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Heterosis and Combining ability Estimates using Line x Tester Analysis to Develop Wide Compatibility and Restorer Lines in Rice

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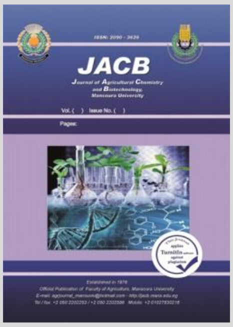

ABSTRACT

This investigation was conducted at Agriculture Research Station, Sakha, Kafr El-Sheikh, Egypt, during 2017 and 2018 rice seasons to study combining ability, gene action, heterosis, and degree of dominance for grain yield and its contributing traits in some wide compatibility lines. Eight genotypes included the three lines; O2428-P-7-7; Norti and Gz 5121-5-2 as female parents with five testers Dular; Nekken 1; Giza 178; Gz 5934-7-2-3 and IR 25571-31-1, are used in a line X testers cross. The analysis of variance revealed significant differences among parents, crosses and line x tester interaction for all studied traits except panicle weight in parents. The ratio of K^2 GCA / K^2 SCA was more than unity for all studied traits except for panicle weight indicated preponderance of additive gene effects in the expression of these traits. Rice varieties; Dular and Nekken 1 can be identified as wide compatible lines. Most of F_1 crosses showed significant values in the heterosis for the studied traits. The crosses Norti X Nekken 1 and Norti X Giza 178 showed the highest values for mean performance and the three types of heterosis for grain yield. In addition, the highest significant positive values of specific combining ability were shown in the four cross combinations O2428-P-7-7 X IR25571-31-1; Gz 5121-5-2 X Gz 5934-7-2-3; Gz 5121-5-2 X Dular and Norti X Giza 178. The results of this study indicate that the parental lines can be used for improvement and utilized in hybrid rice breeding program.

Keywords: Rice, heterosis, combining ability, Line x tester, wide compatibility, restorer lines.

INTRODUCTION

Rice (*Oryza sativa* L) is a essential international agriculture product. Rice is one of the main important food crops of the world. Most of the world's population relies on rice as the major daily source of calories and protein (Jain *et al.,* 2016). The level of heterosis in several hybrid rice varieties is reported to be the highest in *indica* × *japonica* hybrids, but, there is a problem of sterility and semi-sterility in such inter sub specific hybrids. To necessary overcome this problem, it is to develop parental lines contain wide compatibility (S5n) genes, Priyadarshi *et al.,* (2018).

The utilization of distant hybrid vigor is a promising way for raising production. Several studies have shown the yield increase of being more heterozygous in hybrids. Genetic distance was reported to be positively correlated to the heterosis in rice (Luo *et al.,* 1996; Luo *et al.,* 1999; Xu *et al.,* 2002 and Phetmanyseng *et al.,* 2010). The increase in yield of *indica-indica* rice hybrids was higher than 15% of the best pure *indica* varieties, while, hybrids between *indica* and *japonica* have a yield advantage of about 25% (Khush, 1994). However, a variable degree of hybrid sterility is often found in *indica* × *japonica* crosses. Ikehashi and Araki (1984) discovered the importance of wide compatibility gene (s), as a genetic tool to overcome this hybrid sterility problem. Yang *et al.,* (1962); Chu *et al.,* (1964) and Ikehashi and Araki (1984) showed that, wide compatibility varieties (WCVs) are a special class of rice germplasm that is able to produce fertile hybrids when crossed to both *indica* and *japonica* subspecies.

The success in developing *indica* × *japonica* hybrids using new plant type restorers contain wide compatibility genes developed from *indica* × *japonica* crosses derivatives largely depends on the availability of effective restorers and knowledge of the genetics of fertility restoration of such derivative lines. A study using *indica/japonica* restorers and 'WA'-type cytoplasmic male sterile lines revealed that two or three major genes govern the fertility restoration. The hybrids grown in China, India, Vietnam, Bangladesh and other countries are based on *indica* rice sources which on average show a standard heterosis of 15 - 20% in commercial cultivation mainly due to the narrow genetic diversity in the *indica* source material. With the availability of wide compatibility genes allowing normal spikelets fertility in *indica* × *japonica* hybrids. Exploitation of heterosis between the two sub-specific groups has become possible. The level of heterosis in *indica* × *japonica* hybrids is quite high due to their parental lines are too diverse. Hybrids from *indica* and *japonica* parents have been reported to produce 30 - 40% yield advantage over the best existing *indica* × *indica* hybrids, Hossain *et al.,* (2010). This investigation was designed to study and identify the best widely compatible (WC) lines as well as crosses which show high heterosis for yield, in addition to identify good general and specific combining ability under Egyptian conditions. This study might led to introduce restorer genes into the widely compatibles lines for developing the widely compatible restorer (WCR) lines, widely compatible maintainer (WCB) lines and widely compatible cytoplasmic male sterile (WCCMS) lines.

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MATERIALS AND METHODS

The present study was carried out at Sakha Agricultural Research Station, Kafr El-Sheikh, Egypt, during 2017 and 2018 rice seasons. The experiment comprised cross progenies derived from three lines namely O2428-P-7-7 (*japonica*); Norti (*indica*) and Gz 5121-5-2 (*indica/japonica*) as female parents with five lines as pollen parents (testers) namely Dular (*indica*); Nekken 1 (*japonica*); Giza 178 (*indica/japonica*); Gz 5934-7-2-3 (*indica/japonica*) and IR 25571-31-1 (*indica*). At flowering time, hybridization between parental lines was carried out following the technique proposed by Jodon (1938). The 15 crosses generated through line x tester mating design of three lines as female parents with five lines as pollinated parents in 2017 season. The 15 F_1 crosses along with eight parents were grown in a nursery during the second week of May of 2018 season. After 30-days, seedlings of all genotypes were individually transplanted in the field. A randomize complete block design (RCBD) with three replications was used. Each replicate consisted of 23 genotypes, where each genotype was grown in three rows five meters length with 20 x 20cm between rows and plants, each row had 25 hills.

Grain yield and its contributing traits were estimated according to Standard Evaluation System for Rice (SES) of International Rice Research Institute 2014. The studied traits were: days to 50% of heading, plant height (cm), panicles plant^{-1}, panicle length (cm), spikelets panicle^{-1}, pollen fertility (%), spikelets fertility (%), filled grains panicle^{-1}, panicle weight (g) and grain yield plant^{-1} (g).

Statistical analyses: The data were analyzed using the analysis of variances for RCBD as suggested by Panse and Sukhatme (1954) to test the significance of differences among the genotypes. Line x tester analysis was performed according to Kempthorne (1957).

General Combining Ability (GCA) effects for each female or male parent and Specific Combining Ability (SCA) effects for each cross combination were estimated according to Singh and Chaudhary (1977).

The genetic components were estimated based on the expectations of mean squares according to EL-Rouby (2009).

The heterosis was determined for each cross over better parent (BP), mid-parent (MP) and standard heterosis (SH) (Mather 1949 and Mather and Jinks 1982). Appropriate LSD. values were calculated to test the significance of the heterosis effects for better parent, mid-parent and standard heterosis, according to the methods, suggested by Wyanne *et al.*, (1970).

The potence ratio was calculated according to Mather (1949) and Smith (1952) to determine the degree of dominance.

RESULTS AND DISCUSSION

Mean performances:

The mean performances of grain yield and its contributing traits of the 23 rice genotypes are presented in Table 1. The data showed that, for days to 50% heading, the genotypes Dular and Nekken 1 were early heading, their number of days to 50% heading were 84.67 and 89.32 days, respectively. The crosses Norti X Dular, Norti X Nekken 1 and Norti X Gz 5934-7-2-3 were earlier genotypes comparing with other rice genotypes and their number of days to 50% heading were 90.47, 91.17 and 91.24 day, respectively, these results were in agreement with Awad-Allah (2019) and Kumar *et al.*, (2020 a). Concerning plant height, the two parents Nekken 1 and O2428-P-7-7 were the shortest plants and gave the lowest mean values (65.11 and 68.74cm, respectively). While, the genotypes Dular and Norti showed the highest mean values of plant height (135.50 and 93.91cm, respectively). However, the F_1 crosses O2428-P-7-7 X Nekken 1 and O2428-P-7-7 X Gz 5934-7-2-3 gave the lowest plant height values (67.88 and 81.09cm, respectively). While, the crosses O2428-P-7-7 X Dular, Gz 5121 X Dular and Norti X Dular showed the highest mean values for plant height (153.39, 125.14 and 125.07cm, respectively). These results were in agreement with Awad-Allah (2019) and Kumar *et al.*, (2020 a).

Concerning panicles plant^{-1} the three parental genotypes Gz 5121-5-2; Gz 5934-7-2-3 and Giza 178 gave the highest mean values (27.26, 25.56 and 24.10 Panicle, respectively). While, the four crosses Gz 5121-5-2 X Nekken 1, Gz 5121-5-2 X Gz 5934-7-2-3, O2428-P-7-7 X Giza 178 and O2428-P-7-7 X Dular gave the highest mean values (24.03, 22.03, 21.03 and 19.67 Panicle, respectively), the highest mean values of panicles plant^{-1} were recorded by Awad-Allah (2019) and Kumar *et al.*, (2020 a).

The three parental genotypes Norti, Dular and Giza 178 gave the highest mean values of panicle length (25.35, 25.12 and 23.79cm, respectively). On the other hand, the three cross combinations O2428-P-7-7 X IR25571-31-1, O2428-P-7-7 X Giza 178 and Norti X Dular gave the highest mean values of the panicle length (31.93, 29 and 28.71cm, respectively). These results were in harmony with results by Awad-Allah (2019).

For spikelets panicle^{-1}, the highest mean values were recorded for O2428-P-7-7 (224.22) and Giza 178 (190.96). The three crosses of O2428-P-7-7 X Giza 178, O2428-P-7-7 X IR25571-31-1 and Gz 5121 X Giza 178, recorded the highest mean values for spikelets panicle^{-1}, their mean values were 338, 287.77 and 238 spikelet, respectively. The genotypes with more number of spikelets/panicle was identified as a good parents, Awad-Allah (2019).

The rice varieties, Gz 5121-5-2 (*indica/ japonica*) followed by IR 25571-31-1 (*indica*), Dular (*indica*), Giza 178 (*indica/ japonica*), Nekken 1 (*japonica*), Gz 5934-7-2-3 (*indica/ japonica*) and Norti (*japonica*), gave the highest mean values of pollen fertility of, 97.50, 96.67, 96.57, 96.23, 95.30, 95.30 and 93.13%, respectively. The 12 crosses of Norti X IR25571-31-1, followed by Norti X Giza 178, Gz 5121 X Nekken 1, Norti X Nekken 1, O2428-P-7-7 X Gz 5934-7-2-3, O2428-P-7-7 X Nekken 1, Norti X Gz 5934-7-2-3, Gz 5121 X Dular, Norti X Dular, Gz 5121 X Giza 178, O2428-P-7-7 X IR25571-31-1 and O2428-P-7-7 X Dular, gave the highest mean values of pollen fertility %, 98.23, 98.10, 97.73, 97.43, 97.20, 96.47, 94.83, 91.40, 86.23, 84.43, 77.73 and 75.70%, respectively. These results similar with the findings of Awad-Allah (2019) and Jiang *et al.*, (2019).

The rice varieties, Dular (*indica*) and Nekken 1 (*japonica*) which showed spikelets fertility percentage more than 70% when they were crossed with each of *japonica* and *indica* types, indicating that both lines can be identified as wide compatibility. These results were in accordance with the findings of Vaithiyalingan and Nadarajan (2010); Awad-Allah (2016) and (2019). Furthermore, Giza 178 (*indica/japonica*), Gz 5934-7-2-3 (*indica/japonica*) and IR25571-31-1 (*indica*) showed high spikelets fertility percentage, more than 70%, when crossed with *indica* tester. Meanwhile, some crosses which their pollen parents were *indica* showed spikelets fertility less than 70% such as O2428-P-7-7 X Giza 178 (40.12), Gz 5121 X Gz 5934-7-2-3 (46.18) and Gz 5121 X IR25571-31-1 (4.05). This results were agreed with the findings of Guo *et al.,* (2016); Kostylev *et al.,* (2017); Priyadarshi *et al.,* (2018) and Awad-Allah (2019).

Table 1. Mean performance of the rice studied genotypes during 2018 season for the studied traits.

Genotypes / Traits	Days to 50% heading (day)	Plant height (cm)	Panicles plant^{-1}	Panicle length (cm)	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight (g)	Grain yield plant^{-1} (g)
Lines										
O2428-P-7-7	102.03	68.74	19.34	22.92	224.22	84.80	81.67	183.17	2.52	32.70
Norti	95.00	93.91	21.73	25.35	129.00	93.13	89.21	115.11	3.50	33.13
Gz 5121-5-2	100.43	86.96	27.26	22.95	132.84	97.50	94.99	126.13	2.74	31.90
Testers										
Dular	84.67	135.50	22.76	25.12	131.59	96.57	92.79	122.04	3.06	31.57
Nekken 1	89.32	65.11	18.57	18.65	108.69	95.30	91.36	99.28	2.48	22.36
Giza 178	101.29	88.07	24.10	23.79	190.96	96.23	92.50	176.55	3.47	35.12
Gz 5934-7-2-3	91.68	83.16	25.56	17.84	96.44	95.30	91.39	88.13	2.78	31.20
IR 25571-31-1	95.80	86.61	21.43	23.24	160.65	96.67	94.05	151.06	3.59	33.84
F_1 crosses										
O2428-P-7-7 X Dular	94.33	153.39	19.67	27.10	211.67	75.70	70.89	149.91	4.28	19.09
O2428-P-7-7 X Nekken 1	94.50	67.88	11.00	21.34	91.67	96.47	91.89	84.22	2.15	29.22
O2428-P-7-7 X Giza 178	102.53	109.39	21.03	29.00	338.00	44.93	40.12	135.69	2.42	25.09
O2428-P-7-7 X Gz 5934-7-2-3	95.00	81.09	18.27	19.90	155.91	97.20	94.58	147.28	3.45	20.09
O2428-P-7-7 X IR25571-31-1	98.43	81.74	15.17	31.93	287.77	77.73	74.27	213.73	8.37	29.11
Norti X Dular	90.47	125.07	13.00	28.71	101.43	86.23	82.93	84.10	2.89	37.45
Norti X Nekken 1	91.17	96.11	15.67	25.30	177.20	97.43	93.46	165.62	5.12	43.58
Norti X Giza 178	99.33	85.39	11.07	27.24	180.13	98.10	94.46	170.13	3.24	41.43
Norti X Gz 5934-7-2-3	91.24	93.52	16.97	25.68	134.40	94.83	90.54	121.67	2.46	30.34
Norti X IR25571-31-1	93.62	110.32	17.33	23.80	134.80	98.23	94.94	128.00	2.27	30.18
Gz 5121-5-2 X Dular	91.53	125.14	14.00	26.18	158.75	91.40	87.46	138.93	2.23	34.13
Gz 5121-5-2 X Nekken 1	93.87	91.00	24.03	21.41	167.77	97.73	93.99	157.67	2.73	36.70
Gz 5121-5-2 X Giza 178	101.67	88.62	13.33	23.58	238.00	84.43	80.17	190.83	2.84	29.21
Gz 5121-5-2 X Gz 5934-7-2-3	100.00	97.61	22.03	24.90	151.62	47.20	46.18	70.04	2.62	33.30
Gz 5121-5-2 X IR25571-31-1	99.33	95.43	11.00	23.87	124.16	9.12	4.05	5.04	0.92	6.62
LSD 5%	0.72	4.05	2.20	1.11	14.70	2.20	2.82	13.11	0.77	3.46
L.S. 1%	0.96	5.41	2.94	1.48	19.64	2.95	3.77	17.51	1.03	4.62
CV	0.53	2.96	8.40	3.19	6.2	1.84	2.46	7.03	17.17	8.03

The 12 crosses showed the high mean values for spikelets fertility % were Norti X IR25571-31-1 (94.94), O2428-P-7-7 X Gz 5934-7-2-3 (94.58), Norti X Giza 178 (94.46), Gz 5121 X Nekken 1 (93.99), Norti X Nekken 1 (93.46), O2428-P-7-7 X Nekken 1 (91.89), Norti X Gz 5934-7-2-3 (90.54), Gz 5121 X Dular (87.46), Norti X Dular (82.93), Gz 5121 X Giza 178 (80.17), O2428-P-7-7 X IR25571-31-1 (74.27) and O2428-P-7-7 X Dular (70.89). These results were similar with the findings of Guo *et al.,* (2016), Priyadarshi *et al.,* (2018) and Awad-Allah (2019). So, we can identify these genotypes as wide compatibility lines and use it as a source for developing new restorer wide combatable lines, these findings were agreed with the findings of Awad-Allah (2006); Awad-Allah (2016) and Awad-Allah (2019).

The crosses depicting low spikelets fertility percentage was recorded in crosses between the *indica* and *japonica* parents, *indica japonica* X *indica japonica* and *indica japonica* X *indica*. This can be attributed to weak wide compatibility gene effects, in the parental lines. The spikelets low fertility percentage in *indica* X *japonica* crosses has been explained by Ikehashi and Araki (1984) due to gamete abortion by an allelic interaction at a locus causing the hybrid sterility, which can be overcome by incorporation of neutral allele wide compatibility gene (WCG) into one of the parents.

The two *japonica* parents O2428-P-7-7 and Nekken 1 in addition to the *indica* parents Dular and Norti are reported to posses neutral allele $S\text{-}5^n$ normal fertile F_1 generation in combination with most of *indica* and *indica/japonica* restorer lines. The crosses between *japonica* WC parent O2428-P-7-7 with each of *indica* parents Dular, IR25571-31-1 and Gz 5934-7-2-3 (J/I) showed spikelets fertility percentage more than 70 %. Awad-Allah (2019), found that the cross combinations between each of *indica* restorer parents Giza 181 and Giza 182 with *japonica* wide compatibility parent Nekken 1 showed medium fertility of spikelets, possibly due to weak sterility neutralizing effect.

Concerning filled grains panicle^{-1}, O2428-P-7-7 and Giza 178 showed the highest mean values (183.17 and 176.55 grains, respectively). The crosses, O2428-P-7-7 X IR25571-31-1 (J X I), Gz 5121-5-2 X Giza 178 (IJ X IJ), Norti X Giza 178 (I X IJ), Norti X Nekken 1 (I X J) and Gz 5121-5-2 X Nekken 1 (IJ X J) gave the highest mean values (213.73, 190.83, 170.13, 165.62 and 157.67 grains, respectively) for filled grains panicle^{-1}.

Concerning the panicle weight, IR 25571-31-1, Norti and Giza 178 gave the highest mean values of 3.59, 3.50 and 3.47g, respectively. The crosses O2428-P-7-7 X IR25571-31-1 (J X I), Norti X Nekken 1 (I X J), O2428-P-7-7 X Dular (J X I), O2428-P-7-7 X Gz 5934-7-2-3 (J X IJ) and Norti X Giza 178 (I X IJ) gave the highest mean values (8.37, 5.12, 4.28, 3.45 and 3.24g, respectively).

Concerning the grain yield plant^{-1}, the results indicated that the genotypes Giza 178, IR 25571-31-1, Norti and O2428-P-7-7 showed the highest mean values of 35.12, 33.84, 33.13 and 32.70g, respectively for grain yield plant^{-1}. The crosses Norti X Nekken 1 (I X J), Norti X Giza 178 (I X IJ), Norti X Dular (I X I), Gz 5121-5-2 X Nekken 1 (IJ X J) and Gz 5121-5-2 X Dular (IJ X I) gave the highest mean values for the grain yield plant^{-1}, with mean values of 43.58, 41.43, 37.45, 36.70 and 34.13g, respectively. Awad-Allah (2019) found that the crosses between *indica* and *japonica* subspecies (I X J and J X I) where one of the parents is wide combatable lines showed the highest values of grain yield more than the crosses of the same subspecies (I X I). These results were in harmony with that reported by Prasad *et al.,* (2019).

With regarded to grain yield and its contributing traits, the five crosses Norti X Nekken 1 (I/J), Norti X Giza 178 (I/IJ), Norti X Dular (I/I), Gz 5121-5-2 X Nekken 1 (IJ/J) and Gz 5121-5-2 X Dular (IJ/I), showed good desirable traits such as earliness, suitable plant height, high panicles plant^{-1}, long panicle, high spikelets panicle^{-1}, high filled grains panicle^{-1}, heavy panicle weight and high grain yield. So, we can use these crosses as a source for developing new restorer lines and widely compatible lines in hybrid rice breeding program. Yogameenakshi and Vivekanandan (2015), reported that the selection of parental lines is a essential step in breeding programmes for development of promising lines. Parents with high mean performance and good general combining ability for grain yield and yield contributing traits are ideal for getting desirable segregates.

Analysis of variance and gene action:

Understanding of inheritance of various traits and identification of superior parents are important pre-requisites for beginning an effective and efficient breeding programme. Analysis of variance for grain yield and its contributing traits, are presented in Table 2. The results of the F-test showed that the mean squares of the genotypes for all studied traits were highly significant indicate of the presence of large variations among them. Similarly, the results cleared that, the mean squares of the parents, crosses, parents *Vs* crosses, lines, testers and line x tester were highly significant for all the studied traits with some exception. Similar results were obtained by Ambikabathy *et al.,* (2019); Awad-Allah (2019); Singh *et al.,* (2019); Alok and Sujeet (2020) and Kumar *et al.,* (2020 a).

Table 2. Analysis of variance and combining ability for the 23 rice studied genotypes during 2018 season for all studied traits.

Traits / Source of variance	d.f	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
Replications	2	0.04 ns	1.9ns	3.2 ns	1.2 ns	41.5 ns	3.5 ns	3.3 ns	25.6 ns	0.5 ns	1.4 ns
Genotypes	22	68.7**	1424.8**	70.2**	32.9**	11127.3**	1478.9**	1501.5**	6413.4**	5.9**	184.8**
Parents	7	115.4**	1375.9**	26.4**	23.2**	5514.9**	50.6**	52.0**	3589.8**	0.6 ns	45.6**
P. *vs.* Crosses	1	9.4**	2108.1**	632.4**	126.9**	14168.2**	3361.2**	3520.8**	52.2 ns	0.5 ns	49.3**
Crosses	14	49.5**	1400.4**	51.9**	31.0**	13716.3**	2058.6**	2082.1**	8279.5**	8.9**	264.1**
Lines	2	78.6**	46.4*	23.1**	20.6**	19998.2**	3172.9**	3161.4**	4354.1**	13.1**	580.0**
Tester	4	115.5**	3490.2**	29.8**	39.3**	17817.2**	1503.8**	1498.7**	4102.8**	1.6*	257.3**
Line x Tester	8	9.3**	694.0**	70.1**	29.4**	10095.5**	2057.4**	2103.9**	11349.2**	11.6**	188.5**
Error	44	0.3	8.1	2.4	0.6	106.4	3.0	4.0	84.6	0.3	5.4

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Estimation of ratio between K^2 GCA and K^2 SCA for grain yield and its contributing traits are illustrated in Table 3. K^2 GCA / K^2 SCA ratio was more than unity for the studied traits, indicating the importance of additive gene effects in the expression of these traits. Those results are in harmonically with that observed by Sanghera and Hussain (2013); Ali *et al.,* (2014); Upadhyay and Jaiswal (2015) and Ambikabathy *et al.,* (2019). Therefore, the selection procedures based on the accumulation of additive effect would be successful in improving grain yield and its contributing traits, Awad-Allah *et al.,* (2015) and Ambikabathy *et al.,* (2019) reported the importance of additive gene effects in the expression of grain yield, panicles plant^{-1}, filled grains panicle^{-1}, days to 50 % heading, spikelets panicle^{-1} and spikelet fertility percentage.

Table 3. Ratio between K^2 GCA and K^2 SCA for the studied traits in rice genotypes during 2018 season.

Traits / Genetic component	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
K^2 GCA	5.2	2.6	1.4	1.3	1326.1	211.3	210.5	284.6	0.9	38.3
K^2 SCA	12.8	386.9	3.0	4.3	1967.9	166.8	166.1	446.5	0.1	28.0
K^2 GCA / K^2 SCA	3.0	228.7	22.5	9.6	3329.7	684.8	700.0	3754.9	3.8	61.0

General combining ability effects:

General combining ability (GCA) effects were presented for lines in Table 4 and for testers in Table 5. For days to 50% heading, the results revealed that the line Norti showed highly significant desirable negative value (-2.6). While, highly significantly desirable negative values were shown by testers Dular (-3.7); Nekken 1 (-2.6) and Gz 5934-7-2-3 (-0.4). This finding indicated that these lines and testers are identified as good combiners for develop earliness restorer lines, wide compatibility lines, wide compatible restorer lines and maintainer lines. Thus general combining ability estimate could help in identifying the lines and testers would produce promising lines and hybrids having desirable traits. Hence there is a possibility of selecting desirable progenies and fixing them in the early generations. Good general combiners for earliness were also reported by Vadivel *et al.*, (2018) and Kour *et al.*, (2019).

Table 4. General combining ability effects of the lines for the studied traits during 2018 season.

Lines \ Traits	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
O2428-P-7-7	1.2**	-1.4**	0.8**	0.5**	40.1**	-1.4**	-1.6**	15.3**	0.9**	-5.2**
Norti	-2.6**	2.0**	-1.4**	0.8**	-31.3**	15.2**	15.3**	3.0*	-0.003ns	6.9**
Gz 5121-5-2	1.5**	-0.6 ns	0.6**	-1.3**	-8.8**	-13.8**	-13.6**	-18.4**	-0.9**	-1.7**
LSD 5%	0.13	0.73	0.40	0.20	2.66	0.45	0.52	2.37	0.14	0.60
L.S.D1%	0.18	1.04	0.57	0.28	3.77	0.63	0.73	3.36	0.20	0.85

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Table 5. General combining ability effects of the tester lines for the studied traits during 2018 season.

Testers \ Traits	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen Fertility (%)	Spikelets Fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
Dular	-3.7**	34.4**	-0.7*	2.0**	-19.6**	4.7**	4.4**	-6.5**	-0.06 ns	0.5 ns
Nekken 1	-2.6**	-15.1**	0.7*	-2.6**	-31.3**	17.4**	17.1**	5.0**	0.13 ns	6.8**
Giza 178	5.4**	-5.6**	-1.1**	1.3**	75.2**	-4.0**	-4.4**	34.7**	-0.37**	2.2**
Gz 5934-7-2-3	-0.4**	-9.4**	2.9**	-1.8**	-29.6**	-0.04 ns	1.1**	-17.9**	-0.36**	-1.8**
IR 25571-31-1	1.3**	-4.3**	-1.7**	1.2**	5.4**	-18.1**	-18.2**	-15.3**	0.7**	-7.7**
LSD 5%	0.2	0.9	0.5	0.3	3.4	0.6	0.7	3.1	0.18	0.8
L.D 1%	0.2	1.3	0.7	0.4	4.9	0.8	0.9	4.3	0.25	1.1

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Concerning plant height, the line O2428-P-7-7 showed highly significant desirable negative GCA effects (-1.4). While, the testers Nekken 1 (-15.1), Gz 5934-7-2-3 (-9.4), Giza 178 (-5.6) and IR 25571-31-1 (-4.3) showed highly significant desirable negative effects of GCA. The negative values indicate short plant height; therefore it could be useful to breed for short stature rice cultivars, cytoplasmic male sterile lines (CMS), widely compatible CMS lines, maintainer lines, widely compatible restorer lines or hybrid combination. Concerning the panicles plant^{-1}, the GCA effects estimates for the line O2428-P-7-7 (0.8) and Gz 5121-5-2 (0.6) as well as the testers Gz 5934-7-2-3 (2.9) and Nekken 1 (0.7) were highly significant and positive. Those genotypes seemed to be good parental combiners in rice crosses. For panicle length, the results showed that the values of general combining ability effects were highly significant positive for the line Norti (0.8) and O2428-P-7-7(0.5). On the other hand, the testers Dular (2), Giza 178 (1.3) and IR 25571-31-1 (1.2) showed highly significant positive values. These genotypes could help to improve of maintainer lines, restorer lines, widely compatible restorer lines and widely compatible CMS lines. Obviously, spikelets panicle^{-1}, showed highly significant and positive value of general combining ability effects for the line O2428-P-7-7 (40.1). In addition, the testers Giza 178 (75.2) and IR 25571-31-1 (5.4) showed highly significant and positive values of GCA effects. Suggesting that these genotypes could be good parental lines in rice crosses for improving such trait. For pollen fertility percentage, the results indicated that the line Norti (15.2) and the two testers Nekken 1 (17.4) and Dular (4.7) showed highly significant and positive values of GCA effects. These genotypes might be utilized as parents for breeding for more fertile pollen grains and to develop maintainer and restorer lines. Concerning the spikelets fertility percentage, the results indicated that the line Norti (15.3) and three testers Nekken 1 (17.1), Dular (4.4) and Gz 5934-7-2-3 (1.1) recorded highly significant and positive values of general combining ability effects. These genotypes could be utilized as parents for breeding genotypes with more fertile grains per panicle and to develop parental lines. Concerning the filled grains panicles^{-1}, the results revealed that GCA effects the lines O2428-P-7-7 (15.3) and Norti (3) and the testers Giza 178 (34.7) and Nekken 1 (5) were highly significant and positive. Concerning panicle weight, the results indicated that the line O2428-P-7-7 (0.9) and the tester IR 25571-31-1 (0.7) recorded highly significant and positive values of general combining ability effects. Consequently, the previous genotypes can be used in the hybrid rice breeding program as good combiners for heavier panicle weight. Furthermore, the grain yield plant^{-1}, data revealed that the lines Norti (6.9) as well as the testers Nekken 1 (6.8) and Giza 178 (2.2) showed highly significant positive values for general combining ability effects. These genotypes could be good parental lines in rice crosses for improving maintainer lines, restorer lines, widely compatible restorer lines, widely compatible CMS lines and rice cultivars for grain yield plant^{-1}. Good general combiner for grain yield and yield contributing traits were also reported by Suvathipriya and Kalaimagal (2018); Vadivel *et al.*, (2018); Kour *et al.*, (2019) and Singh *et al.*, (2019).

Specific combining ability (SCA) effects:

For days to 50% heading, the results revealed that six crosses recorded highly significant desirable negative estimates for specific combining ability effects. The highly significant negative values were shown in the crosses Gz 5121-5-2 X Dular (-2.1), O2428-P-7-7 X Gz 5934-7-2-3 (-1.6), Norti X Gz 5934-7-2-3 (-1.5), Gz 5121-5-2 X Giza 178 (-1), Norti X IR25571-31-1 (-0.9) and Gz 5121-5-2 X Nekken 1 (-0.8). The dissemble estimates of SCA effects in some crosses, might be not necessarily to be dependent upon the general combining ability effects, i.e. cross Gz 5121-5-2 X Giza 178 (Table 6).

Table 6. Specific combining ability effects for the studied traits of rice crosses during 2018 season.

Traits crosses	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
O2428-P-7-7 XDular	1.1**	20.3**	3.3**	-0.8**	14.3**	-7.4**	-7.9**	10.3**	0.2 ns	-6.0**
O2428-P-7-7 X Nekken 1	0.2 ns	-15.7**	-6.7**	-1.9**	-94.0**	0.6 ns	0.4 ns	-66.9**	-2.1**	-2.1**
O2428-P-7-7 X Giza 178	0.2 ns	16.3**	5.1**	1.9**	45.8**	-29.5**	-29.8	-45.2**	-1.3**	-1.6*
O2428-P-7-7 X Gz 5934-7-2-3	-1.6**	-8.2**	-1.6**	-4.1**	-31.5**	18.8**	19.1**	19.0**	-0.3*	-2.6**
O2428-P-7-7 X IR25571-31-1	0.1 ns	-12.7**	-0.1 ns	4.9**	65.4**	17.4**	18.2**	82.8**	3.6**	12.3**
Norti X Dular	1.0**	-11.4**	-1.1*	0.6*	-24.6**	-13.4**	-12.8**	-43.3**	-0.2 ns	0.3 ns
Norti X Nekken 1	0.6**	9.1**	0.2 ns	1.8**	62.9**	-15.0**	-14.9**	26.7**	1.8**	0.2 ns
Norti X Giza 178	0.8**	-11.0**	-2.6**	-0.2	-40.6**	7.1**	7.6**	1.5 ns	0.4*	2.6**
Norti X Gz 5934-7-2-3	-1.5**	0.8 ns	-0.7 ns	1.4**	18.4**	-0.1 ns	-1.8**	5.6*	-0.4*	-4.5**
Norti X IR25571-31-1	-0.9**	12.5**	4.3**	-3.5**	-16.2**	21.4**	21.9**	9.4**	-1.6**	1.3 ns
Gz 5121-5-2 X Dular	-2.1**	-8.8**	-2.2**	0.2	10.3**	20.8**	20.7**	33.0**	0.03 ns	5.6**
Gz 5121-5-2 X Nekken 1	-0.8**	6.6**	6.5**	0.1	31.0**	14.3**	14.5**	40.2**	0.3*	1.9**
Gz 5121-5-2 X Giza 178	-1.0**	-5.3**	-2.5**	-1.7**	-5.2 ns	22.4**	22.2**	43.6**	0.9**	-1.0 ns
Gz 5121-5-2 X Gz 5934-7-2-3	3.1**	7.4**	2.3**	2.7**	13.1**	-18.7**	-17.3**	-24.6**	0.7**	7.1**
Gz 5121-5-2 X IR25571-31-1	0.7**	0.2 ns	-4.1**	-1.3**	-49.3**	-38.8**	-40.1**	-92.2**	-2.0**	-13.6**
LSD 5%	0.3	1.6	0.9	0.4	6.0	1.0	1.2	5.3	0.3	1.3
L.D 1%	0.4	2.3	1.3	0.6	8.4	1.4	1.6	7.5	0.4	1.9

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Concerning plant height, seven crosses recorded highly significant desirable negative values of SCA effects. The highly significant negative values were shown in the cross O2428-P-7-7 X Nekken 1 (-15.7) followed by O2428-P-7-7 X IR25571-31-1 (-12.7), Norti X Dular (-11.4), Norti X Giza 178 (-11), Gz 5121-5-2 X Dular (-8.8), O2428-P-7-7 X Gz 5934-7-2-3 (-8.2) and Gz 5121-5-2 X Giza 178 (-5.3). The crosses with negative values of SCA effects are desirable and could be useful to breed short stature CMS lines, maintainer lines, widely compatible CMS lines and short stature rice cultivars. While the crosses with positive values of SCA effects could be useful to breed widely compatible restorer lines and restorer lines. Regarding panicles plant^{-1}, five crosses recorded highly significant positive estimates. The highest estimates were shown in the crosses Gz 5121-5-2 X Nekken 1 (6.5); O2428-P-7-7 X Giza 178 (5.1) and Norti X IR25571-31-1 (4.3). For panicle length, six crosses recorded significant and highly significant positive estimates of SCA effects. The highest estimates were shown in the crosses O2428-P-7-7 X IR25571-31-1 (4.9), Gz 5121-5-2 X Gz 5934-7-2-3 (2.7), O2428-P-7-7 X Giza 178 (1.9) and Norti X Nekken 1 (1.8). For spikelets panicle^{-1}, out of the 15 crosses, eight crosses recorded highly significant positive estimates of SCA effects. The highest estimates were shown in the crosses O2428-P-7-7 X IR25571-31-1 (65.4), Norti X Nekken 1 (62.9), O2428-P-7-7 X Giza 178 (45.8) and Gz 5121-5-2 X Nekken 1 (31). For pollen fertility percentage, the results showed that seven crosses recorded highly significant positive estimates of SCA effects. The highest significant positive estimates were shown in the crosses Gz 5121-5-2 X Giza 178 (22.4), Norti X IR25571-31-1 (21.4), Gz 5121-5-2 X Dular (20.8), O2428-P-7-7 X Gz 5934-7-2-3 (18.8) and O2428-P-7-7 X IR25571-31-1 (17.4). High estimates of SCA effects, not necessarily to be dependent upon the general combining ability effects. Concerning spikelets fertility percentage results showed that seven crosses recorded highly significant positive estimates of SCA effects. These crosses are Gz 5121-5-2 X Giza 178 (22.2), Norti X IR25571-31-1 (21.9), Gz 5121-5-2 X Dular (20.7), O2428-P-7-7 X Gz 5934-7-2-3 (19.1), O2428-P-7-7 X IR25571-31-1 (18.2), Gz 5121-5-2 X Nekken 1 (14.5) and Norti X Giza 178 (7.6). These crosses appeared to be good combiners to be used for improving wide compatibility lines, maintainer lines, restorer lines, widely compatible restorer, widely compatible CMS lines, rice cultivars and hybrids for spikelets fertility percentage. Regarding filled grains panicle^{-1}, the results showed that nine crosses recorded highly significant and significant positive values of specific combining ability effects. The highest estimates were shown in the crosses O2428-P-7-7 X IR25571-31-1 (82.8), Gz 5121-5-2 X Giza 178 (43.6), Gz 5121-5-2 X Nekken 1 (40.2), Gz 51215-2 X Dular (33) and Norti X Nekken 1 (26.7). Concerning panicle weight, six crosses recorded highly significant and significant positive values of SCA effects. The highest values were shown in the crosses O2428-P-7-7 X IR25571-31-1 (3.6), Norti X Nekken 1 (1.8) and Gz 5121-5-2 X Giza 178 (0.9). Concerning grain yield plant^{-1}, five crosses recorded highly significant positive estimates of specific combining ability effects. The highest values were shown in the crosses O2428-P-7-7 X IR25571-31-1 (12.3), Gz 5121-5-2 X Gz 5934-7-2-3 (7.1), Gz 5121-5-2 X Dular (5.6) and Norti X Giza 178 (2.6). These results indicated that the non-additive gene effects were major in these particular rice crosses for grain yield plant^{-1}. This could be attributed to the wide differences in grain yield plant^{-1} among the involved parents in these crosses. Accordingly, it could be suggested that of these crosses to be used in improving grain yield in hybrid rice breeding programme. The crosses showing high specific combining ability effects resulted low × low general combiners. Non-additive gene action play the major role in inheritance of grain yield in theses crosses. These cross combinations could be exploited for heterosis in rice breeding programme (Shanthi *et al.* 2011 and Awad-Allah *et al.,* 2015). It is concluded from the present investigation that there is a possibility to breed good rice cultivars, restorer lines, widely compatible lines, widely compatible restorer lines, widely compatible CMS lines, maintainer lines and CMS lines with desirable traits and higher yield than the existing lines through selection in later generations.

While, the crosses resulted from high x high GCA combiners recorded positive non significant estimates for SCA. These results are in accordance with the findings of

Raju *et al*., (2014); Bhatti *et al*., (2015) and Madhuri *et al*., (2017).

The proportional contribution of lines, testers and line × tester interaction for the expression of traits is illustrated in Table 7.

It is evident from the results that testers were more important for days to 50% heading (66.58 %) and plant height (71.21 %). These results were in harmony with those reported by Awad-Allah *et al.,* (2015) and Waza *et al.,* (2015), where they reported that days to 50% heading, plant height revealed preponderance testers influence for these traits. The contribution of maternal and paternal interaction (line x tester) was more important for panicles plant^{-1} (77.20 %), panicle length (54.28 %), spikelets panicle^{-1} (42.06 %), pollen fertility percentage (57.11 %), spikelets fertility percentage (57.74 %), filled grains panicle^{-1} (78.33 %), panicle weight (73.98 %) and grain yield plant^{-1} (40.79 %). Similar results were obtained by Waza *et al.,* (2015) and Rahaman (2016) where they found that the contribution of maternal and paternal interaction (line x tester) was more important for grain yield plant^{-1}.

Table 7. Contribution percentage of lines, testers and lines x testers towards the crosses sum of squares for the studied traits in rice.

Traits	Contribution of line (%)	Contribution of tester (%)	Contribution of line x tester (%)
Days to 50% heading	22.67	66.58	10.75
Plant height	0.47	71.21	28.32
Panicles plant^{-1}	6.37	16.43	77.20
Panicle length	9.49	36.23	54.28
Spikelets panicle^{-1}	20.83	37.11	42.06
Pollen fertility (%)	22.02	20.87	57.11
Spikelets fertility (%)	21.69	20.57	57.74
Filled grains panicle^{-1}	7.51	14.16	78.33
Panicle weight	20.91	5.11	73.98
Grain yield plant^{-1}	31.38	27.84	40.79

Estimation of heterosis :

The results of better parent (BP), mid-parent (MP) and standard heterosis (SH) for grain yield and its contributing traits are shown in Tables 8, 9 and 10. For Days to 50% heading, the results revealed that the cross Norti X IR 25571-31-1 (-1.46) showed highly significant negative value of better parent heterosis. The results also emphasized that the mid-parent (MP) heterosis were highly significant negative for the crosses Norti X Gz 5934-7-2-3 (-2.25), O2428-P-7-7 X Gz 5934-7-2-3 (-1.92), Norti X IR 25571-31-1 (-1.87), O2428-P-7-7 X Nekken 1 (-1.23), Gz 5121-5-2 X Dular (-1.1), Norti X Nekken 1 (-1.08) and Gz 5121-5-2 X Nekken 1 (-1.06). Moreover, the results revealed that the standard heterosis, were highly significant in negative direction for days to 50% heading in 13 crosses. The crosses Norti X Dular (-10.69), Norti X Nekken 1 (-9.99), Norti X Gz 5934-7-2-3 (-9.93) and Gz 5121-5-2 X Dular (-9.63) recorded the highest MP heterosis estimates. Significant and highly significant desirable heterosis for days to 50% heading, also, was recorded by Yuga *et al.,* (2018); Singh *et al.,* (2019); Kumar *et al*., (2020 b) and Yadav *et al.,* (2020).

Concerning the plant height, no negative desirable better parent heterosis (BP) were observed among all studied the crosses. However, for MP heterosis only one cross, namely Norti X Giza 178 (-6.15) recorded highly significant negative desirable heterosis. For standard heterosis results revealed that three crosses showed highly significant negative desirable values. The highest desirable values were observed in the cross O2428-P-7-7 X Nekken 1 (-22.92) followed by O2428-P-7-7 X Gz 5934-7-2-3 (-7.93) and O2428-P-7-7 X IR 25571-31-1 (-7.19). On the other hand 14, 14 and 11 crosses recorded either highly significant or non-significant positive heterosis when it were measured as a deviation from BP, MP and SH, for the same trait, respectively. The crosses showing negative estimates may be useful to breed good widely compatible maintainer lines, widely compatible CMS lines, maintainer lines and rice cultivars. Meanwhile, the crosses showing positive values may be useful to breed good widely compatible restorer lines and restorer lines. Similar results were found by Kostylev *et al.,* (2017); Singh *et al.,* (2019); Kumar *et al*., (2020 b) and Yadav *et al.,* (2020).

Obviously, for panicles plant^{-1}, data presented in Tables 8, 9 and 10, showed that the better parent (BP), mid-parent (M.P) and standard heterosis (SH) were illustrated that no positive estimates of heterosis were observed for all crosses. Similar results were reported by Elixon *et al.,* (2015); Singh *et al.,* (2019) and Kumar *et al.,* (2020 b).

Table 8. Estimates of percentage of heterosis over better-parent for the studied traits of rice crosses.

Traits / crosses	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
O2428-P-7-7 XDular	11.42**	123.13**	-13.59*	7.87**	-5.60ns	-21.61**	-23.60**	-18.16**	40.13**	-41.63**
O2428-P-7-7 X Nekken 1	5.80**	4.25ns	-43.13**	-6.91*	-59.12**	1.22ns	0.58ns	-54.02*	-14.80ns	-10.65ns
O2428-P-7-7 X Giza 178	1.23**	59.13**	-12.72*	21.90**	50.74**	-53.31**	-56.63**	-25.92**	-30.10*	-28.55**
O2428-P-7-7 X Gz 5934-7-2-3	3.62**	17.96**	-28.53**	-13.19**	-30.47**	1.99ns	3.49ns	-19.59**	23.83ns	-38.56**
O2428-P-7-7 X IR25571-31-1	2.75**	18.91**	-29.24**	37.41**	28.34**	-19.59**	-21.03**	16.68**	133.46**	-13.99*
Norti X Dular	6.85**	33.18**	-42.88**	13.27**	-22.92**	-10.70**	-10.63**	-31.09**	-17.41 ns	13.06*
Norti X Nekken 1	2.07**	47.61**	-27.91**	-0.18ns	37.36**	2.24ns	2.30ns	43.88**	46.15**	31.56**
Norti X Giza 178	4.56**	-3.04ns	-54.08**	7.44**	-5.67ns	1.94ns	2.12ns	-3.63ns	-7.52ns	17.97**
Norti X Gz 5934-7-2-3	-0.48ns	12.46**	-33.62**	1.30ns	4.19ns	-0.49ns	-0.93ns	5.69ns	-29.69*	-8.41ns
Norti X IR25571-31-1	-1.46**	27.38**	-20.25**	-6.10*	-16.09**	1.62ns	0.95ns	-15.26**	-36.71**	-10.81ns
Gz 5121-5-2 X Dular	8.11**	43.91**	-48.64**	4.22ns	19.51**	-6.26**	-7.92**	10.15ns	-27.04ns	7.00ns
Gz 5121-5-2 X Nekken 1	5.09**	39.75**	-11.83*	-6.74*	26.29**	0.24ns	-1.05ns	25.01**	-0.37ns	15.04*
Gz 5121-5-2 X Giza 178	1.23**	1.91ns	-51.08**	-0.88ns	24.63**	-13.40**	-15.60**	8.09ns	-18.08ns	-16.82**
Gz 5121-5-2 X Gz 5934-7-2-3	9.08**	17.37**	-19.16**	8.48**	14.14*	-51.59**	-51.38**	-44.47**	-5.87ns	4.39ns
Gz 5121-5-2 X IR25571-31-1	3.69**	10.19**	-59.64**	2.70ns	-22.71**	-90.65**	-95.74**	-96.67**	-74.35**	-80.45**
LSD 5%	0.83	4.67	2.57	1.28	16.97	2.85	3.31	15.13	0.89	3.82
LSD 1%	1.11	6.24	3.44	1.71	22.67	3.80	4.42	20.21	1.18	5.10

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Table 9. Estimates of percentage of heterosis over mid-parents for the studied traits of rice crosses.

Traits / crosses	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
O2428-P-7-7 XDular	1.05**	50.20**	-6.58ns	12.81**	18.98**	-16.52**	-18.73**	-1.77ns	53.52**	-40.60**
O2428-P-7-7 X Nekken 1	-1.23**	1.43ns	-41.97**	2.67ns	-44.93**	7.13**	6.22**	-40.36**	-14.06ns	6.13ns
O2428-P-7-7 X Giza 178	0.86*	39.52**	-3.17ns	24.17**	62.82**	-50.36**	-53.93**	-24.56**	-19.09ns	-26.00**
O2428-P-7-7 X Gz 5934-7-2-3	-1.92**	6.76*	-18.64**	-2.36ns	-2.76ns	7.94**	9.31**	8.57ns	29.90*	-37.12**
O2428-P-7-7 X IR25571-31-1	-0.49ns	5.23*	-25.61**	38.35**	49.54**	-14.33**	-15.47**	27.89**	174.09**	-12.51*
Norti X Dular	0.71ns	9.03**	-41.56**	13.78**	-22.15**	-9.08**	-8.87**	-29.08**	-11.79 ns	15.79**
Norti X Nekken 1	-1.08**	20.88**	-22.25**	15.02**	49.10**	3.41*	3.51*	54.50**	71.14**	57.08**
Norti X Giza 178	1.21**	-6.15**	-51.71**	10.85**	12.60**	3.61**	3.97*	16.66**	-7.03ns	21.41**
Norti X Gz 5934-7-2-3	-2.25**	5.63*	-28.25**	18.93**	19.23**	0.65ns	0.26ns	19.73**	-21.63ns	-5.67ns
Norti X IR25571-31-1	-1.87**	22.23**	-19.69**	-2.02ns	-6.92ns	3.51**	3.62*	-3.82ns	-35.97**	-9.86ns
Gz 5121-5-2 X Dular	-1.10**	12.51**	-44.02**	8.92**	20.07**	-5.81**	-6.84**	11.96*	-23.01ns	7.56ns
Gz 5121-5-2 X Nekken 1	-1.06**	19.67**	4.90ns	2.92ns	38.92**	1.38ns	0.88ns	39.90**	4.54ns	35.26**
Gz 5121-5-2 X Giza 178	0.80*	1.26ns	-48.08**	0.90ns	47.00**	-12.84**	-14.48**	26.09**	-8.44ns	-12.82*
Gz 5121-5-2 X Gz 5934-7-2-3	4.11**	14.75**	-16.57**	22.09**	32.26**	-51.04**	-50.44**	-34.62**	-5.07ns	5.54ns
Gz 5121-5-2 X IR25571-31-1	1.24**	9.97**	-54.82**	3.33ns	-15.39**	-90.61**	-95.72**	-96.37**	-70.90**	-79.87**
LSD 5%	0.72	4.05	2.23	1.11	14.70	2.20	2.86	13.10	0.77	3.31
LSD 1%	0.96	5.41	2.98	1.48	19.64	2.95	3.83	17.51	1.03	4.42

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Table 10. Estimates of standard heterosis percentage for the studied traits of rice crosses.

Traits / crosses	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield plant^{-1}
O2428-P-7-7 XDular	-6.87**	74.16**	-18.40**	13.90**	10.84*	-21.34**	-23.36**	-15.09**	23.56ns	-45.65**
O2428-P-7-7 X Nekken 1	-6.70**	-22.92**	-54.36**	-10.31**	-52.00**	0.24ns	-0.66ns	-52.29**	-37.98**	-16.81**
O2428-P-7-7 X Giza 178	1.23**	24.21**	-12.72*	21.90**	77.00**	-53.31**	-56.63**	-23.14**	-30.10*	-28.55**
O2428-P-7-7 X Gz 5934-7-2-3	-6.21**	-7.93**	-24.20**	-16.36**	-18.35**	1.00ns	2.25ns	-16.58**	-0.58ns	-42.80**
O2428-P-7-7 X IR25571-31-1	-2.82**	-7.19**	-37.07**	34.21**	50.69**	-19.22**	-19.71**	21.06**	141.54**	-17.12**
Norti X Dular	-10.69**	42.01**	-46.06**	20.68**	-46.88**	-10.39**	-10.35**	-52.36**	-16.54ns	6.64ns
Norti X Nekken 1	-9.99**	9.13**	-34.99**	6.35*	-7.21ns	1.25ns	1.04ns	-6.19ns	47.69**	24.09**
Norti X Giza 178	-1.93**	-3.04ns	-54.08**	14.47**	-5.67ns	1.94ns	2.12ns	-3.63ns	-6.54ns	17.97**
Norti X Gz 5934-7-2-3	-9.93**	6.19*	-29.60**	7.93**	-29.62**	-1.45ns	-2.12ns	-31.09**	-28.94*	-13.61*
Norti X IR25571-31-1	-7.58**	25.26**	-28.08**	0.04ns	-29.41**	2.08ns	2.65ns	-27.50**	-34.52**	-14.06*
Gz 5121-5-2 X Dular	-9.63**	42.10**	-41.91**	10.04**	-16.87**	-5.02**	-5.44**	-21.31**	-35.67**	-2.81ns
Gz 5121-5-2 X Nekken 1	-7.33**	3.32ns	-0.28ns	-10.03**	-12.15**	1.56ns	1.61ns	-10.69*	-21.35ns	4.49ns
Gz 5121-5-2 X Giza 178	0.37ns	0.62ns	-44.67**	-0.88ns	24.63**	-12.26**	-13.33**	8.09ns	-18.08ns	-16.82**
Gz 5121-5-2 X Gz 5934-7-2-3	-1.27**	10.83**	-8.58ns	4.65ns	-20.60**	-50.95**	-50.07**	-60.33**	-24.42ns	-5.18ns
Gz 5121-5-2 X IR25571-31-1	-1.93**	8.36**	-54.36**	0.31ns	-34.98**	-90.53**	-95.62**	-97.15**	-73.46**	-81.16**
LSD 5%	0.83	4.67	2.57	1.28	16.97	2.85	3.31	15.13	0.89	3.82
LSD 1%	1.11	6.24	3.44	1.71	22.67	3.80	4.42	20.21	1.18	5.10

**** : Highly significant at 1% ; * : Significant at 5% and ns : Non significant.**

Concerning panicle length, data revealed that highly significant positive heterosis over BP were recorded in six crosses. However, for MP heterosis nine crosses showed highly significant positive heterosis values. While, for SH heterosis, eight crosses showed significant or highly significant positive values. The highest values of heterosis were recorded in the cross O2428-P-7-7 X IR 25571-31-1 (37.41, 38.35 and 34.21) for BP, MP and SH, respectively. Similar results were found by Yuga *et al.,* (2018); Singh *et al.,* (2019); Kumar *et al.,* (2020 b) and Yadav *et al.,* (2020). For spikelets panicle^{-1}, better parent, mid-parent and standard heterosis are shown in Tables 8, 9 and 10. Data revealed that seven crosses showed highly significant or significant positive estimates of BP heterosis. Moreover, ten crosses showed highly significant positive MP heterosis estimates. While, for SH heterosis four crosses showed highly significant or significant positive values. The highest estimates (50.74, 62.82 and 77.00 %) were recorded in the cross O2428-P-7-7 X Giza 178 for BP; MP and SH heterosis, respectively. Number of spikelets per panicle is one of the main important yield components that improve grain yield. The previous data agreed with the data reported by Kostylev *et al.,* (2017); Prasad *et al.,* (2019); Singh *et al.,* (2019) and Yadav *et al.,* (2020).

Obviously the data on pollen fertility percentage revealed that (BP) heterosis and standard heterosis were insignificant for all the studied crosses. While, with regarding to mid parent heterosis (MP) five crosses showed highly significant positive values. The highly significant positive values of mid-parent heterosis were observed in the crosses, O2428-P-7-7 X Gz 5934-7-2-3, O2428-P-7-7 X Nekken 1, Norti X Giza 178, Norti X IR 25571-31-1 and Norti X Nekken 1 their estimated values were (7.94, 7.13, 3.61, 3.51 and 3.41 %, respectively). These crosses have at least one wide compatible parents. Similar results were reported by Awad-Allah (2011 and 2019). Spikelets fertility % is one of the most important traits which directly influences grain yield in rice cultivars and hybrids. The results revealed that the values of better parent (BP) and standard heterosis (SH) were not significant in positive direction in all crosses. On the other hand, highly significant or significant positive estimates of mid parent heterosis were observed in five crosses, their estimates were ranged from 3.51 to 9.31 % in crosses Norti X Nekken 1 and O2428-P-7-7 X Gz 5934-7-2-3, respectively.

Similar results were reported by Awad-Allah *et al.,* (2015); Kostylev *et al.,* (2017) and Yadav *et al.,* (2020).

Filled grains panicle^{-1} is one of the most important trait which directly influences grain yield productivity in hybrid rice and rice varieties. The results showed highly significant or significant positive estimates in BP; MP and SH for three, seven and one cross, respectively. The cross Norti X Nekken 1 showed the highest estimates (43.88 and 54.50 %) of BP and MP heterosis, while the cross O2428-P-7-7 X IR 25571-31-1 (21.06) showed highly significant positive value of SH heterosis. Similar results were reported by Yuga *et al.,* (2018); Prasad *et al.,* (2019); Singh *et al.,* (2019) and Kumar *et al.,* (2020 b).

Heterosis over better parent, mid-parent and standard heterosis for panicle weight are shown in Tables 8, 9 and 10. The results revealed that, three, four and two crosses showed either highly significant or significant positive values of BP, MP and SH heterosis, respectively. The highest values were shown in the cross O2428-P-7-7 X IR 25571-31-1 (133.46, 174.09 and 141.54 % for BP, MP and SH heterosis, respectively). These results were in harmony with the results observed by Awad-Allah *et al.,* (2015 and 2019).

Heterosis over better parent (BP), mid-parent (MP) and standard heterosis (SH) for grain yield are cited in Tables 8, 9 and 10. Data indicated that four, four and two crosses showed either highly significant or significant positive values in BP, mid-parent and standard heterosis, respectively. The highly significant positive values of heterosis over better parent (BP) were observed in the crosses Norti X Nekken 1 (31.56) and Norti X Giza 178 (17.97). Moreover, highly significant positive values of mid-parent heterosis were observed in the crosses Norti X Nekken 1 (57.08), Gz 5121-5-2 X Nekken 1 (35.26), Norti X Giza 178 (21.41) and Norti X Dular (15.79). Highly significant positive estimates of standard heterosis were observed in the crosses Norti X Nekken 1 (24.09) and Norti X Giza 178 (17.97). These results agreed with the data reported by Yuga *et al.,* (2018); Prasad *et al.,* (2019); Singh *et al.,* (2019); Alok and Sujeet (2020); Kumar *et al.,* (2020 b) and Yadav *et al.,* (2020).

The relationship between *per se* performance and genetic components :

In general, the cross combinations having high SCA effects in desirable direction did not always have high mean performance for same traits. Thus, the SCA effect of the cross combinations may not be directly associated to their *per se* performance. This may be attributed to the fact that *per se* performance is a realized value whereas SCA effect is an estimate of F_1 performance over parental one. Therefore, both *per se* performance along with SCA effects should be considered for evaluating the superiority of a cross although the *per se* performance may be more important if development of F_1 hybrids is the final objective. The most promising ten cross combinations having significant and desirable SCA effects for different traits are listed along with their mean performance and GCA effects for their parents in Table 11.

Table 11. Most promising crosses based on mean performance, better parent, mid-parent and standard heterosis for grain yield plant^{-1}.

S.No.	Crosses	*Per se* performance	GCA ‡	SCA	Heterosis over BP	Heterosis over MP	St. Heterosis over CK
1	Norti X Nekken 1	43.58	H X H	0.2 ns	31.56**	57.08**	24.09**
2	Norti X Giza 178	41.43	H X A	2.6**	17.97**	21.41**	17.97**
3	Norti X Dular	37.45	H X L	0.3 ns	13.06*	15.79**	6.64ns
4	Gz 5121-5-2 X Nekken 1	36.70	L X H	1.9**	15.04*	35.26**	4.49ns
5	Gz 5121 X Dular	34.13	L X L	5.6**	7.00ns	7.56ns	-2.81ns
6	Gz 5121 X Gz 5934-7-2-3	33.30	L X L	7.1**	4.39ns	5.54ns	-5.18ns
7	Norti X Gz 5934-7-2-3	30.34	H X L	-4.5**	-8.41ns	-5.67ns	-13.61*
8	Norti X IR25571-31-1	30.18	H X L	1.3 ns	-10.81ns	-9.86ns	-14.06*
9	O2428-P-7-7 X IR25571-31-1	29.11	L X L	12.3**	-13.99*	-12.51*	-17.12**
10	O2428-P-7-7 X Giza 178	25.09	L X A	-1.6*	-28.55**	-26.00**	-28.55**

‡ **H: high, A: average and L: low**

The crosses scheduled in Table 11 may be considered for more utilization owing to their higher genetic worth. The critical examination reveal that the crosses exhibiting high order significant and desirable SCA effects for different traits involved parents having all types of cross combinations of GCA effects such as high × high (H × H), high × average (H × A), high × low (H × L), average × average (A × A), average × low (A × L) and low × low (L × L) general combiner parents. The former observation clearly indicated that there was no particular relationship between positive and significant SCA effects of crosses with GCA effects of their parents for the traits under study. Singh and Kumar (2004) also found that crosses having high order positive SCA effects for grain yield resulted from parents having high × high as well as high × low GCA effects for grain yield. Varpe *et al.,* (2011) and Adilakshmi and Upendra (2014) observed that all crosses identified as superior specific combinations for grain yield plant^{-1} on the basis of SCA effects emerged either through average × low or average × average general combiner parents for grain yield plant^{-1}. according by Singh *et al.,* (2019). The crosses which have better *per se* performance and involved parents high × high as well as high × average, high × low and low × high GCA effects showed highest values of heterosis over better parent and heterosis over mid-parent for grain yield. Similar results were obtained by Prasad *et al.,* (2019) and Kumar *et al.,* (2020 a).

Nature and degree of dominance (potence ratio):

It is clear from Table 12 that the potence ratio values for grain yield and its contributing traits were more than unity in most of the crosses for most traits, indicating the presence of over-dominance for these traits. Moreover, the potence ratio values of some crosses were less than unity indicating the presence of partial dominance in controlling of these traits. Similar results were obtained by AbdAllah (2000) and Awad-Allah *et al.,* (2015).

Table 12. Potence ratio for the studied traits of rice crosses.

Crosses \ Traits	Days to 50 % heading	Plant height	Panicles plant^{-1}	Panicle length	Spikelets panicle^{-1}	Pollen fertility (%)	Spikelets fertility (%)	Filled grains panicle^{-1}	Panicle weight	Grain yield Plant^{-1}
O2428-P-7-7 X Dular	0.1	1.5	-0.8	2.8	0.7	-2.5	-2.9	-0.1	5.6	-23.0
O2428-P-7-7 X Nekken 1	-0.2	0.5	-20.5	0.3	-1.3	1.2	1.1	-1.4	-16.2	0.3
O2428-P-7-7 X Giza 178	2.3	3.2	-0.3	13.0	7.8	-8.0	-8.7	-13.4	-1.2	-7.3
O2428-P-7-7 X Gz 5934-7-2-3	-0.4	0.7	-1.3	-0.2	-0.1	1.4	1.7	0.2	6.1	-15.9
O2428-P-7-7 X IR 25571-31-1	-0.2	0.5	-5.0	55.9	3.0	-2.2	-2.2	2.9	10.0	-7.3
Norti X Dular	0.1	0.5	-18.0	30.7	-22.3	-5.0	-4.5	-10.0	-1.7	6.5
Norti X Nekken 1	-0.3	1.2	-2.8	0.99	5.7	3.0	3.0	7.4	4.2	2.9
Norti X Giza 178	0.4	-1.9	-10.0	3.4	0.7	2.2	2.2	0.8	-13.4	7.3
Norti X Gz 5934-7-2-3	-1.3	0.9	-3.5	1.1	1.3	0.6	0.2	1.5	-1.9	-1.9
Norti X IR 25571-31-1	-4.5	5.5	-28.3	-0.5	-0.6	1.9	1.4	-0.3	-30.6	-9.3
Gz 5121-5-2 X Dular	-0.1	0.6	-4.9	2.0	42.5	-12.1	-5.8	7.3	-4.2	14.4
Gz 5121-5-2 X Nekken 1	-0.2	1.4	0.3	0.3	3.9	1.2	0.5	3.3	0.9	2.0
Gz 5121-5-2 X Giza 178	1.9	2.0	-7.8	0.5	2.6	-19.6	-10.9	1.6	-0.7	-2.7
Gz 5121-5-2 X Gz 5934-7-2-3	0.9	6.6	-5.2	1.8	2.0	-44.7	-26.1	-2.0	-6.0	5.0
Gz 5121-5-2 X IR 25571-31-1	0.5	49.0	-4.6	5.4	-1.6	-211.1	-193.2	-10.7	-5.3	-27.1
P. D.	11	6	3	6	4	1	2	4	2	1
O. D.	4	9	12	9	11	14	13	11	13	14

P. D. : partial dominance and O. D. : over dominance

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تقدير قوة الهجين والقدرة على التآلف باستخدام تحليل السلالة X الكشاف لتطوير سلالات ذات توافق عام وسلالات معيدة للخصوبة في الأرز

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أجريت هذه الدراسة فى محطة البحوث الزراعية بسخا – كفر الشيخ موسمى 2017 و 2018 وذلك لدراسة وتقدير القدرة على الائتلاف والفعل الجيني وقوة الهجين ودرجات السيادة لمحصول الحبوب وبعض الصفات المرتبطة به في الأرز في بعض سلالات التوافق العام بهدف تحسينها والاستفادة منها في برنامج تربية الأرز الهجين. وشملت التجربة 15 هجين ناتجة من ثلاثة تراكيب وراثية كأمهات وهي O2428-P-7-7 ، Norti ، Gz 5121-5-2 و خمس سلالات ملقحة (آباء ذكرية) وهى Dular ، Nekken 1 ، Giza 178، Gz 5934-7-2-3، IR 25571-31-1 وذلك بنظام تزاوج السلالة X الكشاف. وأظهرت نتائج تحليل التباين وجود اختلافات عالية المعنوية ومعنوية داخل مجموعات الآباء (السلالات وسلالات الكشافات) والهجن وتفاعل السلالات مع الآباء لكل الصفات. و كانت النسبة بين القدرة العامة على الائتلاف إلى القدرة الخاصة على الائتلاف أكبر من الواحد لصفة محصول الحبوب ومكوناته مما يدل على رجحان (أو تفوق) تأثير الفعل الجينى المضيف في توارث هذه الصفات فيما عدا صفة وزن الدالية. وخلصت الدراسة الى استكشاف صفة التوافق العام فى الصنفين Dular, Nekken 1. بالإضافة إلى ذلك أظهرت الدراسة أفضل السلالات و الكشافات ذات القدرة العامة على الائتلاف. علاوة على ذلك أظهرت النتائج أن الهجينين Norti X Giza 178; Norti X Nekken 1 كانا أفضل التراكيب الهجينة في قيم المتوسطات وقيم قوة الهجين وكانت التراكيب الهجينية Gz 5121 X Dular; Gz 5121 X Gz 5934-7-2-3; O2428-P-7-7 X IR25571-31-1 الأعلى فى القدرة الخاصة على الائتلاف لصفات محصول الحبوب ومكوناته. وأظهرت معظم التراكيب الهجينية قيم عالية المعنوية ومعنوية فى الثلاثة أنواع من قوة الهجين لكل الصفات تحت الدراسة.