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Estimation of combining ability and heterosis for grain yield, yield components, and some grain quality traits in rice under water deficit conditions

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ABSTRACT

Combining ability analysis was carried out in rice through an 8 x 8 diallel set analysis excluding reciprocals involving 8 diverse parents for grain yield, yield components, and some grain quality traits at the Experimental Farm of the Rice Research Department, Sakha, Kafr El-Sheikh, Egypt, during the 2020 and 2021 summer seasons. The ratio of variances due to general and specific combining abilities (ó2 GCA / ó2 SCA) was less than unity for all the studied traits under water deficit and normal conditions, indicating that the non-additive type of gene action, including dominance, was of great importance in the inheritance of these traits, except that the hulling percentage under normal conditions was higher than unity. Among the parents, IET 1444 and Nerica 9 were found to be significantly superior general combiners for grain yield/plant. The parents IET 1444 and Sakha Super 300 were good general combiners for number of panicles/plants, number of filled grains/panicle and fertility (%). While IET 1444 and Nerica 9 were good general combiners for panicle length and grain yield/plant, Moreover, IR 65600-77 and Nerica 9 were the best general combiners for 100-grain weight. On the other hand, Sakha 109 and IET 1444 were good combiners for earliness. Sakha 108 and Sakha 109 were good combiners for plant height. The rice variety IR 69116 was a good general combiner for grain length and grain shape. while IR 65600-77 was a good combiner for amylose content (%). In addition, a total of 11 crosses exhibited positive significant and highly significant SCA for grain yield/plant. The promising combinations for grain yield and most of the studied traits were IR 69116 × Sakha Super 300, Sakha 109 × IR 65600-77, Sakha 108 × IR 65600-77, IR 69116 × Nerica 9, Sakha 108 × Sakha 104, Sakha 109 × Sakha Super 300, and Sakha 109 × Nerica 9. It is observed that the majority of the crosses with high SCA for grain yield resulted from low/low, high/high, or high/low combining parents. Highly significant negative estimates of SCA for the number of days to 50% heading (earliness) were recorded for Sakha 104 × IR 69116, Sakha 108 × Sakha Super 300, and IR 65600–77 Nerica 9 cross combinations. Moreover, eleven cross combinations were found to be the best specific combinations for plant height. The cross-combination Sakha 108 × Sakha Super 300 was the best specific combination for number of panicles/plant and number of filled grains/panicle. The cross combination, IR 69116 × Nerica 9 was the best specific combination for grain length. Fourteen cross combinations exhibited highly significant and positive SCA effects for fertility (%), while ten crosses were the best cross combinations for 100-grain weight. The results also revealed that a greater magnitude of heterosis, measured as a deviation from mid-parent and better parent, was observed in Sakha 109 × IR 65600-77, IR 65600-77 × Nerica 9, Sakha 108 × IR 65600-77, IR 69116 × Sakha Super 300, and Sakha 109 × Sakha Super 300 rice crosses for grain yield/plant under water deficit condition.

Keywords: Rice, water stress, grain yield, combining ability, and heterosis.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple of more than 3.5 billion people, to obtain 20% of their daily calorie intake. Water is essential for the growth and development of rice plants (Yang, 2012; Ghoneim, 2020). More than 75% of the world's rice is produced under continuous flooding practices (Van *et al*., 2001). The rice production area in Egypt changes yearly based on the available irrigation water and occupies about 20% with a total production of 5.5 million tons. About one-third of the total cultivated area is exposed to water shortage annually in Egypt (Abdallah *et al*., 2016). Hence, irrigation water is the most limiting factor for expanding rice cultivation areas in Egypt.

Drought, like many other environmental stresses, has adverse effects on crop yield. Low water availability is one of the major causes of crop yield reductions in the majority of regions around the world. As water resources for agronomic uses become more limited, the development of drought-tolerant lines becomes increasingly important.

Breeding yield-rich and qualitatively better rice varieties is not possible without prior knowledge of their genetic properties. The breeders, therefore, try with the help of suitable quantitative genetic methods, to combine the desired properties of different varieties. The diallel-cross method was introduced by (Griffing, 1956). Many commercial cultivars, despite their high agronomic performances, perform poorly in the F1 generation due to genetic hindrances in diverse cross combinations. Consequently, crossing in a diallel analysis is the only specific and effective technique for the measurement, identification, and selection of superior genotypes **(**Mohammad**,** 2003). Estimating combining ability through diallel analysis is the first step in most plant breeding programs aimed at improving yield and other related parameters (Griffing, 1956; Pickett, 1993).

The mating designs provide reliable information about the general combining ability (GCA) and specific combining ability (SCA) of the parents and crosses. The differences in GCA are mainly due to additive gene action, while the differences in SCA are attributed to non-additive gene effects (Fasahat *et al*., 2016). Estimation of GCA helps the breeder identify parents with superior combining ability, which may be hybridized to exploit heterosis, and also develop breeding populations from which agronomically superior lines can be selected (Fasahat *et al*., 2016). Therefore, knowledge of combining ability provides information on the nature and magnitude of gene effects that regulate grain yield and yield characteristics, thereby enabling the breeders to design an effective breeding method for genetic enhancement of grain yield and yield components (Dar *et al*., 2014). Selection would be successful during the early generations when additive gene action is predominant. Otherwise, the selection would occur at later generations when these effects are fixed in the homozygous lines. Diallel analysis for grain yield and its related traits could furnish interesting information about the type of gene action, which would be helpful in particular situations to understand the type of gene action involved in the expression of a trait. It can identify genotypes possessing the most dominant and recessive alleles responsible for the expression of a certain trait. This enables breeders to carry out efficient selection in the segregating generations, leading to the improvement of certain traits in breeding populations under water stress conditions. The present investigation aimed to estimate the general and specific combining ability effects and nature of gene action. In addition, heterosis as a deviation from the mid and better parent for grain yield and its related traits.

MATERIALS AND METHODS

The present investigation was carried out at the Experimental Farm of the Rice Research Department, Sakha, Kafr El-Sheikh, Egypt, during the 2020 and 2021 rice growing seasons. Eight local and exotic rice parents, namely, Sakha 108, Sakha 104, IR 69116, Sakha 109, IR 65600-77, Nerica 9, Sakha Super 300, and IET 1444, were provided from the pure genetic stock of the Rice Research Section, Field Crops Research Institute, Agricultural Research Center, were planted in the 2020 season in three successive planting dates at ten-day intervals to overcome the differences in flowering time between these parental genotypes. Thirty-day-old seedlings from each parent were individually transplanted in the permanent field in ten rows. Each row was 5 meters long and contained 25 hills. At flowering time, a crossing program with all possible combinations between the 8 parental lines excluding reciprocals was carried out following the technique proposed by (Jodon, 1938; Butany, 1961).

In the 2021 season, 30 day-old seedlings of 36 rice genotypes (8 parents and 28 F1s) were evaluated in two separate irrigation experiments: the first experiment was irrigated every four days (normal condition), and the second experiment was given a flash irrigation every twelve days after fifteen days from the transplanting of seedlings with a total amount of water of 3.5 m3 during the growth season (Gaballah *et al*., 2020) (a deficit condition). The two experiments were designed in a randomized complete block design with three replications. Each replicate is comprised of 10 rows of each parent and 5 rows of each F1 hybrid. The row was 5 m long, and a 20 x 20 cm space was maintained between rows and seedlings. Recommended cultural practices were followed for the two conditions. At maturity, days to 50% heading, plant height (cm), number of panicles/plant, panicle length (cm), number of filled grains/panicle, 100-grain weight (g), fertility percentage, grain yield/plant (g), grain length (mm), grain shape, hulling (%), milling (%), head rice (%), and amylose content (%) were recorded for randomly chosen guarded 25 plants from the middle row/replicate using the standard evaluation system for rice, (IRRI, 1996). In the laboratory, the grain qualities of 36 rice genotypes were investigated. Cleaned paddy samples from each genotype were dried to 13 % moisture content and milled. The husking machines used were Satake Rubber Roll Huskers. The resulting brown rice was milled for 75 seconds in a Satake grain-testing mill TM05. The milled rice out-turn was expressed as a percent of milled rice. The milled grain length was measured with the help of Dial Caliper on fifteen randomly selected full, healthy rice grains. A sample of rice was floured after storage for four months. The amylase content (A.C) determined the cooking behavior and eating quality of cooked rice. Based on amylose content, milled rice was classified as waxy (1-2% amylose), very low (>2-9% amylose), low (>9-20% amylose), intermediate (>20-25% amylose), and high (25-33% amylose), (Juliano, 1971).

The combining ability analysis was done following (Griffing, 1956), Model 1, Method 2, as follows:

General combining ability sum squares (GCA) and specific combining ability sum squares (GCA)

SS due to GCA = 1/p+2 (∑i (xi. + xii) 2 - 4/p x2

SS due to SCA = ∑i < ∑j. Xij2 - (∑i (xi. + xii) 2 + 2/(p+1)(p+2)x2

General (gi) and specific (Sij) combining ability effects were computed as follows:

gi ={1/p+2 (xi. + Xii) - 2/p X..} and

Sij = Xij - 1/p+2(xi. +xii +xj. +xij) + 2/(p+1)(p+2) x..

Where parents and one set of F_1s were included to estimate the effects of general (GCA) and specific (SCA) combining ability and variance components under the water deficit condition. The GCA/SCA ratio was estimated to study the performance of the effects and to measure the relative importance of additive gene or non-additive gene effects (Singh and Chaudhary, 1979) as follows:

δ2gca/ δ2sca = (((Mg- Me`) / (p+2)) / (Ms-Me`))

Heterosis was estimated according to (Folconer and Mackay, 1996) as follows:

heterosis over the mid-parent = [(F1 – MP) / MP × 100],

S.E. (F1 – MP) = $(3Me / 2r)^{1/2}$,

heterosis over the better-parent = [(F1 – BP) / BP × 100], and

S.E. (F1 – BP) = $(2Me / r)^{1/2}$.

Where Me = error mean squares for parents and F1s from an individual environment; MP = mean mid-parent value = (P1 + P2) / 2; P1 = mean performance of parent one; P2 = mean performance of parent two; BP = mean of better-parent value; r = a number of replications. Furthermore, appropriate L. S. D. values were calculated to test the significance of heterotic effects according to the formula suggested by (Wynne *et al.*, 1970).

RESULTS

Results of the analysis of variance

The mean square estimates of yield and its components and some grain quality traits, i.e., number of days to 50 % heading, plant height, panicle length, number of panicles/plant, number of filled grains/panicle, 100-grain weight (g), fertility percentage, grain yield/ plant (g), grain length (mm), grain shape (mm), hulling (%), milling (%), head rice (%), and amylose content (%) under water deficit and normal conditions are presented in (Table 1). Highly significant mean square estimates were recorded for genotypes, parents, crosses, and the interaction among them for all yield and its components and some grain quality traits under both water deficit and normal conditions, except for 100-grain weight (g) and grain shape traits under both conditions and amylose content (%) under normal condition for parents vs. crosses, which were insignificant. Estimates of both general (GCA) and specific combining ability (SCA) variances were found to be highly significant for all yield and its components and some grain quality traits under both water deficit and normal conditions, except for 100-grain weight (g), grain length (mm), and grain shape traits under both conditions and hulling% for SCA, which were insignificant, indicating the importance of additive and non-additive genetic variances in determining the inheritance of these studied traits. The GCA/SCA ratio of the mean square was found to be less than unity for all traits under both conditions, except hulling% under normal conditions, suggesting greater importance of non-additive genetic variance in the inheritance of these traits. Therefore, selection procedures in late or advanced generations will be very important to improve these traits.

The mean performance of parents and their F_1 generation

Table (2) shows that the tallest plants were observed in IET 1444 followed by Sakha Super 300 under water deficit, Nerica 9, Sakha Super 300, and IET 1444 under normal conditions, while the shortest ones were exhibited in IR 65600-77, Sakha 108 and Sakha 109 rice varieties under water deficit, and Sakha 109 followed by Sakha 108 under normal conditions. Sakha 109 under both conditions, followed by IET 1444 and Sakha 108 under water deficit, Nerica 9 and IET 1444 under normal conditions were early rice genotypes, otherwise, Sakha Super 300 under both conditions, Nerica 9 and IR 65600-77 under water deficit, and Sakha 108 and IR 69116 under normal conditions were late rice cultivars compared with other rice cultivars. In addition, IET 1444 has the longest panicle (22.70 cm) under water deficit and superior grain yield (40.0 g/plant) under water deficit and (52.00 g/plant) under normal conditions, while Nerica 9 under normal conditions has the longest panicle (27.70 cm). A high number of panicles/plant was detected for IET 1444 (17.0) under water deficit and Sakha 104 (24.0) under normal conditions. The highest mean values for number of filled grains/panicle were recorded by IET 1444 (155.3) under water deficit conditions and by IR 69116 (231.0) under normal conditions. On the contrary, the lowest mean values were recorded by Sakha 109 under water deficit and Sakha 108 under normal conditions, with mean values of (53.0, 129.0) under water deficit and normal conditions, respectively. Nerica.9 was found to have the highest mean values (3.00 g/100 grains) under water deficit, while, IR 65600-77 had the highest mean values (3.60 g/100 grains) under normal conditions. Moreover, high fertility % (97.0 and 98.22) were observed for IET 1444 under water deficit and normal conditions, respectively. For grain shape (L/W ratio), the most desirable short to bold grain genotypes were IR 69116 and Sakha Super 300 for grain shape (L/W ratio) under both conditions, indicating that these genotypes could be used as good grain shape donors under both conditions. The highest estimated values of hulling %, milling % and head rice % were detected for Sakha 104, Sakha 109, and Sakha Super 300 rice genotypes under both conditions. In addition, IR 69116 recorded the lowest mean values of hulling %, milling %, and head rice % under both conditions. For amylose content %, the parental variety Sakha 108 had the lowest amylose content %; its estimated values were 18.25 and 19.19 % under water deficit and normal conditions, respectively. While the variety IET 1444 had the highest amylose content, its estimated values were 25.23 and 24.20 % under water deficit and normal conditions, respectively.

In addition, the F1 mean values of plant height were ranged between 70.00 cm for Sakha 104 × Sakha 109 and 112.0 cm for Sakha 104 × IET 1444 and IR 65600-77 × Nerica 9 under water deficit, while the F1 mean values of plant height under normal conditions were ranged between (102.0 cm, 130.0 cm) for Sakha 108 × Sakha 104 and Sakha 108 × IET 1444, respectively. The crosses Sakha 109 × Nerica 9 and Sakha 109 × IR 65600-77 exhibited the lowest mean values of the number of days to 50 % heading under water deficit and normal conditions. About five rice crosses under water deficit were found to have longer panicles than the longest panicle parent, their estimated values of panicle length were ranged between 17.0 cm for Sakha 104 × IR 65600-77 and 26.0 cm for Nerica 9 × IET 1444 under water deficit, while panicle lengths were ranged between 20.0 cm for IR 69116 × Sakha Super 300 and 27.30 cm for IR 65600-77 × Nerica 9 under normal conditions. The cross IR 65600-77 × Sakha Super 300 gave the highest mean values of 19.00 and 28.00 panicle/plant, under water deficit and normal conditions, respectively. The crosses, IR 65600-77 × Sakha Super 300, IR 65600-77 × Nerica 9 and Nerica 9 × IET 1444 under water deficit, Sakha Super 300 × IET 1444, IR 69116 × IET 1444 and IR 65600-77 × Sakha Super 300 under normal conditions, exhibited the highest mean values for the number of filled grains/panicle with the mean values of (171.0, 165.0, and 161.0) and (284.0, 245.0, and 242.0), respectively. While the lowest mean values were recorded by the crosses Sakha 108 × IR 69116 and Sakha 108 × IR 65600-77 under water deficit and normal conditions, respectively. The cross, IR 65600-77 × Nerica 9 exhibited the highest mean values for 100-grain weight (3.20 g, and 3.80 g) under water deficit and normal conditions, respectively. While, the crosses, Sakha 104 × IR 69116 and IR 69116 × IET 1444 under water deficit conditions, and Nerica 9 × IET 1444 under normal conditions, gave the lowest mean values. The cross, Nerica 9 × Sakha Super 300 (94.10) under water deficit and Sakha Super 300 × IET 1444 (98.25) under normal conditions exhibited the highest mean values for fertility %. Regarding grain yield/plant, the highest mean values were recorded by crosses: Nerica 9 × IET 1444 under water deficit conditions and IR 65600-77 × Sakha Super 300 under normal conditions, while the lowest mean values were recorded by crosses: Sakha 108 × IR 69116 under both conditions. The crosses IR 69116 × IET 1444 and IR 65600-77 × Sakha Super 300 exhibited the lowest mean values of grain length (4.60 and 5.15 mm) under water deficit and normal conditions, respectively.

Table (1): Mean square estimates of ordinary and combining ability analyses for grain yield, yield components, and some grain quality traits under water deficit and normal conditions.

Source	d.f	days to 50% heading (day)		Plant height (cm)		No. of panicles/plant		Panicle length (cm)		No. of filled grains/ panicle		100-grain weight (g)		Fertility %	
		N	D	N	D	N	D	N	D	N	D	N	D	N	D
Replication	2	4.70	28.70	2.40	5.68	2.86	2.26	1.78	0.25	15.34	10.48	0.02	0.01	8.25	6.59
Genotype	35	160.19**	205.35**	240.08**	344.28**	54.90**	31.06**	10.10**	21.56**	3947.06**	3518.39**	0.39	0.39	25.02**	489.42**
Parent	7	210.80**	312.64**	361.71**	233.95**	48.86**	16.23**	11.32**	29.29**	4018.66**	4419.14**	0.54	0.33	67.55**	625.12**
Crosses	27	149.91**	158.23**	194.48**	364.67**	46.63**	34.73**	9.98**	18.90**	4006.94**	3372.17**	0.37	0.42	12.84**	472.00**
Parents vs. Crosses	1	83.35**	726.39**	619.72**	565.89**	320.38**	35.91**	4.90*	39.28**	1829.08**	1161.13**	0.15	0.33	56.16**	9.75**
Error	70	1.08	0.25	12.24	9.02	1.11	1.04	0.98	0.25	8.74	7.91	0.01	0.01	4.03	4.03
GCA	7	158.94**	143.71**	142.76**	222.33**	15.85**	24.03**	8.31**	15.74**	2044.63**	2681.63**	0.34	0.27	21.85**	275.96**
SCA	28	27.01**	49.64**	64.34**	87.87**	18.91**	6.93**	2.13**	5.05**	1133.45**	795.59**	0.08	0.10	4.96**	134.93**
Error	70	0.36	0.08	4.08	3.01	0.37	0.35	0.33	0.08	2.91	2.64	0.00	0.00	1.34	1.34
GCA/SCA		0.59	0.29	0.23	0.25	0.08	0.36	0.44	0.31	0.18	0.33	0.44	0.28	0.57	0.21

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

Table (1): Continued

Source	d.f	Grain yield/ plant (g)		Grain length		Grain shape		Hulling %		Milling %		Head rice %		Amylose content %	
		N	D	N	D	N	D	N	D	N	D	N	D	N	D
Replication	2	16.10	15.79	0.01	0.003	0.001	0.01	2.26	1.23	1.78	1.45	3.12	2.51	6.65	4.12
Genotype	35	207.91**	110.71**	0.90	0.77	0.29	0.22	7.34**	7.86**	10.59**	10.16**	14.34**	14.21**	20.40**	22.56**
Parent	7	218.95**	135.27**	2.20*	1.80	0.60	0.49	13.23**	13.23**	8.57**	8.57**	26.95**	26.95**	9.95**	18.08**
Crosses	27	145.77**	88.26**	0.56	0.46	0.22	0.15	5.11**	5.57**	11.49**	10.95**	10.85**	10.75**	23.85**	23.89**
Parents vs. Crosses	1	1808.68**	544.79**	1.11	1.90	0.21	0.22	26.19**	32.30**	0.38	0.00	20.25**	18.45**	0.53	18.00**
Error	70	9.19	8.89	0.01	0.01	0.004	0.005	1.12	0.75	0.98	0.78	1.13	0.83	1.29	1.00
GCA	7	157.33**	70.40**	0.75	0.62	0.21	0.18	7.80**	7.81**	9.66**	9.14**	15.32**	14.46**	15.71**	18.69**
SCA	28	47.30**	28.53**	0.19	0.16	0.07	0.05	1.11	1.32	2.00**	1.95*	2.14**	2.30**	4.57**	4.73**
Error	70	3.06	2.96	0.006	0.002	0.003	0.003	0.37	0.25	0.33	0.26	0.38	0.28	0.43	0.33
GCA/SCA		0.34	0.26	0.40	0.37	0.29	0.36	1.01	0.70	0.55	0.52	0.84	0.70	0.36	0.41

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

While the cross IR 65600-77 × Nerica 9 (6.71 and 7.15 mm) exhibited the highest mean values of grain length under water deficit and normal conditions, respectively, the crosses Sakha 108 × Nerica 9 and Sakha 104 × IR 69116 exhibited the lowest mean values of grain shape (1.58 and 1.57 L/W ratio) under water deficit and normal conditions, respectively, compared with the other crosses under the same conditions. While the crosses, IR 65600-77 × Nerica 9, Sakha 108 × Sakha Super 300 (2.47 and 2.60 L/W ratios), exhibited the highest mean values of grain shape under water deficit and normal conditions, respectively. The cross Sakha 104 × Sakha Super 300 exhibited the highest mean value of hulling % (80.3 and 85.0 %), under water deficit and normal conditions, respectively. While the crosses Sakha 108 × Sakha 109, Sakha 104 × IR 69116, Sakha 109 × Sakha Super 300, and IR 65600-77 × Sakha Super 300 exhibited the highest mean values of milling % (68.0 and 73.0%) under water deficit and normal conditions, respectively. Moreover, the crosses Sakha 108 × Sakha 104, Sakha 108 × Sakha 109, Sakha 108 × Sakha Super 300, Sakha 104 × IR 69116, Sakha 104 × IR 65600-77, Sakha 104 × Sakha Super 300, and IR 65600-77 × Sakha Super 300 under water deficit and normal conditions exhibited the highest mean values of head rice % (58.0 and 63.0 %), respectively the lowest mean values were recorded by the cross IR 69116 × Sakha Super 300 (15.22, 13.85) under water deficit and normal conditions, respectively. While cross namely, IR 69116 × IET 1444 exhibited the highest mean values (27.10 and 26.14%) of amylose content under water deficit and normal conditions, respectively.

Table 2: Mean performance of the eight parents and their F_1 generation of 8 x 8 diallel crosses for grain yield, yield components, and some grain quality traits under water deficit and normal conditions

Genotype	days to 50% heading, day		Plant height, cm		No. of panicles/ plant		Panicle length, cm		No. of filled grains/ panicle		100-grain weight, g		Fertility %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108	113.0	115.0	102.0	73.0	17.0	14.0	23.3	17.4	129.0	78.6	2.8	2.2	88.20	73.04
Sakha 104	108.0	108.0	109.0	75.0	24.0	13.0	22.2	16.8	145.0	63.6	2.7	2.2	93.33	64.00
IR 69116	110.0	112.0	109.0	87.0	12.0	10.0	23.4	19.2	231.0	145.0	2.8	2.5	98.13	93.01
Sakha 109	96.0	88.0	101.0	74.0	20.0	10.0	22.5	18.0	137.0	53.0	2.7	2.2	89.26	59.21
IR 65600-77	107.0	116.0	117.0	72.0	14.0	13.0	25.2	20.7	154.0	89.0	3.6	2.5	94.25	90.31
Nerica.9	98.0	116.0	130.0	87.0	15.0	13.0	27.7	22.5	188.0	119.0	3.1	3.0	95.22	85.17
Sakha Super 300	121.0	118.0	127.0	88.0	14.0	11.0	22.0	13.4	184.0	130.0	2.7	2.2	97.07	94.23
IET 1444	100.0	101.0	121.0	95.0	20.0	17.0	25.0	22.7	209.0	155.3	2.1	1.9	98.22	97.00
Sakha 108 ×Sakha 104	110.0	118.0	102.0	73.0	23.0	10.0	26.4	21.3	157.0	94.6	2.8	2.2	96.18	75.29
Sakha 108 × IR 69116	110.0	120.0	117.0	78.0	19.0	9.0	23.6	17.7	159.0	54.6	2.5	1.9	94.26	56.02
Sakha 108 × Sakha 109	111.0	121.0	123.0	77.0	21.0	9.0	25.5	17.5	228.0	67.6	2.9	2.1	93.12	63.07
Sakha 108 × IR 65600-77	109.0	119.0	120.0	80.0	18.0	14.0	26.0	18.0	137.0	83.0	3.0	2.5	93.01	78.29
Sakha 108 × Nerica 9	111.6	121.0	112.0	89.0	23.0	13.0	24.3	20.7	152.0	92.0	2.9	2.3	91.29	69.14
Sakha 108 × Sakha Super 300	102.0	112.0	122.0	80.0	25.0	19.0	26.3	22.7	207.0	160.6	2.1	1.6	95.09	93.19
Sakha 108 × IET 1444	114.6	115.0	130.0	100.0	26.0	17.0	25.8	19.3	185.0	110.6	2.5	2.2	97.10	89.11
Sakha 104 × IR 69116	114.0	127.0	127.6	75.6	23.0	9.0	23.3	19.5	155.0	98.6	2.7	1.4	95.16	83.20
Sakha 104 × Sakha 109	99.0	108.0	126.0	70.0	21.0	9.0	23.0	17.1	228.0	74.6	2.7	2.1	95.23	72.32
Sakha 104 × IR 65600-77	108.0	109.0	117.0	74.0	16.0	13.0	24.4	17.0	153.0	77.0	2.7	2.2	96.07	74.27
Sakha 104 × Nerica 9	106.6	112.0	118.0	80.0	16.0	13.0	22.9	19.0	157.0	110.6	2.7	2.2	96.06	83.01
Sakha 104 × Sakha Super 300	109.0	111.0	127.0	81.0	23.0	14.0	22.6	18.5	158.6	108.6	2.7	2.3	96.26	81.31
Sakha 104 × IET 1444	113.0	113.0	127.0	112.0	21.0	18.0	25.0	18.2	172.0	105.6	2.4	2.3	95.22	86.16
IR 69116 × Sakha 109	98.0	106.0	106.3	84.0	15.3	11.6	25.3	19.9	161.0	111.0	2.8	2.6	94.10	87.31
IR 69116 × IR 65600-77	114.0	124.0	122.0	85.0	25.6	9.0	25.2	20.8	219.0	160.0	3.2	2.3	93.03	90.10
IR 69116 × Nerica 9	109.0	112.0	123.0	90.0	15.6	12.0	25.7	21.2	182.0	118.0	2.2	2.0	97.32	92.03
IR 69116 × Sakha Super 300	119.0	124.0	129.3	96.0	21.6	16.0	20.0	18.8	181.0	103.0	2.7	2.5	94.22	86.12
IR 69116 × IET 1444	116.0	127.0	108.3	76.0	12.6	10.6	22.7	18.2	245.0	56.0	2.8	1.4	97.13	47.20
Sakha 109 × IR 65600-77	96.0	104.0	108.6	85.0	25.0	18.0	24.0	19.3	149.0	100.0	2.7	2.4	93.02	83.25
Sakha 109 × Nerica 9	94.6	101.6	104.0	80.0	24.0	17.0	24.7	22.4	143.0	97.0	2.9	2.6	96.25	55.07
Sakha 109 × Sakha Super 300	115.0	121.0	125.0	102.0	25.0	15.0	23.0	19.4	145.0	100.0	2.8	2.4	95.25	83.13
Sakha 109 × IET 1444	100.0	111.0	125.0	95.0	16.0	14.0	24.3	23.0	179.0	147.0	2.8	2.03	97.30	91.10
IR 65600-77× Nerica 9	99.0	109.0	129.0	112.0	17.0	16.0	27.3	24.4	198.0	165.0	3.8	3.2	86.24	74.16
IR 65600-77× Sakha Super 300	114.0	122.0	123.0	92.0	28.0	19.0	25.1	24.5	242.0	171.0	2.8	2.5	94.32	91.33
IR 65600-77× IET 1444	110.0	125.0	122.0	93.0	24.0	17.0	27.2	24.5	170.0	141.0	3.1	2.2	88.31	83.07
Nerica 9 × Sakha Super 300	118.0	122.0	126.0	86.0	21.0	16.0	21.1	18.2	177.0	150.0	2.7	2.4	95.31	94.10
Nerica 9 × IET 1444	105.0	109.0	120.0	93.0	23.0	19.0	27.0	26.0	173.0	161.0	2.0	1.8	96.26	92.10
Sakha Super 300 × IET 1444	119.0	110.0	127.0	94.0	23.0	15.0	22.2	21.2	284.0	120.0	2.3	2.1	98.25	89.03
L.S.D :0.05	1.69	0.81	5.71	4.90	1.72	1.67	1.61	0.82	4.83	4.59	0.16	0.16	3.28	3.28
:0.01	2.25	1.08	7.60	6.52	2.29	2.22	2.15	1.09	6.42	6.11	0.21	0.22	4.36	4.36

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

Table 2: Continued

Genotype	Grain yield /plant, g		Grain length		Grain shape		Hulling, %		Milling, %		Head rice, %		Amylose content, %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108	45.0	23.0	5.47	5.12	1.80	1.82	82.0	77.0	70.0	65.0	60.0	55.0	19.19	18.25
Sakha 104	49.0	24.1	5.36	5.23	1.79	1.84	83.0	78.0	73.0	68.0	62.0	57.0	19.28	18.32
IR 69116	30.0	26.0	5.03	5.20	1.52	1.65	78.0	73.0	69.0	64.0	55.0	50.0	20.06	20.02
Sakha 109	48.0	26.1	5.68	5.37	1.94	1.97	83.0	78.0	73.0	68.0	63.0	58.0	20.18	21.13
IR 65600-77	50.0	17.5	6.96	6.15	2.01	2.26	79.0	74.0	70.0	65.0	60.0	55.0	20.14	20.09
Nerica.9	31.0	24.0	7.41	7.23	2.82	2.79	80.0	75.0	70.0	65.0	56.0	51.0	23.07	23.19
Sakha Super 300	46.0	20.0	5.25	4.79	1.60	1.68	83.0	78.0	73.0	68.0	63.0	58.0	20.32	19.03
IET 1444	52.0	40.0	5.70	5.67	2.50	2.45	79.0	74.0	70.0	65.0	60.0	55.0	24.20	25.23
Sakha 108 ×Sakha 104	54.0	31.0	5.27	5.28	1.58	1.72	83.0	78.3	73.0	68.0	63.0	58.0	19.23	20.17
Sakha 108 × IR 69116	44.0	18.0	5.39	4.77	1.76	1.63	82.0	77.3	71.0	66.3	60.3	55.0	19.87	19.10
Sakha 108 × Sakha 109	56.0	24.0	5.66	4.74	1.67	1.69	83.0	78.3	73.0	68.0	63.0	58.0	22.13	21.12
Sakha 108 × IR 65600-77	59.1	32.0	5.60	5.40	1.84	2.00	82.0	77.3	70.0	65.30	60.0	55.0	20.85	22.02
Sakha 108 × Nerica 9	48.6	33.1	5.41	5.08	1.65	1.58	81.0	76.0	66.0	61.0	56.3	51.0	22.16	22.27
Sakha 108 × Sakha Super 300	51.0	32.0	5.71	5.11	2.60	2.04	84.0	79.0	71.0	66.0	63.0	58.0	25.32	24.30
Sakha 108 × IET 1444	65.0	30.0	5.50	5.30	1.95	2.00	80.0	75.0	70.0	65.3	62.0	57.0	24.01	25.10
Sakha 104 × IR 69116	55.0	18.0	5.20	4.89	1.57	2.18	81.3	76.0	73.0	68.0	63.0	58.0	20.11	21.27
Sakha 104 × Sakha 109	62.2	25.0	5.60	5.03	1.75	1.84	83.0	78.0	71.0	66.0	61.3	56.0	20.28	21.08
Sakha 104 × IR 65600-77	59.0	28.0	5.51	5.47	1.82	2.01	79.3	74.3	72.0	67.0	63.0	58.0	18.17	18.12
Sakha 104 × Nerica 9	55.1	30.0	5.46	5.26	1.80	1.90	83.0	78.3	71.0	66.0	62.3	57.0	21.32	21.04
Sakha 104 × Sakha Super 300	59.1	31.0	5.54	5.27	1.79	1.82	85.0	80.3	73.0	68.0	63.0	58.0	20.88	23.22
Sakha 104 × IET 1444	64.0	35.0	5.54	5.37	1.92	2.05	82.0	77.3	70.0	65.3	59.3	54.0	20.96	22.21
IR 69116 × Sakha 109	47.0	27.0	5.69	5.55	1.93	2.02	83.0	78.0	69.0	64.0	58.0	53.0	18.17	20.07
IR 69116 × IR 65600-77	52.0	22.0	6.00	5.26	1.77	1.70	81.3	76.3	70.0	65.0	59.0	54.0	18.12	19.13
IR 69116 × Nerica 9	40.3	34.0	5.22	5.00	1.83	1.90	80.0	75.3	65.0	60.3	58.0	53.3	18.78	20.14
IR 69116 × Sakha Super 300	48.0	36.0	5.76	5.60	2.00	1.95	83.0	78.0	72.0	67.3	61.0	56.0	13.85	15.22
IR 69116 × IET 1444	46.0	27.0	5.40	4.60	1.70	1.69	82.0	77.0	69.0	64.3	58.0	53.3	26.14	27.10
Sakha 109 × IR 65600-77	56.6	35.0	5.61	5.37	1.96	1.90	81.0	76.0	71.0	66.0	61.0	56.0	17.20	19.26
Sakha 109 × Nerica 9	52.3	36.0	5.70	5.31	1.97	1.97	81.6	77.0	72.0	67.0	62.0	57.0	24.07	25.16
Sakha 109 × Sakha Super 300	60.0	35.0	5.46	5.17	1.80	1.86	84.0	79.0	73.0	68.0	63.0	57.6	21.40	22.07
Sakha 109 × IET 1444	50.0	31.4	5.84	5.29	2.03	2.27	82.0	76.6	71.0	66.3	60.0	55.0	23.41	23.03
IR 65600-77× Nerica 9	52.0	33.0	7.15	6.71	2.45	2.47	81.0	76.0	70.0	65.3	60.0	55.0	21.13	20.04
IR 65600-77× Sakha Super 300	67.0	27.0	5.15	5.61	1.66	1.89	82.0	77.0	73.0	68.0	63.0	58.0	19.09	18.22
IR 65600-77× IET 1444	40.0	35.0	6.73	5.79	2.31	2.10	81.0	76.6	72.0	67.0	60.0	54.6	18.26	19.12
Nerica 9 × Sakha Super 300	50.0	33.0	5.25	5.07	1.67	1.69	83.0	78.6	71.0	66.3	61.0	56.0	24.19	24.20
Nerica 9 × IET 1444	52.2	39.0	5.6.0	5.17	2.46	2.34	81.0	76.0	70.0	65.0	60.0	55.3	23.11	25.04
Sakha Super 300 × IET 1444	58.0	37.0	5.25	5.17	1.65	2.33	83.0	78.0	72.0	67.3	62.0	57.0	25.02	27.08
L.S.D :0.05	4.95	4.87	0.13	0.07	0.09	0.09	1.73	1.41	1.61	1.44	1.74	1.49	1.85	1.63
:0.01	6.59	6.48	0.18	0.10	0.12	0.12	2.29	1.88	2.15	1.92	2.31	1.98	2.46	2.17

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

Estimates of general (GCA) and specific (SCA) combining ability

Estimates of GCA effects showed that the parents, IET 1444 and Nerica 9, under water deficit, and Sakha 104 and IR 65600-77 under normal conditions, were found to be good general combiners for grain yield/plant (Table 3). The high GCA effect of Sakha Super 300 for number of filled grains/panicle was associated with its high GCA effect for fertility%, hulling%, milling%, and head rice% under water deficit and normal conditions, while IET 1444 for grain yield was associated with its high GCA effect for number of panicles/plant under water deficit conditions. The good combining ability of cultivar Nerica 9 under water deficit conditions and IR 65600-77 under normal conditions was due to its heaviest grains, while the high estimates of general combining ability of cultivar Nerica 9 for grain yield/plant were due to its highest estimated panicle length and 100 grain weight under water deficit conditions. The results also revealed that among the studied parents, Sakha 104, Sakha 108, and Sakha 109 under water deficit and Sakha 109, Sakha 108, and IR 69116 under normal conditions were the best general combiners for short stature. Moreover, Sakha 109, Sakha 104, and IET 1444 under water deficits and Sakha 109, Nerica 9, and IR 65600-77 under normal conditions were the best general combiners for earliness. In addition, the parents, Sakha Super 300 and IET 1444, were good combiners for fertility % under water deficit and normal conditions. Highly significant and positive estimates of the general combining ability of panicle length were recorded for Nerica 9, IR 65600-77, IET 1444, and Sakha 108, indicating that these four parents were the greatest combiners for improving this trait under water deficit and normal conditions. Nerica 9 and IR 65600-77 were found to be good combiners for 100-grain weight under water deficit and normal conditions. Highly significant and negative estimates of general combining ability of grain length and grain shape were recorded for Sakha 108, IR 69116, and Sakha Super 300 under water deficit conditions, and for Sakha 104, IR 69116, and Sakha Super 300 under normal conditions, indicating that these parents were the greatest combiners for improving this trait. Sakha Super 300, Sakha 104, and Sakha 109 were found to be good combiners for hulling %, milling % and head rice under water deficit and normal conditions. Moreover, IR 65600-77, IR 69116, and Sakha 104 were the best general combiners for amylose content % under water deficit and normal conditions. Generally, Sakha Super 300 was the best one, since it possessed significant and desirable GCA effects for most of the studied traits under water deficit and normal conditions, followed by Sakha 109 and IET 1444. Therefore, it may be concluded that crosses involving these parents would result in the identification of superior segregants with favorable genes for grain yield and its related traits in this investigation. High GCA effects are related to additive and additive × additive components for genetic variation; the parents with higher positive significant GCA effects are considered good combiners, while those with negative GCA effects are poor general combiners except in the case of earliness, plant height, grain length, grain shape, and amylose content %. According to the results, most of the studied genotypes were good combiners for water deficit conditions; consequently, a successful breeding program could be conducted for drought tolerance depending on the pyramiding of gene specific to the studied traits, and selection must be done in a later generation for most studied traits and under controlled conditions in order to minimize environmental effects.

The estimates of specific combining ability for twenty eight crosses for fourteen grain yield, its related traits, and some grain quality traits are presented in (Table 4). Highly significant negative estimates of SCA for the number of days to 50% heading (earliness) were recorded for thirteen and ten cross-combinations under water deficit and normal conditions, respectively. Moreover, eleven and eight cross combinations, under water deficit and normal conditions, respectively, exhibited

Table 3: Estimates of general combining ability (GCA) effects for grain yield, yield components, and some grain quality traits under water deficit and normal conditions.

Source	days to 50% heading, day		Plant height, cm		No. of panicles / plant		Panicle length, cm		No. of filled grains/ panicle		100-grain weight, g		Fertility %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108	1.99**	2.91**	-4.08**	-4.79**	0.70**	-0.43*	0.57**	0.77**	-13.54**	-17.24**	-0.04**	-0.09**	-1.46**	-5.47**
Sakha 104	0.13	-1.29**	-0.82	-5.52**	0.90**	-1.13**	-0.68**	-1.56**	-14.78**	-19.58**	-0.06**	-0.10**	0.58	-4.13**
IR 69116	2.56**	3.71**	-1.92**	-1.22*	-2.50**	-2.60**	-0.62**	-0.52**	14.56**	-0.18	-0.02	-0.10**	1.05**	0.32
Sakha 109	-6.88**	-7.82**	-5.08**	-2.99**	0.53**	-0.97**	-0.40*	-0.52**	-11.14**	-18.98**	0.03*	0.05**	-0.82*	-7.12**
IR 65600-77	-1.04**	1.71**	0.48	-0.59	-0.03	0.87**	1.08**	1.01**	-4.24**	8.19**	0.38**	0.22**	-2.65**	1.41**
Nerica 9	-3.44**	-0.82**	2.12**	3.31**	-1.23**	0.87**	0.96**	1.71**	-6.04**	13.86**	0.07**	0.24**	0.62	2.13**
Sakha Super 300	6.36**	3.11**	6.25**	3.61**	1.27**	1.27**	-1.45**	-0.97**	14.43**	18.03**	-0.12**	0.01	1.18**	8.18**
IET 1444	0.33	-1.49**	3.05**	8.21**	0.37*	2.13**	0.54**	1.60**	20.76**	15.89**	-0.26**	-0.23**	1.50**	4.69**
SE (gi) :0.05	0.35	0.17	1.19	1.03	0.36	0.35	0.34	0.17	1.01	0.96	0.03	0.03	0.69	0.69
:0.01	0.47	0.23	1.59	1.36	0.48	0.46	0.45	0.23	1.34	1.28	0.04	0.05	0.91	0.91
SE (gi-gj) :0.05	0.54	0.26	1.80	1.56	0.54	0.52	0.52	0.26	1.52	1.46	0.06	0.06	1.04	1.04
:0.01	0.71	0.34	2.40	2.07	0.72	0.69	0.66	0.34	2.02	1.94	0.08	0.08	1.38	1.38

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

Table 3: Continued

Source	Grain yield/plant, g		Grain length		Grain shape		Hulling %		Milling %		Head rice %		Amylose content %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108	0.41	-1.77**	-0.15**	-0.22**	-0.06**	-0.14**	0.28	0.33*	-0.40*	-0.39*	0.15	0.12	0.35	-0.22
Sakha 104	4.27**	-1.76**	-0.22**	-0.11**	-0.14**	-0.05**	0.65**	0.66**	1.10**	1.04**	1.28**	1.22**	-0.89**	-0.90**
IR 69116	-7.14**	-2.99**	-0.23**	-0.20**	-0.16**	-0.14**	-0.75**	-0.81**	-1.10**	-1.06**	-1.88**	-1.82**	-1.32**	-1.07**
Sakha 109	1.64**	0.18	-0.01	-0.09**	-0.02*	-0.03**	0.75**	0.69**	0.80**	0.74**	0.82**	0.78**	-0.14	0.13
IR 65600-77	2.22**	-1.69**	0.46**	0.38**	0.06**	0.08**	-1.05**	-1.04**	0.00	-0.03	-0.02	-0.02	-1.53**	-1.67**
Nerica 9	-5.10**	2.24**	0.36**	0.40**	0.23**	0.17**	-0.55**	-0.48**	-1.30**	-1.29**	-1.45**	-1.42**	1.25**	1.15**
Sakha Super 300	2.15**	0.71	-0.24**	-0.15**	-0.09**	-0.08**	1.38**	1.39**	1.30**	1.31**	1.58**	1.58**	0.20	-0.04
IET 1444	1.55**	5.07**	0.02	-0.01	0.18**	0.19**	-0.72**	-0.74**	-0.40*	-0.33*	-0.48**	-0.45**	2.09**	2.63**
SE (gi) :0.05	1.04	1.02	0.03	0.02	0.02	0.02	0.36	0.29	0.34	0.30	0.36	0.31	0.39	0.34
:0.01	1.38	1.35	0.04	0.03	0.03	0.03	0.48	0.39	0.45	0.40	0.48	0.41	0.52	0.45
SE (gi-gj) :0.05	1.56	1.54	0.04	0.02	0.02	0.02	0.54	0.44	0.52	0.46	0.54	0.48	0.58	0.52
:0.01	2.07	2.04	0.05	0.03	0.03	0.03	0.72	0.58	0.69	0.61	0.71	0.63	0.77	0.69

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

negative and highly significant SCA effects for plant height. Significant and highly significant positive estimates of specific combining ability effects were recorded in eleven crosses under water deficit and fourteen crosses under normal conditions for the number of panicles/plants, The highest positive values were estimated for the crosses: Sakha 108 × Sakha Super 300 and Sakha 109 × IR 65600-77 under water deficit, and IR 69116 × IR 65600-77 and IR 65600-77 × Sakha Super 300 under normal conditions. Significant and highly significant and positive estimates of specific combining ability effects were detected for twelve crosses under water deficit and nine crosses under normal conditions for panicle length. The highest positive values were estimated for the crosses, IR 65600-77 × Sakha Super 300 and Sakha 108 × Sakha Super 300 under water deficit, Sakha 108 × Sakha Super 300 and Sakha 108 × Sakha 104 under normal conditions, The crosses that gave the highest SCA values for panicle length could be used in breeding programs to increase this trait under water deficit conditions. Significant and highly significant positive estimates of specific combining ability effects were detected for twelve crosses under water deficit and nine crosses under normal conditions for the number of filled grains/panicle. The highest positive value was estimated for the cross Sakha 108 × Sakha Super 300 under water stress and Sakha 104 × Sakha 109 under normal conditions. Significant and highly significant positive estimates of specific combining ability effects were detected for eleven crosses under water deficit and normal conditions for 100-grain weight, The highest positive value was estimated for the cross IR 65600-77 × Nerica 9 under water stress and normal conditions, the highest SCA values for 100-grain weight could be used in a breeding program to increase this trait. Highly significant positive estimates of specific combining ability were recorded in fourteen crosses under water deficit and seven crosses under normal conditions for fertility %, the highest positive values were estimated for the crosses IR 69116 × Sakha 109 and Sakha 109 × IET 1444 under water deficit and Sakha 104 × IR 65600-77 and Sakha 108 × IR 65600-77 under normal conditions. Significant and highly significant positive estimates of specific combining ability effects were recorded in eleven and twelve crosses for grain yield/plant under water deficit and normal conditions, respectively. The highest positive values were estimated for the crosses, IR 69116 × Sakha Super 300 and Sakha 109 × IR 65600-77 under water deficit conditions, Sakha 108 × IET 1444, and IR 65600-77 × Sakha Super 300 under normal conditions. It is observed that the majority of the crosses with high SCA effects for grain yield resulted from low/low, high/high, or high/low combining parents. But very few crosses, including low/low general combiners, gave high SCA effects. Fourteen and eleven hybrid combinations, under water stress and normal conditions, respectively, recorded significant and highly significant negative estimates of SCA effects for grain length; the best cross combinations were Nerica 9 × IET 1444 and IR 65600-77 × Sakha Super 300 under water deficit and normal conditions, respectively. Significant and highly significant negative estimates of specific combining ability effects were detected for fifteen, thirteen, crosses for grain shape under water deficit and normal conditions, respectively; the best cross combination was Sakha 108 × Nerica 9 under water stress and normal conditions. The estimates of SCA effects showed that highly significant positive (SCA) values were recorded in ten, eight crosses under water deficit, and normal conditions for hulling %, respectively. The best cross was IR 69116 × IET 1444 under water deficit and normal conditions. The estimates of SCA showed that significant and highly significant positive (SCA) values were recorded in seven crosses, under water deficit and normal conditions; their estimates were maximized in the case of the cross, Sakha 104 × IR 69116, which appeared to be the best specific cross combinations for milling% under both conditions. Significant and highly significant positive estimates of specific combining ability effects were recorded in ten and eight crosses for head rice % under water deficit and normal conditions, respectively. Under both conditions, the crosses Sakha 109 × Nerica 9 and Sakha 104 × IR 69116 had the highest estimated positive values. Significant and highly significant negative estimates of SCA in eight crosses were found for amylose content % under water deficit and normal conditions, the highest negative values were estimated for the cross, IR 69116 × Sakha Super 300 under both conditions. The results revealed that there is a preponderance of non-additive gene action for grain yield, and most of its related traits in the hybrids resulted in a high amount of vigor in F1. Selection can be postponed to a later generation.

Table 4: Estimates of specific combining ability (SCA) effects for grain yield and some grain quality traits under water deficit and normal conditions.

Crosses	days to 50% heading, day		Plant height, cm		No. of panicles/plant		Panicle length, cm		No. of filled grains/ panicle		100-grain weight, g		Fertility %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	-0.39	2.28**	-12.08**	-2.34	1.18*	-2.14**	2.20**	3.65**	5.49**	21.14**	0.15**	0.16**	2.50**	4.34**
Sakha 108 × IR 69116	-2.82**	-0.72**	4.02*	-1.64	0.58	-1.67**	-0.66	-0.98**	-21.84**	-38.26**	-0.19**	-0.14**	0.11	-19.37**
Sakha 108 × Sakha 109	7.61**	11.81**	13.19**	-0.87	-0.46	-3.30**	1.02*	-1.19**	72.86**	-6.46**	0.16**	-0.10*	0.84	-4.89**
Sakha 108 × IR 65600-77	-0.22	0.28	4.62**	-0.27	-2.89**	-0.14	0.04	-2.22**	-25.04**	-18.29**	-0.09*	0.14**	2.56**	1.81
Sakha 108 × Nerica 9	4.85**	4.81**	-5.01**	4.83**	3.31**	-1.14*	-1.54**	-0.22	-8.24**	-14.96**	0.12**	-0.08	-2.43**	-8.06**
Sakha 108 × Sakha Super 300	-14.62**	-8.12**	0.85	-4.47**	2.81**	4.46**	2.87**	4.46**	26.29**	49.54**	-0.49**	-0.55**	0.81	9.93**
Sakha 108 × IET 1444	4.08**	-0.52*	12.05**	10.93**	4.71**	1.60**	0.38	-1.51**	-2.04	1.67	0.05	0.28**	2.50**	9.35**
Sakha 104 × IR 69116	-2.95**	-8.52**	-7.25**	-3.91**	5.38**	3.03**	-0.81	-1.10**	-34.61**	-26.93**	0.03	0.17**	-2.86**	-12.73**
Sakha 104 × Sakha 109	-2.52**	3.01**	12.92**	-7.14**	-0.66	-2.60**	-0.23	-0.80**	74.09**	2.87*	-0.02	-0.09*	0.91	3.03**
Sakha 104 × IR 65600-77	0.65	-5.52**	-1.65	-5.54**	-5.09**	-0.44	-0.31	-2.43**	-7.81**	-21.96**	-0.37**	-0.15**	3.58**	-3.55**
Sakha 104 × Nerica 9	1.71**	0.01	-2.28	-3.44*	-3.89**	-0.44	-1.69**	-1.13**	-2.01	6.04**	-0.06	-0.17**	0.31	4.47**
Sakha 104 × Sakha Super 300	-5.75**	-4.92**	2.59	-2.74*	0.61	0.16	0.42	1.05**	-20.81**	-0.13	0.13**	0.16**	-0.06	-3.28**
Sakha 104 × IET 1444	4.28**	1.68**	5.79**	23.66**	-0.49	3.30**	0.83	-1.82**	-13.81**	-0.99	-0.03	0.39**	-1.42	5.06**
IR 69116 × Sakha 109	-5.95**	-3.99**	-5.65**	2.56	-2.92**	1.53**	2.01**	0.96**	-22.24**	19.81**	0.04	0.41**	-0.68	13.58**
IR 69116 × IR 65600-77	4.21**	4.48**	4.45**	1.16	7.98**	-2.97**	0.43	0.33	28.86**	41.64**	0.09*	-0.05	0.08	7.83**
IR 69116 × Nerica 9	1.61**	-4.99**	3.82*	2.26	-0.82	0.03	1.05*	0.03	-6.34**	-6.03**	-0.60	-0.37**	1.10	9.05**
IR 69116 × Sakha Super 300	1.81**	3.08**	6.02**	7.96**	2.68**	3.63**	-2.24**	0.31	-27.81**	-25.19**	0.09*	0.36**	-2.57**	-2.91**
IR 69116 × IET 1444	4.85**	10.68**	-11.78**	-16.64**	-5.42**	-2.57**	-1.53**	-2.86**	29.86**	-70.06**	0.33**	-0.51**	0.02	-38.35**
Sakha 109 × IR 65600-77	-4.35**	-3.99**	-5.71**	2.93*	4.28**	4.40**	-0.99*	-1.17**	-15.44**	0.44	-0.46**	-0.11*	1.94*	8.42**
Sakha 109 × Nerica 9	-3.29**	-3.79**	-12.01**	-5.97**	4.48**	3.40**	-0.17	1.23**	-19.64**	-8.23**	0.05	0.07	1.90*	-20.47**
Sakha 109 × Sakha Super 300	7.25**	11.61**	4.85**	15.73**	2.98**	1.00*	0.54	0.91**	-38.11**	-9.39**	0.14**	0.10*	0.34	1.53
Sakha 109 × IET 1444	-1.72**	6.21**	8.05**	4.13**	-5.12**	-0.87	-0.15	1.94**	-10.44**	39.74**	0.28**	-0.03	2.07*	12.99**
IR 65600-77× Nerica 9	-4.79**	-5.99**	7.42**	23.63**	-1.96**	0.56	0.95*	1.70**	28.46**	32.61**	0.60**	0.51**	1.73	6.24**
IR 65600-77× Sakha Super 300	0.41	3.08**	-2.71	3.33*	6.54**	3.16**	1.16*	4.48**	51.99**	34.44**	-0.21**	0.04	1.23	1.20
IR 65600-77× IET 1444	2.45**	10.68**	-0.51	-0.27	3.44**	0.30	1.27**	1.91**	-26.34**	6.57**	0.23**	-0.03	-5.10**	-3.57**
Nerica 9 × Sakha Super 300	6.81**	5.61**	-1.35	-6.57**	0.74	0.16	-2.72**	-2.52**	-11.21**	7.77**	0.00	-0.08	-1.05	3.25**
Nerica 9 × IET 1444	-0.15	-2.79**	-4.15*	-4.17**	3.64**	2.30**	1.19*	2.71**	-21.54**	20.91**	-0.56**	-0.45*	-0.41	4.74**
Sakha Super 300 × IET 1444	4.05**	-5.72**	-1.28	-3.47*	1.14*	-2.10**	-1.20**	0.59*	68.99**	-24.26**	-0.07	0.08	1.01	-4.38**
SE (sij) :0.05	0.94	0.45	3.19	2.74	0.96	0.93	0.90	0.46	2.69	2.56	0.09	0.09	1.83	1.83
:0.01	1.26	0.60	4.24	3.64	1.28	1.24	1.20	0.61	3.58	3.41	0.12	0.12	2.43	2.43
SE (sij-skj) :0.05	1.52	0.72	5.1	4.38	1.54	1.48	1.44	0.74	4.32	4.10	0.14	0.14	2.94	2.94
:0.01	2.02	0.95	6.78	5.82	2.04	1.96	1.91	0.98	5.74	5.45	0.18	0.18	3.91	3.91

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

Table 4: Continued

Crosses	Grain yield/plant, g		Grain length		Grain shape		Hulling %		Milling %		Head rice %		Amylose content %	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	-2.22	5.20**	-0.03	0.26**	-0.14**	-0.05*	0.27	0.45	1.41**	1.36**	0.88	1.02*	-1.17*	-0.12
Sakha 108 × IR 69116	-0.80	-6.57**	0.11**	-0.15**	0.07**	-0.06*	0.67	0.92*	1.61**	1.79**	1.38**	1.05*	-0.09	-1.03*
Sakha 108 × Sakha 109	2.41	-3.74**	0.16**	-0.30**	-0.17**	-0.11**	0.17	0.42	1.71**	1.66**	1.35**	1.45**	0.98	-0.20
Sakha 108 × IR 65600-77	5.00**	6.13**	-0.38**	-0.11**	-0.07**	0.09**	0.97*	1.15**	-0.49	-0.24	-0.82	-0.75	1.09*	2.49**
Sakha 108 × Nerica 9	1.82	3.37**	-0.46**	-0.44**	-0.43**	-0.42**	-0.53	-0.75	-3.19**	-3.31**	-3.05**	-3.35**	-0.37	-0.08
Sakha 108 × Sakha Super 300	-3.01*	3.73**	0.43**	0.13**	0.83**	0.29**	0.54	0.39	-0.79	-0.91*	0.58	0.65	3.84**	3.14**
Sakha 108 × IET 1444	11.50**	-2.55	-0.04	0.18**	-0.09**	-0.02	-1.36**	-1.48**	-0.09	0.06	1.65**	1.69**	0.64	1.26**
Sakha 104 × IR 69116	0.34	-0.41	0.14**	0.19**	0.18**	0.06*	1.30**	1.25**	2.11**	2.03**	1.91**	1.95**	0.56	-1.12*
Sakha 104 × Sakha 109	4.77**	-2.75*	0.16**	-0.11**	0.00	-0.05*	-0.20	-0.25	-1.79**	-1.77**	-1.45**	-1.65**	0.38	0.44
Sakha 104 × IR 65600-77	0.98	2.13	-0.41**	-0.15**	-0.02	0.01	-2.06**	-2.18**	0.01	-0.01	1.05*	1.15**	-0.34	-0.72
Sakha 104 × Nerica 9	4.41**	0.19	-0.35**	-0.37**	-0.20**	-0.19**	1.10*	1.25**	0.31	0.26	1.81**	1.55**	0.03	-0.63
Sakha 104 × Sakha Super 300	1.22	2.73*	0.33**	0.19**	0.11**	-0.02	1.17*	1.39**	-0.29	-0.34	-0.55	-0.45	0.64	2.74**
Sakha 104 × IET 1444	6.64**	2.37	0.07*	0.14**	-0.03	-0.06*	0.27	0.52	-1.59**	-1.37**	-2.15**	-2.41**	-1.17*	-0.94*
IR 69116 × Sakha 109	0.97	0.48	0.26**	0.50**	0.20**	0.21**	1.20*	1.22**	-1.59**	-1.67**	-1.62**	-1.61**	-1.30*	-0.41
IR 69116 × IR 65600-77	5.40**	-2.64	0.09*	-0.26**	-0.05*	-0.22**	1.34**	1.29**	0.21	0.09	0.21	0.19	0.04	0.45
IR 69116 × Nerica 9	1.05	5.43**	-0.58**	-0.54**	-0.15**	-0.10**	-0.50	-0.28	-3.49**	-3.31**	0.65	0.92*	-2.08**	-1.36**
IR 69116 × Sakha Super 300	1.47	8.96**	0.56**	0.61**	0.33**	0.20**	0.57	0.52	0.91*	1.09**	0.61	0.59	-5.96**	-5.09**
IR 69116 × IET 1444	0.06	-4.40**	-0.06	-0.54**	-0.23**	-0.34**	1.67**	1.65**	-0.39	-0.27	-0.32	-0.05	4.44**	4.12**
Sakha 109 × IR 65600-77	1.27	7.18**	-0.52**	-0.27**	0.01	-0.13**	-0.50	-0.55	-0.69	-0.71	-0.49	-0.41	-2.07**	-0.61
Sakha 109 × Nerica 9	4.26**	4.25**	-0.32**	-0.34**	-0.15**	-0.14**	-0.33	-0.11	1.61**	1.56**	1.95**	1.99**	2.02**	2.46**
Sakha 109 × Sakha Super 300	4.68**	4.78**	0.04	0.07**	-0.01	-0.01	0.07	0.02	0.01	-0.04	-0.09	-0.35	0.41	0.56
Sakha 109 × IET 1444	-4.73**	-3.16*	0.15**	0.05**	-0.04	0.13**	0.17	-0.18	-0.29	-0.07	-1.02*	-0.98*	0.52	-1.15**
IR 65600-77× Nerica 9	3.42*	3.13*	0.66**	0.59**	0.25**	0.25**	0.80	0.62	0.41	0.66	0.78	0.79	0.48	-0.86
IR 65600-77× Sakha Super 300	11.10**	-1.34	-0.74**	0.04*	-0.23**	-0.09**	-0.13	-0.25	0.81	0.73	0.75	0.79	-0.51	-1.49**
IR 65600-77× IET 1444	-15.25**	2.30	0.57**	0.07**	0.16**	-0.15**	0.97*	1.55**	1.51**	1.36**	-0.19	-0.51	-3.23**	-3.27**
Nerica 9 × Sakha Super 300	1.42	0.73	-0.54**	-0.52**	-0.38**	-0.37**	0.37	0.85*	0.11	0.33	0.18	0.19	1.80**	1.68**
Nerica 9 × IET 1444	4.27**	2.37	-0.45**	-0.56**	0.14**	0.01	0.47	0.32	0.81	0.63	1.25**	1.55**	-1.17*	-0.16
Sakha Super 300 × IET 1444	2.77*	1.90	-0.20**	-0.01	-0.36**	0.25**	0.54	0.45	0.21	0.36	0.21	0.22	1.80**	3.07**
SE (sij) :0.05	2.76	2.72	0.07	0.04	0.05	0.05	0.96	0.79	0.90	0.80	0.97	0.83	1.03	0.91
:0.01	3.67	3.61	0.10	0.05	0.07	0.07	1.28	1.05	1.20	1.07	1.29	1.11	1.37	1.21
SE (sij-skj) :0.05	4.42	4.36	0.12	0.06	0.08	0.08	1.54	1.26	1.44	1.28	1.56	1.34	1.66	1.46
:0.01	5.87	5.79	0.15	0.07	0.10	0.10	2.04	1.67	1.91	1.70	2.07	1.78	2.20	1.94

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

Estimates of mid and better parent heterosis

The estimates of mid-parent and better parent heterosis for different traits are presented in (Table 5). For grain yield/plant a greater magnitude of heterosis when measured as a deviation from the mid-parent and better parent was observed in crosses Sakha 109 × IR 65600-77, IR 65600-77 × Nerica 9, Sakha 108 × IR 65600-77, and IR 69116 × Sakha Super 300 under water deficit, IR 65600-77 × Sakha Super 300, Sakha 104 × IR 69116, Sakha 104 × Nerica 9 and Sakha 109 Nerica 9 under normal conditions. The availability of sufficient hybrid vigor in several crosses in respect of grain yield suggests that a hybrid breeding program could be profitably undertaken in rice under water deficit and normal conditions. The crosses Sakha 108 × Sakha super 300 under water deficit and normal conditions, IR 65600-77 × Nerica 9 under water deficit, exhibited the highest negative heterosis for days to 50% heading measured as a deviation from mid-parent and better parent. The appearance of significant and negative heterosis for a number of days to 50% heading indicated the possibility of exploiting heterosis for earliness. Highly significant and negative estimates of heterosis for plant height measured as a deviation from mid-parent and better parent in cross Sakha 104 × Sakha 109 under water deficit conditions. High estimated values of mid parent heterosis were recorded in Sakha 109 × Nerica 9 and IR 69116 × IET 1444 under normal conditions. IR 65600-77 × Sakha Super 300 under both conditions, IR 69116 × Sakha Super 300 under water deficit, and IR 69116 × IR 65600-77 under normal conditions exhibited highly significant and positive estimates of heterosis for the number of panicles/plant. Moreover, highly significant and positive estimates of mid and better parent heterosis were observed for panicle length in several crosses, the highest estimated values were observed in Sakha 108 × Sakha super 300 under both conditions, Nerica 9 × IET 1444 and IR 65600-77 × Sakha super 300 under water deficit, and Sakha 108 × Sakha 104 and Sakha 108 × Sakha 109 under normal conditions. The crosses IR 65600-77 × Sakha super 300 under both conditions, IR 65600-77 × Nerica 9, and Sakha 108 × Sakha super 300 under water deficit, and Sakha 108 × Sakha 109 and Sakha Super 300 × IET 1444 under normal conditions exhibited the highest positive heterosis of number of filled grains/panicle measured as a deviation from mid-parent and better parent. On the other hand, IR 65600-77 × Nerica 9 under both conditions, Sakha 104 × IET 1444 under water stress and Sakha 109 × IET 1444 under normal conditions recorded significant positive mid and better parent heterosis for 100-grain weight. Under water deficit conditions, the cross Sakha 104 × Sakha 109 exhibited the highest positive heterosis for fertility % measured as a deviation from mid-parent and better parent. In highly significant and negative estimates of heterosis for grain length measured as a deviation from mid-parent and better parent in ten crosses, the highest values were observed in Nerica 9 × IET 1444 and IR 69116 × Nerica 9 under water deficit conditions, while five crosses exhibited significant and highly significant negative measures of heterosis measured as a deviation from mid-parent and better parent under normal conditions. Moreover, highly significant and negative estimates of mid- and better-parent heterosis were observed for grain shape; the highest estimated values were observed in Sakha 108 × Nerica 9, Sakha 108 × Sakha 109, Sakha 108 × Sakha 104 and Nerica 9 × IET 1444 under both conditions. The crosses IR 69116 × IET 1444, IR 69116 × IR 65600-77, IR 65600-77 × IET 1444, and Sakha 104 × Sakha Super 300 under both conditions exhibited the highest positive heterosis of hulling % measured as a deviation from mid-parent and better parent. Highly significant and positive estimates of heterosis for milling % measured as a deviation from mid-parent and better parent in cross IR 65600-77 × IET 1444 under both conditions. On the other hand, the crosses IR 69116 × Nerica 9 and Sakha 108 × IET 1444 under both conditions exhibited the highest positive heterosis of head rice % measured as a deviation from mid-parent and better parent. Moreover, the cross IR 69116 × Sakha super 300 and IR 65600-77 × IET 1444 exhibited the highest negative heterosis of amylose content % measured as a deviation from mid-parent and better parent under both conditions.

Table 5: Estimates of heterosis as a deviation from mid- and heterbelitosis of the twenty-eight rice crosses for grain yield, yield components, and some grain quality traits under water stress and normal conditions.

Genotype	days to 50% heading				Plant height (cm)				No. of panicles/plant				Panicle length (cm)			
	MP		BP		MP		BP		MP		BP		MP		BP	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	-0.45	5.83**	1.85*	9.26**	-3.32	-1.35	0.00	0.00	12.20**	-25.93**	-4.17**	-28.57**	16.04**	24.44**	13.30**	22.18**
Sakha 108 × IR 69116	-1.35	5.73**	0.00	7.14**	10.90**	-2.50	14.71**	6.85**	31.03**	-25.00**	11.76**	-35.71**	1.07	-3.45**	0.85	-7.97**
Sakha 108 × Sakha 109	6.22**	19.21**	15.63**	37.50**	21.18**	4.76*	21.78**	5.48*	13.51**	-25.00**	5.00**	-35.71**	11.35**	-1.22**	9.44**	-2.78**
Sakha 108 × IR 65600-77	-0.91	3.03**	1.87*	3.48**	9.59***	10.34**	17.65**	11.11**	16.13**	3.70**	5.88**	0.00	7.22**	-5.59**	3.17**	-13.04**
Sakha 108 × Nerica 9	5.85**	4.76**	13.95**	5.22**	-3.45	11.25**	9.80**	21.92**	43.75**	-3.70**	35.29**	-7.14**	-4.71**	3.67**	-12.27**	-8.00**
Sakha 108 × Sakha Super 300	-12.82**	-3.86**	-9.73**	-2.61**	6.55*	-0.62	19.61**	9.59**	61.29**	52.00**	47.06**	35.71**	16.11**	47.24**	12.88**	30.21**
Sakha 108 × IET 1444	7.67**	6.48**	14.67**	13.86**	16.59**	19.05**	27.45**	36.99**	40.54**	9.68**	30.00**	0.00	6.83**	-3.82**	3.20**	-14.98**
Sakha 104 × IR 69116	4.59**	15.45**	5.56**	17.59**	17.13**	-6.58**	17.13**	0.89	27.78**	-21.74**	-4.17**	-30.77**	2.19**	8.23**	-0.43	1.39**
Sakha 104 × Sakha 109	-2.94**	10.20**	3.13**	22.73**	20.00**	-6.04**	24.75**	-5.41*	-4.55**	-21.74**	-12.50**	-30.77**	2.91**	-1.72**	2.22**	-5.00**
Sakha 104 × IR 65600-77	0.47	-2.68**	0.93	0.93*	3.54	0.68	7.34*	2.78	-15.79**	0.00	-33.33**	0.00	2.95**	-9.33**	-3.17**	-17.87**
Sakha 104 × Nerica 9	3.56**	0.00	8.84**	3.70**	-1.26	-1.23	8.26**	6.67**	-17.95**	0.00	-33.33**	0.00	-8.22**	-3.31**	-17.33**	-15.56**
Sakha 104 × Sakha Super 300	-4.80**	-1.77**	0.93	2.78**	7.63**	-0.61	16.51**	8.00**	21.05**	16.67**	-4.17**	7.69**	2.26**	22.52**	1.80	10.12**
Sakha 104 × IET 1444	8.65**	8.13**	13.00**	11.88**	10.43**	31.76**	16.51**	49.33**	-4.55**	20.00**	-12.50**	5.88**	5.93**	-7.85**	0.00	-19.82**
IR 69116 × Sakha 109	-4.85**	6.00**	2.08*	20.45**	1.27	4.35*	5.28	13.51**	-4.17**	16.67**	-23.33**	16.67**	10.24**	6.89**	8.12**	3.47**
IR 69116 × IR 65600-77	5.07**	8.77**	6.54**	10.71**	7.96**	6.92**	11.93**	18.06**	97.44**	-21.74**	83.33**	-30.77**	3.70**	4.17**	0.00	0.48
IR 69116 × Nerica 9	4.81**	-1.75**	11.22**	0.00	2.93	3.45	12.84**	3.45	16.05**	4.35**	4.44**	-7.69**	0.59	1.60**	-7.22**	-5.78**
IR 69116 × Sakha Super 300	3.03**	7.83**	8.18**	10.71**	9.60**	9.71**	18.65**	10.34**	66.67**	52.38**	54.76**	45.45**	-11.89**	15.22**	-14.53**	-2.25**
IR 69116 × IET 1444	10.48**	19.25**	16.00**	25.74**	-5.80*	-16.48**	-0.61	-12.64**	-20.83**	-20.99**	-36.67**	-37.25**	-6.20**	-13.20**	-9.20**	-19.82**
Sakha 109 × IR 65600-77	-5.42**	1.96**	0.00	18.18**	-0.31	16.44**	7.59*	18.06**	47.06**	56.52**	25.00**	38.46**	0.63	-0.26	-4.76**	-6.76**
Sakha 109 × Nerica 9	-2.41**	-0.33	-1.39	15.53**	-9.96**	-0.62	2.97	8.11**	37.14**	47.83**	20.00**	30.77**	-1.59*	10.62**	-10.83**	-0.44
Sakha 109 × Sakha Super 300	5.99**	17.48**	19.79**	37.50**	9.65**	25.93**	23.76**	37.84**	47.06**	42.86**	25.00**	36.36**	3.37**	23.57**	2.22**	7.78**
Sakha 109 × IET 1444	2.04**	17.46**	4.17**	26.14**	12.61**	12.43**	23.76**	28.38**	-20.00**	3.70**	-20.00**	-17.65**	2.32**	13.02**	-2.80**	1.32**
IR 65600-77× Nerica 9	-3.41**	-6.03**	1.02	-6.03**	4.45	40.88**	10.26**	55.56**	17.24**	23.08**	13.33**	23.08**	3.21**	12.96**	-1.44	8.44**
IR 65600-77× Sakha Super 300	0.00	4.27**	6.54**	5.17**	0.82	15.00**	5.13	27.78**	100.00**	58.33**	100.00**	46.15**	6.36**	43.70**	-0.40	18.36**
IR 65600-77× IET 1444	6.28**	15.21**	10.00**	23.76**	2.52	11.38**	4.27	29.17**	41.18**	13.33**	20.00**	0.00	8.37**	12.90**	7.94**	7.93**
Nerica 9 × Sakha Super 300	7.76**	4.27**	20.41**	5.17**	-1.95	-1.71	-0.79	-1.15	44.83**	33.33**	40.00**	23.08**	-15.09**	-19.11**	-23.83**	-19.11**
Nerica 9 × IET 1444	6.06**	0.46	7.14**	7.92**	-4.38	2.20	-0.83	6.90**	31.43**	26.67**	15.00**	11.76**	2.47**	44.04**	-2.53**	14.54**
Sakha Super 300 × IET 1444	7.69**	0.46	19.00**	8.91**	2.42	2.73	4.96	6.82**	35.29**	7.14**	15.00**	-11.76**	-5.53**	17.45**	-11.20**	-6.61**
L.S.D : 0.05	1.47	0.70	1.69	0.81	4.95	4.25	5.71	4.90	1.49	1.44	1.72	1.67	1.40	0.71	1.61	0.82
:0.01	1.95	0.93	2.25	1.08	6.58	5.65	7.60	6.52	1.98	1.92	2.29	2.22	1.86	0.94	2.15	1.09

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

Table 5: Continued

Genotype	No. of filled grains/ panicle				100-grain weight (g)				Fertility %				Grain yield/plant (g)			
	MP		BP		MP		BP		MP		BP		MP		BP	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	14.60**	33.02**	8.28**	20.34**	1.82**	0.00	0.00	0.00	5.97**	3.07*	3.06	3.07	14.89**	31.45**	10.20**	28.28**
Sakha 108 × IR 69116	-11.67**	-51.12**	-31.17**	-62.30**	-10.71**	-19.15**	-10.71**	-24.00**	1.18	-28.64**	-3.94*	-39.77**	17.33**	-26.53**	-2.22	-30.77**
Sakha 108 × Sakha 109	71.43**	2.78	66.42**	-13.98**	5.45**	-4.55**	3.57**	-4.55**	4.95**	-13.66**	4.32*	-13.66**	20.43**	-2.37	16.67**	-8.28**
Sakha 108 × IR 65600-77	-3.18	-0.99	-11.04**	-6.74**	-6.25**	6.38**	-16.67**	0.00	1.96	4.73**	-1.32	-13.31**	24.56**	58.02**	18.33**	39.13**
Sakha 108 × Nerica 9	-4.10	-6.91**	-19.15**	-22.69**	-1.69**	-11.54**	-6.45**	-23.33**	-0.46	-12.60**	-4.12*	-18.82**	28.07**	40.88**	8.15**	37.72**
Sakha 108 × Sakha Super 300	32.27**	48.84**	12.50**	39.13**	-23.64**	-27.27**	-25.00**	-27.27**	2.65	**11.42	-2.04	-1.11	12.27**	48.84**	11.05**	39.13**
Sakha 108 × IET 1444	9.47**	-5.41**	-11.48**	-28.76**	2.04**	7.32**	-10.71**	0.00	4.17*	4.81**	-1.15	-8.13**	34.02**	-4.61*	25.00**	-24.92**
Sakha 104 × IR 69116	-17.55**	-5.43**	-32.90**	-31.95**	-1.82**	-40.43**	-3.57**	-44.00**	-0.60	5.98**	-3.03	-10.55**	39.24**	-28.24**	12.24**	-30.77**
Sakha 104 × Sakha 109	61.70**	28.00**	57.24**	17.28**	0.00	-4.55**	0.00	-4.55**	4.31*	17.39**	2.04	12.99**	28.29**	-0.66	26.98**	-4.46
Sakha 104 × IR 65600-77	2.34	0.87	-0.65	-13.48**	-14.29**	-6.38**	-25.00**	-12.00**	2.43	-3.74*	1.92	-17.76**	19.19**	34.40**	18.00**	15.86**
Sakha 104 × Nerica 9	-5.71**	21.17**	-16.49**	-7.00**	-6.90**	-15.38**	-12.90**	-26.67**	1.90	11.29**	0.89	-2.54	37.78**	24.35**	12.47**	24.14**
Sakha 104 × Sakha Super 300	-3.55	12.22**	-13.77**	-16.41**	0.00	4.55**	0.00	4.55**	1.12	2.77	-0.83	-13.71**	24.56**	40.38**	20.75**	28.28**
Sakha 104 × IET 1444	-2.82	-3.50	-17.70**	-31.97**	0.00	12.20**	-11.11**	4.55**	-0.58	7.03**	-3.06	-11.17**	26.73**	9.00**	23.08**	-12.62**
IR 69116 × Sakha 109	-12.50**	12.12**	-30.30**	-23.45**	1.82**	10.64**	0.00	4.00**	0.43	14.71**	-4.11*	-6.13**	20.51**	3.51	-2.08	3.18
IR 69116 × IR 65600-77	13.77**	36.75**	-5.19*	10.34**	0.00	-8.00**	-11.11**	-8.00**	-3.28*	-1.71	-5.19**	-3.14	30.00**	1.15	4.00	-15.38**
IR 69116 × Nerica 9	-13.13**	-10.61**	-21.21**	-18.62**	-25.42**	-27.27**	-29.03**	-33.33**	0.67	3.30*	-0.83	-1.05	32.24**	35.77**	30.11**	30.77**
IR 69116 × Sakha Super 300	-12.77**	-25.09**	-21.65**	-28.97**	-1.82**	6.38**	-3.57**	0.00	-3.46*	-8.01**	-3.98*	-8.60**	26.32**	56.52**	4.35	38.46**
IR 69116 × IET 1444	11.36**	-62.71**	6.06*	-63.95**	14.29**	-36.36**	0.00	-44.00**	-1.07	-50.32**	-1.12	-51.34**	12.20**	-18.25**	-11.54**	-32.59**
Sakha 109 × IR 65600-77	2.41	40.85**	-3.25	12.36**	-14.29**	2.13**	-25.00**	-4.00**	1.38	**11.35	-1.3	-7.82**	15.65**	60.31**	13.33**	33.76**
Sakha 109 × Nerica 9	-12.00**	12.79**	-23.94**	-18.49**	0.00	0.00	-6.45**	-13.33**	4.35*	-23.71**	1.08	-35.34**	32.49**	43.28**	9.03**	37.58**
Sakha 109 × Sakha Super 300	-9.66**	9.29**	-21.20**	-23.08**	3.70**	9.09**	3.70**	9.09**	2.25	8.36**	-1.87	-11.78**	27.66**	51.62**	25.00**	33.76**
Sakha 109 × IET 1444	3.47	41.12**	-14.35**	-5.36*	16.67**	-0.81**	3.70**	-7.58**	3.80*	16.63**	-0.94	-6.09**	0.00	-5.10*	-3.85	-21.55**
IR 65600-77× Nerica 9	15.79**	58.65**	5.32*	38.66**	13.43**	16.36**	5.56**	6.67**	-0.51	2.93*	-1.01	0.00	28.56**	58.72**	4.13	37.02**
IR 65600-77× Sakha Super 300	43.20**	44.00**	31.52**	35.00**	-11.11**	6.38**	-22.22**	0.00	-1.40	-1.02	-2.83	-3.08	39.58**	44.00**	34.00**	35.00**
IR 65600-77× IET 1444	-6.34**	15.42**	-18.66**	-9.23**	8.77**	0.00	-13.89**	-12.00**	-8.24**	-11.31**	-10.09**	-14.37**	-21.46**	21.63**	-22.97**	-12.62**
Nerica 9 × Sakha Super 300	-4.84*	20.48**	-5.85*	15.38**	-6.90**	-7.69**	-12.90**	-20.00**	-1.81	4.90**	-1.81	-0.14	29.87**	49.72**	8.70**	37.02**
Nerica 9 × IET 1444	-12.85**	17.38**	-17.22**	3.65	-23.08**	-26.53**	-35.48**	-40.00**	-2.00	1.11	-2.00	-5.06**	25.90**	21.62**	0.48	-2.63
Sakha Super 300 × IET 1444	44.53**	-15.89**	35.89**	-22.75**	-4.17**	2.44**	-14.81**	-4.55**	0.03	-6.89**	0.03	-8.22**	18.37**	23.22**	11.54**	-7.62**
L.S.D : 0.05	4.18	3.98	4.83	4.59	0.14	0.14	0.16	0.16	3.28	2.84	3.28	3.28	4.29	4.22	4.95	4.87
:0.01	5.56	5.29	6.42	6.11	0.19	0.19	0.21	0.22	4.36	3.78	4.36	4.36	5.70	5.61	6.59	6.48

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

Table 5: Continued

Genotype	Grain length				Grain shape				Hulling%				Milling%			
	MP		BP		MP		BP		MP		BP		MP		BP	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	-2.65**	2.03**	-1.62**	3.13**	-11.96**	-5.83**	-11.87**	-5.31**	0.61	1.08	0.00	0.43	2.10**	2.26**	0.00	0.00
Sakha 108 × IR 69116	2.70**	-7.56**	7.15**	-6.84**	6.22**	-6.05**	16.01**	-1.21**	2.50**	3.11**	0.00	0.43	2.16**	2.84**	1.43	2.05**
Sakha 108 × Sakha 109	1.55**	-9.63**	3.53**	-7.42**	-7.22**	-10.82**	-7.22**	-7.14**	0.61	1.08	0.00	0.43	2.10**	2.26**	0.00	0.00
Sakha 108 × IR 65600-77	-9.92**	-4.17**	2.31**	5.47**	-3.06**	-1.96**	2.59**	9.89**	1.86*	2.43**	0.00	0.43	0.00	0.51	0.00	0.51
Sakha 108 × Nerica 9	-16.01**	-17.73**	-1.10**	-0.78**	-28.53**	-31.45**	-8.15**	-13.19**	0.00	0.00	-1.22	-1.3	-5.71**	-6.15**	-5.71**	-6.15**
Sakha 108 × Sakha Super 300	6.46**	3.13**	8.69**	6.68**	52.94**	16.57**	62.50**	21.43**	1.82*	1.94**	1.20	1.28	-0.70	-0.75	-2.74**	-2.94**
Sakha 108 × IET 1444	-1.55**	-1.76**	0.49**	3.52**	-9.15**	-6.32**	8.52**	9.89**	-0.62	-0.66	-2.44**	-2.60**	0.00	0.51	0.00	0.51
Sakha 104 × IR 69116	0.10	-6.23**	3.31**	-5.96**	-4.92**	24.93**	3.73**	32.12**	1.04	0.66	-2.01*	-2.56**	2.82**	3.03**	0.00	0.00
Sakha 104 × Sakha 109	1.51**	-4.97**	4.60**	-3.70**	-6.33**	-3.41**	-2.60**	0.00	0.00	0.00	0.00	0.00	-2.74**	-2.94**	-2.74**	-2.94**
Sakha 104 × IR 65600-77	-10.55**	-3.75**	2.80**	4.72**	-4.38**	-1.95**	1.30**	9.24**	-2.06**	-2.19**	-4.42**	-4.70**	0.70	0.75	-1.37	-1.47*
Sakha 104 × Nerica 9	-14.53**	-15.52**	1.87**	0.64**	-22.13**	-17.93**	0.19**	3.26**	1.84*	2.40**	0.00	0.43	-0.70	-0.75	-2.74**	-2.94**
Sakha 104 × Sakha Super 300	4.52**	5.32**	5.58**	10.16**	5.79**	3.41**	12.29**	8.33**	2.41**	2.99**	2.41**	2.99**	0.00	0.00	0.00	0.00
Sakha 104 × IET 1444	0.30**	-1.35*	3.48**	2.80**	-10.32**	-4.27**	7.24**	11.59**	1.23*	1.75**	-1.20	-0.85	-2.10**	-1.75*	-4.11**	-3.92**
IR 69116 × Sakha 109	6.12**	5.01**	12.97**	6.73**	11.75**	11.60**	27.19**	22.42**	3.11**	3.31**	0.00	000	-2.82**	-3.03**	-5.48**	-5.88**
IR 69116 × IR 65600-77	0.03	-7.31**	19.13**	1.15**	0.28**	-13.04**	16.45**	3.03**	3.61**	3.85**	2.95**	3.15**	0.72	0.78	0.00	0.00
IR 69116 × Nerica 9	-16.17**	-19.55**	3.64**	-3.85**	-15.64**	-14.41**	20.61**	15.15**	1.27	1.80**	0.00	0.44	-6.47**	-6.46**	-7.14**	-7.18**
IR 69116 × Sakha Super 300	11.95**	12.11**	14.36**	16.91**	28.21**	17.12**	31.58**	18.18**	3.11**	3.31**	0.00	0.00	1.41*	2.02**	-1.37	-0.98
IR 69116 × IET 1444	0.59**	-15.36**	7.21**	-11.54**	-15.09**	-17.56**	12.28**	2.42**	4.46**	4.76**	3.80**	4.05**	-0.72	-0.26	-1.43	-1.03
Sakha 109 × IR 65600-77	-11.28**	-6.77**	-1.35**	0.00	-0.42**	-10.17**	1.37**	-3.55**	0.00	0.00	-2.41**	-2.56**	-0.70	-0.75	-2.74**	-2.94**
Sakha 109 × Nerica 9	-12.95**	-15.71**	0.29**	-1.12**	-17.20**	-17.23**	1.72**	0.00	0.20	0.65	-1.61	-1.28	0.70	0.75	-1.37	-1.47*
Sakha 109 × Sakha Super 300	-0.06	1.77**	4.06**	7.93**	1.69**	1.92**	12.50**	10.71**	1.20	1.28*	1.20	1.28	0.00	0.00	0.00	0.00
Sakha 109 × IET 1444	2.58**	-4.05**	2.70**	-1.37**	-8.26**	2.71**	4.98**	15.23**	1.23	0.88	-1.20	-1.71*	-0.70	-0.25	-2.74**	-2.45**
IR 65600-77× Nerica 9	-0.44**	0.40**	2.83**	9.21**	1.45**	-2.18**	22.06**	9.29**	1.89*	2.01**	1.25	1.33	0.00	0.51	0.00	0.51
IR 65600-77× Sakha Super 300	-15.61**	2.68**	-1.90**	17.26**	-7.66**	-4.06**	4.17**	12.50**	1.23	1.32*	-1.20	-1.28	2.10**	2.26**	0.00	0.00
IR 65600-77× IET 1444	6.37**	-1.92**	18.13**	2.23**	2.73**	-10.69**	15.26**	-6.93**	2.53**	3.60**	2.53**	3.60**	2.86**	3.08**	2.86**	3.08**
Nerica 9 × Sakha Super 300	-17.07**	-15.53**	0.00	5.98**	-24.40**	-24.38**	4.58**	0.60**	1.84*	3.51**	0.00	0.85	-0.70	-0.25	-2.74**	-2.45**
Nerica 9 × IET 1444	-14.61**	-19.74**	-1.75**	-8.70**	-7.38**	-10.69**	-1.33**	-4.49**	1.89*	2.70**	1.25	2.70**	0.00	0.00	0.00	0.00
Sakha Super 300 × IET 1444	-4.14**	-1.02**	-0.06	8.07**	-19.51**	12.83**	3.12**	38.69**	2.47**	2.63**	0.00	0.00	0.7.0	1.25*	-1.37	-0.98
L.S.D : 0.05	0.12	0.06	0.13	0.07	0.08	0.08	0.09	0.09	1.49	1.22	1.73	1.41	1.40	1.25	1.61	1.44
:0.01	0.15	0.08	0.18	0.10	0.11	0.11	0.12	0.12	1.99	1.62	2.29	1.88	1.86	1.66	2.15	1.92

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

Table 5: Continued

Genotype	Head rice%				Amylose content%			
	MP		BP		MP		BP	
	N	D	N	D	N	D	N	D
Sakha 108 ×Sakha 104	3.28**	3.57**	1.61	1.75*	10.32**	0.00	10.54**	0.24
Sakha 108 × IR 69116	4.93**	4.76**	0.56	0.00	-0.17	1.27	4.67**	3.58**
Sakha 108 × Sakha 109	2.44**	2.65**	0.00	0.00	7.28**	12.40**	15.74**	15.32**
Sakha 108 × IR 65600-77	0.00	0.00	0.00	0.00	14.85**	6.04**	20.64**	8.67**
Sakha 108 × Nerica 9	-2.87**	-3.77**	-6.11**	-7.27**	7.45**	4.89**	22.01**	15.51**
Sakha 108 × Sakha Super 300	2.44**	2.65**	0.00	0.00	30.37**	28.18**	33.14**	31.98**
Sakha 108 × IET 1444	3.33**	3.64**	3.33**	3.64**	15.44**	10.70**	37.51**	25.15**
Sakha 104 × IR 69116	7.69**	8.41**	1.61	1.75*	10.96**	2.25**	16.10**	4.32**
Sakha 104 × Sakha 109	-1.87*	-2.61**	-2.65**	-3.45**	6.88**	2.78**	15.06**	5.19**
Sakha 104 × IR 65600-77	3.28**	3.57**	1.61	1.75*	-5.64**	-7.80**	-1.09	-5.76**
Sakha 104 × Nerica 9	5.65**	5.56**	0.54	0.00	1.34	0.68	14.81**	10.58**
Sakha 104 × Sakha Super 300	0.80	0.87	000	0.00	24.32**	5.44**	26.70**	8.30**
Sakha 104 × IET 1444	-2.73**	-3.57**	-4.30**	-5.26**	1.99**	-3.56**	21.21**	8.73**
IR 69116 × Sakha 109	-1.69*	-1.85**	-7.94**	-8.62**	-2.45**	-9.70**	0.25	-9.42**
IR 69116 × IR 65600-77	2.61**	2.86**	-1.67	-1.82*	-4.61**	-9.83**	-4.44	-9.65**
IR 69116 × Nerica 9	4.50**	5.61**	3.57**	4.58**	-6.77**	-12.90**	0.62	-6.36**
IR 69116 × Sakha Super 300	3.39**	3.70**	-3.17**	-3.45**	-22.06**	-31.39**	-20.02**	-30.94**
IR 69116 × IET 1444	0.87	1.59*	-3.33**	-3.03**	19.79**	18.13**	35.38**	30.30**
Sakha 109 × IR 65600-77	-0.81	-0.88	-3.17**	-3.45**	-6.53**	-14.70**	-4.11**	-14.60**
Sakha 109 × Nerica 9	4.20**	4.59**	-1.59	-1.72*	13.53**	11.27**	19.07**	19.24**
Sakha 109 × Sakha Super 300	0.00	-0.57	0.00	-0.57	9.90**	5.68**	15.97**	6.04**
Sakha 109 × IET 1444	-2.44**	-2.65**	-4.76**	-5.17**	-0.63	5.48**	9.01**	15.97**
IR 65600-77× Nerica 9	3.45**	3.77**	0.00	0.00	-7.38**	-2.20**	-0.23	4.93**
IR 65600-77× Sakha Super 300	2.44**	2.65**	0.00	0.00	-6.86**	-5.62**	-4.26**	-5.18**
IR 65600-77× IET 1444	0.00	-0.61	0.00	-0.61	-15.63**	-17.61**	-4.84**	-9.30**
Nerica 9 × Sakha Super 300	2.52**	2.75**	-3.17**	-3.45**	14.65**	11.47**	27.20**	19.01**
Nerica 9 × IET 1444	3.45**	4.40**	0.00	0.61	3.43**	-2.24**	7.98**	0.14
Sakha Super 300 × IET 1444	0.81	0.88	-1.59	-1.72*	22.37**	12.41**	42.32**	23.12**
L.S.D : 0.05	1.50	1.29	1.74	1.49	1.41	1.60	1.63	1.85
:0.01	2.00	1.72	2.31	1.98	1.88	2.13	2.17	2.46

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

DISCUSSION

Discussion of analysis of variance

The analysis for variance of genotypes (parents, crosses, and parents vs. crosses) under water deficit and normal conditions showed highly significant differences for all traits evaluated, implying an appreciable amount of genetic variability in the parents, crosses, and parents vs. crosses used in the study, except for 100-grain weight (g) and grain shape traits under both conditions and amylose content (%) under normal conditions for parents vs. crosses, which were insignificant. Thus, the genotypes evaluated can be selected for genetic improvement of grain yield, its components, and some grain quality traits under water deficit and normal conditions. Significant parents vs. crosses for most traits studied refer to useful heterosis and could improve most traits under water deficit, while normal conditions were used for crosses. These results agree with those obtained by (Saleem *et al.*, 2010; Negm, 2011; Daher, 2018; Sakran *et al.*, 2022). The combining ability analysis revealed significant GCA and SCA variances for all of the traits under water deficit and normal conditions, except for 100-grain weight (g), grain length (mm), and grain shape traits under both conditions, and hulling% for SCA, which was insignificant, indicating the importance of additive and non-additive genetic variances in determining the inheritance of these studied traits. A similar trend of results was obtained by (Rahimi *et al.*,2010). The GCA/SCA ratio was used to identify the nature of gene action. Therefore, the GCA/SCA ratio is less than unity in all studied traits except hulling% under normal conditions, suggesting greater importance of non-additive genetic variance in the inheritance of these traits; therefore, selection procedures in late or advanced generations will be very important to improve these traits. The obtained results are in harmony with those previously observed by (El-Naem, 2010; Raja *et al*., 2018; Devi *et al*., 2018; Sakran *et al.,* 2022).

Mean performance

The shortest genotypes were exhibited in IR 65600-77, Sakha 108, Sakha 109, and Sakha 104 × Sakha 109 under water deficit, while Sakha 109 was followed by Sakha 108 and Sakha 108 × Sakha 104 under normal condition. Sakha 109 under both conditions, followed by IET 1444, Sakha 108, and Sakha 109 × Nerica 9 under water deficit, and Nerica 9, IET 1444, and Sakha 109 × IR 65600-77 under normal conditions, were early genotypes. In addition, IET 1444 has the longest panicle, and Nerica 9 × IET 1444 under water deficit, while Nerica 9 and IR 65600-77 × Nerica 9 under normal conditions were the longest panicles. A high number of panicles/plants was detected for IET 1444 under water deficit and Sakha 104 under normal conditions, and IR 65600-77 × Sakha Super 300 under both conditions. The highest mean values for number of filled grains/panicle were IET 1444 and IR 65600-77 × Sakha Super 300 under water deficit conditions and IR 69116 and Sakha Super 300 × IET 1444 under normal conditions. Nerica.9 under water deficit, IR 65600-77 under normal conditions, and IR 65600-77 × Nerica 9 under both conditions exhibited the highest mean values for 100-grain weight. High fertility % were observed for IET 1444 under both conditions, Nerica 9 × Sakha super 300 under water deficit and Sakha super 300 × IET 1444 under normal conditions exhibited the highest mean values for fertility %. The highest mean values were recorded by IET 1444 under both conditions, Nerica 9 × IET 1444 under water deficit, and IR 65600-77 × Sakha Super 300 under normal conditions for grain yield/plant. The crosses, IR 69116 × IET 1444 and IR 65600-77 × Sakha Super 300 exhibited the lowest mean values of grain length under water deficit and normal conditions, respectively. For grain shape (L/W ratio), the most desirable short to bold grain genotypes were IR 69116 and Sakha 108 × Nerica 9 under water deficit, and Sakha Super 300 and Sakha 104 × IR 69116 under normal conditions, indicating that these genotypes could be used as good grain shape donors under both conditions. The highest estimated values of hulling %, milling % and head rice % were detected for Sakha 104, Sakha 109, Sakha Super 300, Sakha 104 × Sakha Super 300, Sakha 108 × Sakha 109, IR 65600-77 × Sakha Super 300, Sakha 108 × Sakha 104 and Sakha 108 × Sakha 109 genotypes under both conditions. For amylose content %, Sakha 108 and IR 69116 × Sakha Super 300 had the lowest amylose content % under both conditions.

Combining ability

The results showed that, the parents IET 1444 and Sakha Super 300 were good general combiners for number of panicles/plants, number of filled grains/panicle and fertility (%) under water deficit. While, IET 1444 and Nerica 9 were good general combiners for panicle length and grain yield/plant under water deficit. Moreover, IR 65600-77 and Nerica.9 were the best general combiners for 100-grain weight under water deficit. On the other hand, Sakha 109 and IET 1444 were good combiners for earliness under water deficit. Sakha 108 and Sakha 109 were good combiners for plant height under water deficit.

The parent IR 69116 was a good general combiner for grain length and grain shape under water deficit. While, the parent IR 65600-77 was a good combiner for amylose content (%) under water deficit. In addition, the promising combinations for grain yield and most of the studied traits were IR 69116 × Sakha Super 300, Sakha 109 × IR 65600-77, Sakha 108 × IR 65600-77, IR 69116 × Nerica 9, Sakha 108 × Sakha 104, Sakha 109 × Sakha Super 300 and Sakha 109 × Nerica 9 under water deficit conditions. It is observed that the majority of the crosses with high SCA for grain yield resulted from low/low, high/high, or high/low combining parents. Highly significant negative estimates of SCA for the number of days to 50% heading (earliness) were recorded for Sakha 104 × IR 69116, Sakha 108 × Sakha Super 300, and IR 65600-77 × Nerica 9 cross combinations. Moreover, the cross Sakha 108 × IR 69116 was found to be the best specific combination for plant height under water deficit. The cross combination, Sakha 108 × Sakha Super 300 was the best specific combination for number of panicles/plant and number of filled grains/panicle under water deficit. While, the cross combination, IR 69116 × Nerica 9 was the best specific combination for grain length under water deficit. The cross-combination IR 69116 × Sakha 109 exhibited highly significant and positive SCA effects for fertility (%) under water deficit, while, the cross IR 65600-77 × Nerica 9 was the best cross combination for 100-grain weight under both conditions. These findings were in agreement with those of (El-Naem 2010; El-Sherif, 2011; El-Badri, 2013; Abo-Zeid, 2016; Raja *et al*., 2018; Devi *et al*., 2018; Sakran *et al.,* 2022).

Heterosis

Sakha 108 × Sakha Super 300 and Sakha 109 × Sakha Super 300 exhibited highly significant positive estimates of heterosis over mid-parent and better parent for panicle length and amount of panicles/plant under both conditions. While, the cross IR 65600-77 × Nerica 9 exhibited highly significant and positive estimates of mid- and better-parent heterosis for number of filled grains/panicle and 100-grain weight (g) under both conditions, The crosses IR 65600-77 × Sakha super 300, Sakha 104 × Nerica 9, Sakha 109 × Nerica 9 and Sakha 109 × Sakha super 300 exhibited the highest positive heterosis for grain yield/ plant (g) measured as a deviation from mid-parent and better parent under both conditions. Highly significant and negative estimates of heterosis for grain length and grain shape measured as a deviation from mid-parent and better parent in the cross, Nerica 9 × IET 1444 under both conditions. IR 65600-77 × IET 1444 exhibited the highest positive heterosis of hulling% and milling% measured as a deviation from mid-parent and better parent under both conditions. the cross IR 69116 × Sakha super 300, IR 65600-77 × IET 1444 and Sakha 109 × IR 65600-77 exhibited highest negative heterosis of amylose content % measured as a deviation from mid-parent and better parent under both conditions. Similar results were reported by several scientists, like, (El-Naem, 2010; El-Badri, 2013; El-Naem, 2014; Abo-Zeid, 2016; Raja *et al*., 2018; Devi *et al*., 2018; Sakran *et al.,* 2022).

CONCLUSION

The most desirable mean values were the parent Sakha 109 for earliness and plant height under both conditions except plant height under water deficit, the parent IET 1444 for yield and most components, and Sakha Super 300 for grain quality traits except, amylose content, and cross IR 65600-77 × Sakha Super 300 for most studied characters under water deficit and normal conditions. Sakha Super 300 was the best one, since it possessed significant and desirable GCA effects for most of the studied characters under water deficit and normal conditions, followed by IET 1444. The estimates of SCA showed that the cross Sakha 108 × Sakha Super 300 was the best cross for most of the studied characters under water deficit and normal conditions. The most useful heterosis effects relative to the mid- and better- parents were detected in the cross Sakha 108 × Sakha Super 300 for most of the studied characters under water deficit and normal conditions.

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تقدير القدرة على التآلف وقوة الهجين لمحصول الحبوب ومكوناته وبعض صفات الجوده فى الارز تحت ظروف نقص المياه

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تمت دراسة القدرة على التآلف وقوة الهجين لمحصول الحبوب والصفات المتعلقة به وبعض صفات جوده الحبوب فى الارز تحت ظروف نقص المياه باستخدام نظام الهجن التبادلية بين ثمانية تراكيب وراثية مختلفة وذلك بدون الهجن العكسية وذلك بالمزرعة البحثية لقسم بحوث الارز – سخا – كفرالشيخ – مصر وذلك أثناء موسمى 2020 و2021. أوضحت النتائج أن النسبة بين كل من تباين القدرة العامة على التآلف وتباين القدرة الخاصة على التآلف أقل من الواحد الصحيح مشيرةٍ إلى أهمية الفعل الجينى السيادى فى التحكم فى السلوك الوراثى لجميع الصفات المدروسه ما عدا صفه النسبه المئويه للتقشير تحت الظروف الطبيعيه أعلى من الواحد الصحيح. ومن بين الاباء، اظهرت الاصناف أى إى تى 1444 و نيركا 9 قدره عامة فائقة المعنوية كافضل الاباء لصفة مجصول النبات الفردى تحت ظروف نقص المياه. كما كانت الاصناف أى إى تى 1444 وسخا سوبر 300 افضل الاباء قدرة عامة على التالف لصفات عدد السنابل/ نبات, عدد الحبوب الممتلئه فى السنبله والنسبة المئوية للخصوبه تحت ظروف نقص المياه. إضافة الى ذلك كانت الاصناف أى إى تى 1444 و نيركا9 افضل الاباء قدرة عامة على التالف لصفتى طول السنبله ,محصول الحبوب للنبات الفردى تحت ظروف نقص المياه. فضلا عن ذلك كانت الاصناف أى أر 77- 65600 ونيركا 9افضل الاباء قدرة عامة على التالف لصفه وزن 100 حبه تحت كلتا الظروف. ومن جهة اخرى، كانت الاصناف سخا 109و أى إى تى 1444 افضل الاباء قدرة عامة على التالف لصفة التبكير تحت ظروف نقص المياه, وكانت الأصناف سخا 108 , سخا 109 افضل الاباء قدرة عامة على التالف لصفة طول النبات تحت كلتا الظروف, بينما الصنف أى أر 69116 كان افضل الاباء لصفتى طول الحبه وشكل الحبه تحت كلتا الظروف والصنف أى أر 77- 65600 افضل الاباء قدرة عامة على التالف لصفة محتوى الاميلوز تحت كلتا الظروف.

اضافة الى ذلك فقد اظهر احدي عشر هجينا تحت ظروف نقص المياه قدرة خاصة على التآلف عالية المعنوية وموجبة لصفة محصول النبات الفردى. وكانت الهجن أى أر 69116 × سخا سوبر 300, سخا 109 × أى أر 77- 65600, سخا 108 × أى أر 77- 65600, أى أر 69116 × نيركا9, سخا 108 × سخا 104, سخا 109 × سخا سوبر 300 وسخا 109 × نيركا9 افضل التراكيب الوراثية قدرة خاصة على التالف لمحصول الحبوب ومعظم الصفات المدروسة. كما اظهرت النتائج ان بعض الهجن ذات القدرة الخاصة الفائقة على التالف لصفة محصول الحبوب كانت نتيجة التهجين بين اباء ذات قدرة عامة منخفضة على التالف × اباء ذات قدرة عامة منخفضة على التالف بينما كانت فائقة فى غالبية الهجن التى بها اباء ذات قدرة عامة عالية على التالف × اباء ذات قدرة عامة عالية على التالف و اباء ذات قدرة عامة عالية على التالف × اباء ذات قدرة عامة منخفضة على التالف. كما كانت تقديرات القدرة الخاصة على التالف عالية المعنويه وسالبة لصفة عدد الأيام الى 50% تزهير (التبكير) فى الهجن سخا 104 × أى أر 69116, سخا 108 × سخا سوبر 300 وأى أر 77- 65600 × نيركا9 تحت ظروف نقص المياه. كما اظهر إحدى عشر تركيبا وراثيا افضل قدرة خاصة على التالف لصفة طول النبات تحت ظروف نقص المياه, بينما كان الهجين سخا 108 × سخا سوبر 300 افضل التراكيب الوراثية قدرة خاصة على التالف لصفتى عدد السنابل/ نبات وعدد الحبوب الممتلئه/ السنبله تحت ظروف نقص المياه . بينما كان الهجين أى أر 69116 × نيركا 9 افضل الهجن قدره خاصه على التالف لصفه طول الحبه تحت ظروف نقص المياه. كما اظهر اربعه عشر هجينا قدرة خاصة عالية المعنوية وموجبه لصفة النسبة المئوية للخصوبه تحت ظروف نقص المياه. بينما اظهرعشره هجن قدره خاصه عاليه المعنويه وموجبه لصفه وزن المائه حبه تحت ظروف نقص المياه.

كما اوضحت النتائج ان قوة الهجين كانت عالية المعنويه وموجبه عند قياسها كانحراف عن قيم متوسط الابوين وقيم الاب الافضل فى معظم الهجن الدروسه وكانت أفضل الهجن تحت ظروف نقص المياه سخا 109 × أى أر 77- 65600, أى أر 77- 65600 × نيركا9, سخا 108 × أى أر 77- 65600 , أى أر 69116 × سخا سوبر 300 وسخا 109 × سخا سوبر 300 لصفة محصول النبات الفردى.

مما سبق نستنتج ان الصنف سخا 109 هو افضل الأصناف فى متوسطات القيم بالنسبه للتبكير وطول النبات تحت كلتا الظروف ماعدا طول النبات تحت ظروف نقص المياه فكان الافضل هو الصنف أى أر 77- 65600, بينما كان الصنف أى إى تى 1444 هو الافضل لمعظم صفات المحصول ومكوناته والصنف سخا سوبر 300 لمعظم صفات الجوده وكذلك الهجين أى أر 77- 65600 × سخا سوبر 300 كان الأفضل لمتوسطات القيم لمعظم الصفات المدروسه تحت كلتا الظروف. كما كانت الأصناف سخا سوبر 300 و أى إى تى 1444 هما الأفضل للقدره العامه على التالف لمعظم الصفات المدروسه تحت كلتا الظروف. بينما كان الهجين سخا 108 × سخا سوبر 300 هو افضل الهجن قدره خاصه على التالف وكذلك لقوه الهجين لبعض الصفات الدروسه تحت كلتا الظروف.

الكلمات المفتاحية: الأرز ، الإجهاد المائي ، محصول الحبوب ، القدرة على التآلف و قوة الهجين.