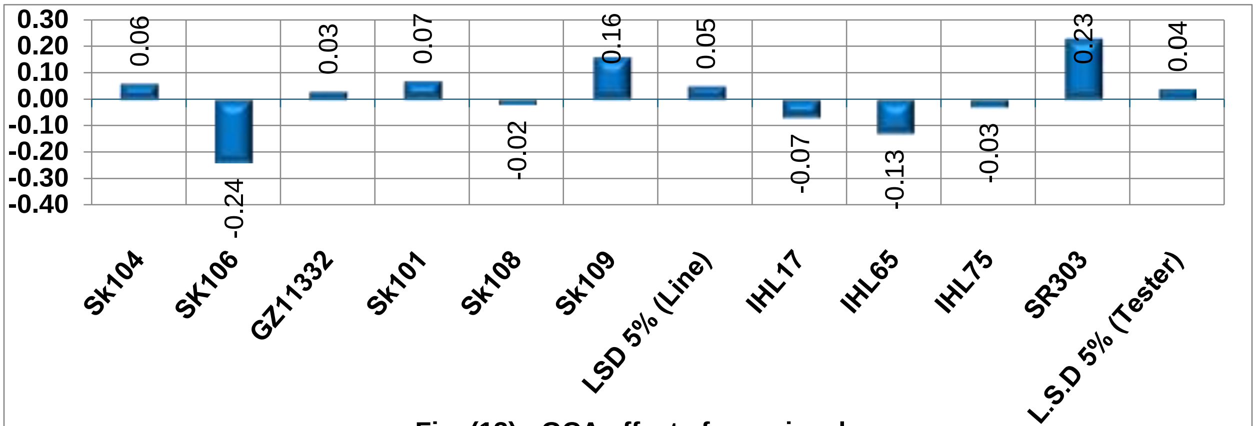

Fig. (13): GCA effects for grain shape

References

Aamer, S.M., H.E.A. Ibrahim (2020). Assessment of Combining ability for some Grain Yield and Quality Traits in Rice (*Oryza sativa* L.) by using Griffing Method and Biplot Analysis. J. of Plant Production, Mansoura Univ., Vol 11 (12):1615 – 1623. http://www.jpp.journals.ekb.eg

Abd El-Aty, M.S., M.A. El-Hity, M.I. Abo-Youssef, M.A. Abo Omar and M.M. Kamara (2020). Genetic behavior of rice (*Oryza sativa* L.) genotypes under normal and infested weed conditions. Indian Journal of Agricultural Sciences 90 (6): 1145–1148. https://doi.org/10.56093/ijas.v90i6.104787

Abd- El-Aty, M.S., M.I. Abo-Youssef, M.M. Bahgt, O.M. Ibrahim, H. Faltakh, H. Nouri, S.M. Korany, E.A. Alsherif, H. Abd Elgawad and A.M. El-Tahan (2023) Mode of gene action and heterosis for physiological, biochemical, and agronomic traits in some diverse rice genotypes under normal and drought conditions. Front. Plant Sci. 14:1108977. **https://doi.org/10.3389/fpls.2023.1108977**

Abo-Yousef, M.I., W.F. Ghidan, I.A. Talha, A.B. Elsehely and D.M. Tabi (2020). Combining Ability, Heterosis and Gene Action for Grain Yield and Its Related Traits of Some WA-CMS with Tester Lines of Rice (*Oryza sativa* L.). J. of Experimental Agriculture International. 42(9): 102-123. **http://creativecommons. org/licenses/by/4.0**

Abo-Youssef, M.I., M.S. Abd El-Aty, S.A. Yousef, A.A. Salama, O.M. Ibrahim, M.A. Eweda, H. AbdElgawad, and A.M. El-Tahan (2024). An Analysis of the Total Protein and Genetic Components for Yield and Its Constituents in some Hybrid Rice (*Oryza sativa* L.). Egypt. J. Bot. Vol. 64, No. 1, pp. 193-209. **http://ejbo. journals.ekb.eg/**

Al-Daej, M.I. (2023). Identifying the combining ability and genetic components of some rice agronomic traits (*Oryza sativa* L.). Journal of King Saud University – Science. 35 (2023) 102657. https://doi.org/10.1016/ j.jksus.2023.102657

Ayuba, S., T. Vange, G.O.S. Ojo and A.E. Ochigho (2022). Combining Ability Estimates and Heterosis for Yield and Yield Components in Rice (*Oryza sativa* L.) in Nigeria, Global Journal of Agricultural Research, Vol.10 (5): 10-27. **https://www.eajournals.org/**

Bayoumi, A.T.A., M.E.M. El-Badawy, A.A.A. El-Hosary, M.I. Abo Yousef and S.A. Sedhom (2022). Assessment of genetic diversity, combining ability and photosynthetic parameters of some rice genotypes under two sowing dates. Benha Journal of Applied Sciences (BJAS). Vol. 7 (1):45- 62. **https://www.researchgate. net/publication/359166214**

Butany, W. T. (1961). Mass emasculation in rice. International Rice Com. Newsletter., Vol (9): 9-13.

Das, R., D. Rajkhowa, S. Ngomle and B. Lointongbum (2023). Combining ability analysis for grain yield and yield contributing characters in rice (*Oryza sativa* L.). Biological Forum – An International Journal 15(12): 138-148.

El-Badawy, A.S., N.Kh. El-Gizawy, G.Y. Hammam, M.I. Abo-Yousef and S.A. Sedhom (2022). Genetic diversity, combining ability, heterosis and antioxidant enzymes of some rice genotypes under normal and water deficit. Benha Journal of Applied Sciences (BJAS). Vol. (7) Issue (1): (63- 79). http://bjas.journals.ekb.eg

El-Gammaal, A.A., M.E. El-Denay, M.I. Abo Yousef, M.S. Abd-Elaty, A.T. Bayoumi and A.B. Elsehely (2022). Genetic Behavior of Grain Yield and Quality Traits under Water Deficit and Normal Conditions of some Rice Genotypes. J. of Plant Production, Mansoura Univ., Vol. 13 (6):225-239. **www.jpp.journals.ekb.eg.**

El-Naem, S.A., E.M. Daher, M.I. Ghazy and A.G. Hefeina (2024). Studies on combining ability and heterosis for yield, its components and some grain quality traits in rice using line x tester under normal and water deficit. Menoufia J. Plant Prod., Volume 9 (2): 37- 53. https://mjppf.journals.ekb.eg/

El-Sharnobi, D.E., E.F.A. Arsfst, R.M. Abdallah and M.E. Negm (2022). Study of combining ability of some important traits in some hybrid rice combinations**.** Menoufia J. Plant Prod., Vol. (7): 57 – 74. https://mjppf.journals.ekb.eg/

Gaballa, M.M., A.F. Abu El-Ezz, A.D. Ghoneim, B. Yang, and L. Xiao (2021). Exploiting heterosis and combining ability in two-line hybrid rice. Acta Agriculturae Slovenica, 11(1): 1–16. doi:10.14720/aas.2021.117.1.1847

Kempthorne, O. (1957). An Introduction to Genetics Statistics, 1st eds., John Wiley and sons, New York. Pp: 457-471.

Kumar, A. and D.P. Pandy (2023). Study on gene action and combining ability for yield and its component traits in rice for rainfed upland condition in Himachal Pradesh. Himachal Journal of Agricultural Research 49(1): 38-43.

Kumar, T.A., S.Thippani, M. Paidakula and Y. Hari (2024). Unveiling superior hybrid combinations: insights from line × tester analysis on combining ability in rice (*Oryza sativa* L.). International Journal of Research in Agronomy. 7(12): 431-436. https://doi.org/10.33545/2618060X.2024.v7.i12f.2187

Kushal, G., J. Suresh, S. Sreedhar, and Y. Hari (2023). Study of combining ability in association with heterosis in rice (*Oryza sativa* L.). Int. J. Environ. Clim. Change, vol. 13, no. 9, pp. 2829-2847**. https://www.sdiarticle5.com/review-history/104557**

Lingaiah, N., S. Raju, N. Sarta and K. Radhika (2024). Understanding of gene action for nutritional traits in elite rice (*Oryza sativa* L.) Crosses Agricultural Science Digest, Volume 44 (1): 94-99.

Mather, K. and I. L. Jinks (1982). "Biometrical Genetics" 3rd ed. Chapman and Hall, London.PP:382.

Modarresi, M., M. AllahGholiour, and A. A. Ebadi (2024). Estimation of Gene Effect and Combining Ability for Yield and Yield Components Using Line x Tester Analysis in Rice (*Oryza sativa*). Plant Breed. Biotech. 12.17~29. **https://doi.org/10.9787/PBB.2024.12.17**

Santhiya, S., R. Pushpam, A. Subramanian, A. John Joel and A. Senthil (2023). Nature of gene action and combining ability effects for grain yield and quality traits in rice (*Oryza sativa* L.). Electronic J. of Plant Breeding. Vol 15(1): 11-20. https://doi.org/10.37992/2024.1501.003

Savi, Suvi, W.T.; Shimelis, H.; Laing, M.; Mathew, I.; Shayanowako, A.I.T. (2021). Determining the Combining Ability and Gene Action for Rice Yellow Mottle Virus Disease Resistance and Agronomic Traits in Rice (*Oryza sativa* L.). Agronomy 2021, 11, 12. https://dx.doi.org/10.3390/agronomy11010012

Singh, S.K., S. Bindal, A. Singh, and S. Srivastava (2019). Combining ability effects for yield traits in rice (Oryza sativa L.) under sodic soil. Journal of Pharmacognosy and Phytochemistry, 8(1): 281-283.

Singh, U., A. Sao and S.K. Verma (2025). Unlocking hybrid potential: A detailed analysis of heterosis, GCA, and SCA for enhancing agronomic performance and yield in rice (*Oryza sativa* l.). Plant Archives Vol. 25, Supplement 1: 971-978. DOI Url: https://doi.org/10.51470/ PLANTARCHIVES.2025. v25.supplement-1.132

Steel, R.G.and J.H. Torri. (1980). Principles and procedures of statistics McGraw-Hill book Co., New York

Thakur, K., A. Sao, D. Gauraha, S. Nair and K. Tandekar (2023). Estimation of Combining Ability using Line × Tester Analysis for Yield and its Contributing Traits in Aromatic rice *(Oryza sativa* L.). Biological Forum – An International Journal 15(7): 01-09.

Thang, N.B. (2024). Combining Ability Analysis for Quality Traits in Selected Rice Varieties (*Oryza sativa* L.). Vietnam Journal of Agricultural Sciences. 7(3): 2208-2216. https://doi.org/10.31817/vjas.2024.7.3.03

USDA, World agriculture production, foreign agriculture service, circular series WAP. 10 Jan 2020

Vennila, B.M.S. (2024). Combining Ability and Gene Action for Yield Traits for Selected Crosses of Rice (*Oryza sativa* L.). Environment and Ecology 42 (4C): 2081—2085.