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Genetic behavior of earliness and yield traits of some rice (*Oryza sativa* L.) genotypes



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ABSTRACT

Rice (*Oryza sativa* L.) is a critical staple food crop that provides more than half of the world's population with its primary nutritional source. Breeders and growers of rice would profit from robust genotypes with improved morphological and yield-related characteristics. The aim of this work is to determine the nature and magnitude of gene action on yield quantity and quality, to define the best combinations of earliness and yield characters, develop hybrids that perform better on yield quantity and quality. Three replications were used in the experiment's randomized complete block design (RCBD). During the 2016 season, seven different parents, namely Sakha 101, Sakha 104, Sakha 105, Giza 177, Black rice 1, Black rice 2, and Black rice 3, were crossed using A 7 × 7 half-diallel set analysis without reciprocals to generate 21 F1 crosses. The results indicated that genotype-dependent mean squares were very significant for main characteristics. Significant combining ability SCA variance estimates were more considerable than general combining ability (GCA) variance for all characters except days to 50% flowering. It demonstrated that both additive and non-additive genetic variance played a role in expressing the attributes investigated. The Parents, Black rice, Sakha 105, and Sakha 101, were recognized as the best general combiner for most growth and yield attributes. Sakha105 × Black Rice 1, Sakha105 × Black Rice 2, Sakha101 × Sakha104, Sakha105 × Giza 177, and Sakha101 × Giza 177 all demonstrated non-additive gene activity for the majority of maturity and yield traits. Heterosis breeding would be most efficient for qualities where high performance was determined by dominance and dominance gene effects. The increased yield of crosses results from parents with a diverse genetic background and genetic diversity.

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1. Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops in the universe, providing food for more than half of the world's population (Baroudy et al., 2020). It is also one of the most economi-

cally viable crops, ranking second only to wheat as the world's second-largest cereal crop, with 430 million metric tons produced (Irri, 1996). As a result, breeding efforts must emphasize enhancing its productivity. Reduced plant height, moderate tillering, large and compact panicles, increased kernel number per panicle, increased thousand kernel weight, and improved yield are the most critical rice traits to examine through breeding programs (Paterson et al., 2005). (Smith and Dilday, 2002) 15–30% higher than inbred varieties (Yuan and prospects, 1994; Fujimura et al., 1996), therefore developing a more advantageous cross combination is critical.

Diallel analysis of earliness, grain yield, and related attributes may reveal fascinating information about the kind of gene action involved in the expression of a trait. Additionally, conventional

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breeding between relevant varieties (Hassanien et al, 2020) may be helpful in specific scenarios to understand the type of gene action involved in the expression of a trait. The addition of some natural components with biological activities to rice crops i.e. amino acids (El-Sobki et al., 2021); peptides, nanoparticles (Saad et al., 2021), herbal extracts, and essential oils may enhance gene expression besides breeding. It can identify genotypes that contain the most prevalent and recessive alleles responsible for expressing a particular trait; this enables breeders to ensure efficient selection decisions during segregating generations, enhancing certain traits in breeding populations (Hassanien et al, 2020). In diallel analysis, general combining ability is considered an indicator of additive gene action, whereas specific combining ability is regarded as an indicator of non-additive gene action (Sprague and Tatum, 1942).

Additionally, it provides genetic information and enables breeders to select the most optimal breeding strategies for hybrid variety or cultivar development projects. In the early stages of breeding techniques, additive and non-additive gene action estimations are critical (Dudley and Moll, 1969). Selection would be successful in the early generations when additive gene action is the dominating mode of action. Unless these effects are fixed in the homozygous line, selection will occur in later generations. This study aimed to assess heterosis, combining ability and genetic parameters for earliness and yield traits in rice.

2. Materials and methods

The present study used 21 rice crosses generated by crossing the seven rice genotypes (Sakha101, Sakha104, Sakha105, Giza177, Black rice 1, Black rice 2, and Black rice 3) in a half-diallel fashion (without reciprocals) at the Experimental Farm of the Rice Research and Training Center, Sakha, Kafr El-Sheikh, Egypt, during the 2016 and 2017 seasons.

In the 2016 season, the rice genotypes, as mentioned above, were planted in three sequential planting dates separated by ten days to compensate for the flowering time disparities between these parental genotypes. Thirty-day-old seedlings from each parent were transplanted individually in 10 rows into the permanent field. Each row was five meters long and contained twenty-five hills. A crossing program was conducted at flowering using all possible combinations of the seven parental lines, eliminating reciprocals. Bulk emasculation was performed using a modified version of the (Jodon, 1938) hot-water technique (Butany, 1961).

In the 2017 season, seedlings of 28 rice genotypes (7 parents and 21 F1's) were transplanted 30 days after planting in a randomized complete block design with three replications. Each hill was planted with a single seedling. The Rice research and training center RRTC (2015) recommended package of procedures and plant protection measures were implemented. Observations were made on randomly selected five plants for morphological and yield characteristics as recommended by (Irri, 1996) International Rice Research Institute IRRI (1996), i.e., days to heading, plant height (cm), flag leaf area (cm²), number of panicle per plant, panicle weight (g), panicle length (cm), fertility percentage (%), 1000 grains weight (g), grain yield per plant (g), and harvest index (%).

2.1. Statistical analysis

Griffing's (1956b) Method 2 Model 1 was used to assess the impacts of general (GCA) and specific (SCA) combining ability and variance components. The GCA: SCA ratio was calculated to examine effect performance and quantify additive and non-additive gene effects (Singh and Chaudhary, 1979). Heterotic effects were computed compared to mid-and better-performing parents, as Falconer and Mackay (1996) described. Additionally,

relevant LSD values were generated to assess the importance of heterotic effects using the Wynne et al. (1970) formula. Steel and Torrie's standard analysis of RCBD was used (1980). Additionally, some essential genetic characteristics such as additive variance, non-additive variance, degree of dominance (d), broad-sense heritability (H_{2b}), and narrow-sense heritability (H_{2n}) were evaluated using Falconer and Mackey's method (1996).

3. Results

3.1. Substantial variations in both growth and yield characteristics

The analysis of variance revealed that all genotypes (parents and hybrids) demonstrated substantial variations in both growth and yield characteristics, as indicated in Table 1. The analysis of variance found that the crosses varied significantly from one another, showing that there were acceptable variances between the characters. For all qualities, both general and specific combining ability variants were shown to be very significant, suggesting the importance of additive and non-additive genetic variances in affecting the performance of these ten traits. SCA variance estimates (σ^2 SCA) were more extensive than GCA variance estimates (σ^2 GCA) for all characters except days to heading. The ratio of general combining ability to specific combining ability was employed to denote the genetic diversity involved. Except for days to heading, the variance ratio of GCA to SCA was less than unity, showing a predominance of non-additive genetic variance in the inheritance of these variables.

3.2. Mean performance of parents and their F1 generation

Table 2 summarizes the mean performance of the seven genotypes and their diallel crosses for the traits investigated. The parental varieties demonstrated a wide range of performance. The earliest cultivars in the heading were black rice varieties. Sakha 101 had the shortest plant (87.83 cm), the heaviest panicles weight (4.68 g), the most significant grain yield per plant (47.11 g), the most significant number of panicles per plant, and the highest harvest index, followed by Sakha 104. The crosses Sakha 105 × Black rice 1, Black rice 1 × Black rice 2, and Black rice 2 × Black rice 3 are the earliest crosses. In contrast, the F1 crosses (Sakha 101 × Black rice 1), (Sakha 101 × Black rice 2), (Sakha 101 × Black rice 3), (Sakha 105 × Giza 177), (Sakha 105 × Sakha 104), and (Sakha 104 × Black rice3) were shorter in plant height than their parental means. Black rice 1 × Black rice 2 and Sakha 101 × Giza 177 had the highest flag leaf area values. The number of panicles per plant ranged from (15.67) for Black rice 1 × Black rice 3 to (31) for Giza 177 × Black rice 1. The crosses Sakha 101 × Giza 177, Sakha 101 × Black rice 1, and Sakha 101 × Black rice 2 had the most significant values for panicle length. In terms of grain weight, the cross Sakha 105 × Giza 177 was superior. Regarding grain yield per plant, four crosses, Sakha 101 × Sakha 104, Sakha 105 × Giza 177, and Sakha 101 × Giza 177, were all much greater than their parental averages. Finally, Sakha 101 × Black rice 1 yielded the highest harvest index (54.4 %). The increased yield of crosses results from parents with a diverse genetic base and genetic diversity.

3.3. General combining ability effect (GCA)

The GCA values for the parents are listed in Table 3. Days to 50% heading, Black rice 1, Black rice 2, Black rice 3, and Sakha 105 were the finest general earliness combiners. Additionally, the results indicated that Sakha 101, followed by Black rice 3, were the greatest general combiners for short stature among the examined par-

Table 1
Analysis of variance for the ordinary and combining ability for growth, yield, and components in the 2017 season.

S.O.V.	DF	Days to 50% heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of Panicles / plant	Panicle length (cm)	Panicle weight (g)	Seed set %	1000 grains weight (g)	Grain yield /plant (g)	Harvest index (%)
Reps	2	0.72 ns	0.92 ns	1.29	1.30 ns	0.15 ns	0.00 ns	0.40 ns	0.00 ns	0.75 ns	2.03 ns
Genotypes(G)	27	56.40**	41.44**	87.18	73.44**	8.09**	1.08**	99.58**	5.83**	227.34**	66.40 **
Parents	6	137.77**	78.16**	28.30**	52.05**	14.56**	2.21**	8.27**	13.10**	287.00**	153.87**
Crosses	20	34.51**	31.37**	101.54**	46.85**	4.53**	0.58**	113.12**	3.23**	119.08**	29.92**
P v. Cr	1	5.93**	22.56**	153.41**	733.73**	40.50**	4.26**	376.62**	14.23**	2034.69**	271.21**
GCA	6	75.92**	28.50**	41.56**	40.63**	8.10**	1.07**	6.31**	5.47**	208.62**	62.82**
SCA	21	2.48**	9.62**	25.49**	19.87**	1.15**	0.15**	40.87**	0.94**	37.83**	10.51**
Error	54	0.28	1.33	0.99	0.63	0.13	0.00	0.51	0.08	0.44	0.48
K2GCA/K2SCA		3.82	0.340	0.182	0.228	0.806	0.778	0.017	0.659	0.615	0.673

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

ents. Regarding flag leaf area, Black rice 2 and Black rice 1 have the largest significant GCA (2.12 and 1.91, respectively); this indicates that these two parents were superior general combiners. Sakha 104 and G177, followed by Sakha 101, had the most outstanding significant positive GCA values for the total number of panicles per plant (2.77, 1.66 and 1.14, respectively).

In contrast, Black 1 and Black 3 parents had the highest significant negative GCA values for this trait (-2.29 and -2.77, respectively). These findings suggest that two parents, Giza 177 and Sakha 104, are effective general combiners for increasing the total number of panicles per plant. These parents could be utilized in breeding programs to improve this feature. Sakha 101, Sakha 104, and Sakha 105 all had highly significant and positive estimations of general combining ability for panicle length, indicating that these two parents were the top combiners for improving this characteristic. Additionally, all parents investigated except Black 1, Black 2, and Black 3 were good combiners for fertility %. Although Sakha 101 and Sakha 105 were the best overall combiners for this feature.

In the 1000 grain weight situation, parents Short Sakha 104, Giza 177, and Sakha 105 demonstrated the most excellent significant GCA effect (0.793, 0.939, and 0.720, respectively), demonstrating that these cultivars are effective general combiners for increasing trait value. Sakha 101's most significant GCA effect on grain yield per plant was also its greatest GCA influence on panicle weight and harvest index. By and large, Sakha 101 was the best of

Table 2
Mean performance of the seven parents and their F1 generation of 7*7 diallel cross for growth and yield characters in the 2017 season.

Genotypes	Days to 50% heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of panicles per plant	Panicle length (cm)	Panicle weight (g)	Seed set %	1000 grains weight (g)	Grain yield per plant (g)	Harvest index (%)
Parents:										
Sakha 101 (P1)	108.33	87.83	29.50	24.00	24.38	4.68	93.48	24.38	47.11	50.94
Sakha 105 (P2)	95.00	96.33	27.60	21.67	22.50	3.62	93.56	27.33	43.90	50.23
Giza 177 (P3)	95.00	98.67	28.03	19.33	21.80	3.60	92.39	27.13	42.33	49.79
Sakha 104 (P4)	101.00	104.00	26.80	22.33	22.55	4.20	90.35	27.40	45.40	49.40
Black rice 1 (P5)	90.00	101.00	29.90	13.67	21.80	2.26	95.12	23.57	23.48	33.43
Black rice 2 (P6)	90.00	96.67	33.07	15.67	18.50	2.95	91.06	24.67	27.13	38.07
Black rice 3 (P7)	91.00	95.33	35.20	14.33	18.41	2.66	91.5	24.30	30.29	40.31
Mean for parents	95.76	97.11	30.01	18.71	21.42	3.42	92.49	25.54	37.09	44.59
Crosses:										
Sakha101 × Sakha105	98.00	100.98	32.76	27.00	23.93	4.42	94.21	27.60	53.21	51.03
Sakha101 × Giza 177	99.00	99.17	42.75	26.00	25.40	4.34	94.17	27.53	57.91	51.98
Sakha101 × Sakha 104	104.00	102.50	31.27	27.00	24.43	4.87	94.75	28.20	63.42	50.90
Sakha101x Black rice 1	101.00	92.50	38.25	23.00	25.23	4.71	83.20	25.33	48.27	54.40
Sakha101x Black rice 2	100.00	92.07	37.39	25.00	24.93	4.63	84.57	26.47	46.35	50.66
Sakha101x Black rice 3	98.00	95.47	33.49	25.00	23.83	4.25	81.87	26.09	47.89	52.64
Sakha105 × Giza 177	97.00	96.67	30.80	25.67	23.42	3.73	94.80	29.43	57.44	52.47
Sakha105 × Sakha 104	98.67	96.70	34.20	27.33	23.63	3.98	94.43	28.22	53.92	52.22
Sakha105 × Black rice 1	90.00	101.70	34.20	24.33	22.70	3.88	82.63	26.62	47.77	49.79
Sakha105 × Black rice 2	93.00	101.45	31.20	26.00	22.07	3.74	84.50	26.33	45.77	46.66
Sakha105 × Black rice 3	93.00	99.60	29.54	24.00	21.56	3.52	82.70	27.87	46.90	48.41
Giza 177 × Sakha 104	98.33	102.83	28.30	30.00	22.80	3.78	94.62	28.59	51.18	48.79
Giza 177 × Black rice 1	96.00	100.40	26.70	31.00	21.56	3.74	81.90	27.78	46.97	48.45
Giza 177 × Black rice 2	94.00	98.33	29.50	28.33	22.70	3.88	80.00	27.75	46.14	48.15
Giza 177 × Black rice 3	96.00	96.87	26.20	26.00	21.93	3.71	82.37	27.35	47.57	47.72
Sakha 104 × Black rice1	96.00	102.77	28.80	26.67	22.98	3.62	79.33	27.65	47.57	46.81
Sakha 104 × Black rice 2	97.00	98.90	28.25	30.00	22.67	3.92	84.37	27.33	46.48	43.37
Sakha 104 × Black rice 3	97.33	96.30	25.65	30.00	21.60	3.13	82.93	26.60	46.67	45.20
Black rice 1 × Black rice 2	92.23	98.70	47.16	22.00	22.47	3.87	94.28	26.41	34.86	44.55
Black rice 1 × Black rice 3	92.77	99.20	41.13	15.67	21.80	3.58	94.60	25.43	41.87	44.74
Black rice 2 × Black rice 3	92.53	97.37	38.30	16.33	21.83	3.56	93.67	26.53	39.49	44.69
Mean for crosses	96.37	98.59	33.13	25.53	23.02	3.94	87.61	27.19	48.45	48.74
L.S.D 0.05	1.490	1.043	1.628	1.300	0.591	0.110	1.167	0.465	1.086	1.131
0.01	1.985	1.390	2.168	1.732	0.786	0.146	1.554	0.619	1.447	1.506

Table 3
Estimates of general combining ability (GCA) effects for growth and yield characters in the 2017 season.

Parents:	Days to heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of panicles per plant	Panicle length (cm)	Panicle weight (g)	Seed set %	1000 grains weight (g)	Grain yield per plant (g)	Harvest index (%)
Sakha 101 (P1)	5.209**	-3.050**	1.786**	1.148**	1.728**	0.674**	1.004**	-0.475**	5.149**	3.538**
Sakha 105 (P2)	-1.123**	0.441**	-1.216**	0.778**	0.148*	-0.001	1.079**	0.720**	3.096**	2.153**
Giza 177 (P3)	0.063	0.644**	-2.059**	1.667**	0.048	-0.017	0.216	0.939**	2.992**	1.722**
Sakha 104 (P4)	2.618**	2.466**	-3.197**	2.778**	0.248**	0.131**	0.049	0.793**	3.900**	0.491**
Black rice 1(P5)	-2.419**	1.274**	1.911**	-2.296**	-0.071	-0.290**	-0.501**	-0.878**	-5.631**	-2.895**
Black 2 rice (P6)	-2.334**	-0.627**	2.122**	-1.296**	-0.812**	-0.114**	-0.800**	-0.456**	-5.732**	-3.049**
Black 3 rice (P7)	-2.015**	-1.148**	0.652**	-2.778**	-1.289**	-0.383**	-1.047**	-0.643**	-3.775**	-1.959**
L.S.D 0.05	0.325	0.228	0.355	0.284	0.129	0.024	0.255	0.101	0.237	0.247
0.01	0.433	0.303	0.473	0.378	0.172	0.032	0.339	0.135	0.316	0.329

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

all the qualities investigated since they exhibited significant and desirable GCA effects for most of the attributes studied.

3.4. Specific combining ability effect (SCA):

The cross's specific combining ability (SCA) is the estimation and comprehension of the effect of non-additive gene action on a trait. A trait's non-additive gene action serves as a marker for selecting a hybrid combination. As a result, a highly significant SCA effect is desirable for a hybrid breeding program to be successful. The effects of SCA are estimated in Table 4. The results indicated that four of the twenty-one hybrid combinations, namely Sakha 101 × Sakha105, Sakha 101 × G177, Sakha 101 × Black rice 3, and Sakha 105 × Black rice 1, possessed significant and negative SCA effects on growth duration. While the cross combination Sakha 105 × Black rice 1 possessed significant and adverse SCA effects on growth duration, which was desirable for early maturity hybrids (-2.68). Similarly, seven crosses, Sakha 101 × Black 1, Sakha 101 × Black 2, Sakha 105 × Giza 177, Sakha 105 × Sakha 104, Sakha 104 × Black rice 3, Sakha 104 × Black rice 2, and Sakha 104 × Black rice 3, possessed considerable and negative SCA, which

was beneficial for plant height shortening (-3.94,-2.48,-2.64,-4.43,-0.885,-1.165 and -3.244 respectively). The crosses Sakha101 × Giza 177 and Black 1 × Black rice 2 were the most specific combinations for the flag leaf area. The crosses Giza 177 × Black 1 and Sakha 104 × Black 3 produced the highest significant and positive values of the SCA effect in terms of panicles per plant.

The combinations Sakha 101 × Black rice 1 (0.510) had the most considerable significant and positive SCA effect on Panicle weight, followed by Black rice 1 × Black rice 2. (0.461). At 1000 grains weight, significant and positive SCA effects were reported in thirteen crosses, ranging from (0.273) to (1.1), while the cross Sakha101 × Sakha 104 producing the highest SCA impact. The crosses Black rice 1 × Black rice 2, Black rice 1 × Black rice 3, and Black rice 2 × Black rice 3 all had highly significant and positive estimates of SCA for fertility (%) and grain yield per plant. Nineteen of the twenty-one crosses had highly significant positive GCA effects, with Sakha 101 × Sakha 104 the highest. While twelve of twenty-one crossings had substantial positive SCA impacts on the harvest index, the best two were Sakha 101 × Black rice 1 and Sakha 101 × Black rice 3.

Table 4
Estimates of Specific combining ability (SCA) effects for growth and yield characters in the 2017 season.

Crosses	Days to heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of panicles per plant	Panicle Length (cm)	Panicle weight (g)	Seed set %	1000 grains weight (g)	Grain yield /plant (g)	Harvest index (%)
Sakha101 × Sakha105	-2.308**	5.367**	-0.165	1.241**	-0.565**	-0.069**	3.295**	0.572**	-0.655**	-2.371**
Sakha101 × Giza 177	-2.493**	3.348**	10.668	-0.648	1.002**	-0.137	4.111**	0.287*	4.152**	-0.983**
Sakha101 × Sakha 104	-0.049	4.859**	0.326	-0.759*	-0.165	0.253**	4.861**	1.100**	8.757**	-0.839**
Sakha101x Black rice 1	1.988**	-3.949**	2.198	0.315	0.954**	0.510**	-6.139**	-0.099	3.138**	6.051**
Sakha101x Black rice 2	0.903*	-2.481**	1.127	1.315**	1.396**	0.257**	-4.474**	0.622**	1.320**	2.465**
Sakha101x Black rice 3	-1.415**	1.439**	-1.303	2.796**	0.773**	0.147**	-6.926**	0.423**	0.899**	3.355**
Sakha105 × Giza 177	1.839**	-2.644**	1.719	-0.611	0.599**	-0.065**	4.669**	0.992**	5.732**	0.889**
Sakha105 × Sakha 104	0.950*	-4.433**	6.257	-0.056	0.615**	0.031	4.470**	-0.078	1.304**	1.866**
Sakha105 × Black rice 1	-2.680**	1.760**	1.149	2.019**	0.000	0.355**	-6.784**	-0.004	4.685**	2.822**
Sakha105 × Black rice 2	0.235	3.414**	-2.062	2.685**	0.109	0.036	-4.615**	-0.720**	2.787**	-0.154
Sakha105 × Black rice 3	-0.084	2.082**	-2.252	2.167**	0.079	0.092**	-6.167**	1.015**	1.963**	0.513
Giza 177 × Sakha 104	-0.569	1.498**	1.201	1.722**	-0.118	-0.147**	5.516**	0.080	-1.329**	-1.129**
Giza 177 × Black rice 1	2.135**	0.257	-5.507	7.796**	-1.043**	0.230**	-6.651**	0.934**	3.988**	1.921**
Giza 177 × Black rice 2	0.050	0.091	-2.918	4.130**	0.842**	0.191**	-8.252**	0.485**	3.260**	1.774**
Giza 177 × Black rice 3	1.731**	-0.855**	-4.748	3.278**	0.553**	0.294**	-5.638**	0.273*	2.733**	0.254
Sakha 104 × Black rice1	-0.421	0.801**	-2.269	2.352**	0.184	-0.037	-9.051**	0.954**	3.681**	1.508**
Sakha 104 × Black rice 2	0.494	-1.165**	-3.031	4.685**	0.609**	0.087**	-3.718**	0.211	2.696**	-1.782**
Sakha 104 × Black rice 3	0.509	-3.244**	-4.161	6.167**	0.019	-0.430**	-4.911**	-0.331*	0.925**	-1.039**
Black rice1 × Black rice 2	0.765	-0.172	10.772	1.759**	0.728**	0.461**	6.741**	0.965**	0.603*	2.785**
Black rice1 × Black rice 3	0.979*	0.849**	6.212	-3.093**	0.538**	0.434**	7.312**	0.167	5.656**	1.885**
Black rice 2 × Black rice 3	0.661	0.923**	3.171	-3.426**	1.313**	0.238**	6.678**	0.844**	3.378**	1.995**
LSD 0.05	0.805	0.564	0.879	0.702	0.319	0.059	0.630	0.251	0.587	0.611
0.01	1.072	0.750	1.171	0.935	0.425	0.079	0.839	0.334	0.781	0.813

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

3.5. Estimates of heterosis as a deviation from mid parents

The estimates of heterosis between mid-parents for several attributes are shown in (Table 5). Positive heterotic effects are desirable for all attributes except earliness and plant height. In comparison, the negative heterotic effects are desired. For days to 50% heading, the crosses Sakha 101 × Sakha 105, Sakha 101 × Giza 177, Sakha 101 × Black rice 3, and Sakha 105 × Black rice 1 demonstrated the significant negative heterosis (−3.60, −2.62, −1.67 and −2.70 % respectively). The considerable and negative heterosis for the number of days to 50% heading showed the possibility of utilizing heterosis for earliness. For plant height, the majority of the crosses examined exhibited significant mid-parents heterosis in a desirable negative direction; however, the crosses Sakha 101 × Black rice 1, Sakha105 × Sakha 104, Sakha 104 × Black rice 2, and Sakha 104 × Black rice 3 exhibited the greatest negative heterosis for plant height (−2.03, −3.46, −1.43 and −3.38 respectively). For flag leaf area, highly positive and significant heterosis over mid-parents (49.79 and 48.62 %, respectively) was reported in two crosses, Black rice 1 × Black rice 2 and Sakha 101 × G177. The highest significant mid-parents-based heterosis was estimated for Giza 177 × Black rice 1 in terms of the number of panicles per plant (87.88 %).

Furthermore, except for the cross G177 × Black rice1, all examined crosses had extremely significant and positive estimates of mid-parents-based heterosis for panicle length; the cross Black rice 2 × Black rice 3 had the highest estimate heterosis (18.32 %). When tested as a deviation from mid-parents heterosis, the cross Black rice 1 × Black rice 2 displayed the highest positive heterosis for panicle weight (48.59 %). For 1000 grains weight of rice, the cross Giza 177 × Black rice 1 exhibited the greatest heterosis values as a deviation from the mid parents (9.57). The highest positive significant heterosis was estimated for Black rice 1 × Black rice 3 in grain yield (55.73 %). Sakha 101 × Black 1 has the highest positive significant heterosis for mid-parents in Harvest index (%) (28.95 %).

3.6. Genetic parameters

The calculated values of genetic components, heritability in wide and narrow senses, and the relative importance of GCA %

and SCA % for all growth and yield and its components for all traits under study are provided in Table 6. The results indicate that for all attributes except days to heading, the estimates of the dominance variance (σ^2D) and the relative importance of SCA % were greater than the estimates of the additive variance (σ^2A) and relative importance of GCA %. These findings revealed that the action of dominant genes substantially determined these traits.

4. Discussion

To evaluate the ability of growth and yield traits to combine to find optimal genotypes for the hybridization program's parents. Montazeri et al. (2014), Waza et al. (2015), and Priyanka et al. (2014) have also reported the existence of both additive and non-additive (dominance) types of gene action for many growths and yield characteristics. Abo-Yousef et al. (2017), Saravanan et al. (2006), Kumar et al. (2004), and Thakare et al. (2013), on the other hand, revealed a smaller value of σ^2A than σ^2D for all features tested, showing the preponderance of non-additive gene action. Singh et al. (2005), Venkatesan et al. (2007), Dalvi and Patel (2009), Saidaiah et al. (2010), and Hasan et al. (2013) have all reported a predominance of non-additive gene action for grain yield and its components; consequently, selection procedures in a late or advanced generation will be critical for improving these traits. General combining ability (GCA) and specific ability (SCA) effects were assessed for growth and yield characters.

Since high GCA effects are associated with additive and additive X additive components of genetic variation, parents with higher positive significant GCA effects are considered better combiners. In contrast, those with negative GCA effects are generally considered poor combiners, except for earliness and short stature. Abd El-Aty (2001) obtained comparable results. Estimates of combining ability effects assist in selecting ideal parents and crossings and developing appropriate breeding processes for further enhancement of various traits, Sarkar et al., (2002) and Waza et al., 2003. (2015). The addition of some natural components with biological activities to rice crops i.e. amino acids (El-Sobki et al., 2021); peptides, biological nanoparticles (Saad et al., 2021), herbal extracts, and essential oils may enhance gene expression besides

Table 5

Heterosis estimates as a deviation from mid parents of the twenty-one rice crosses for growth and yield characters in the 2017 season.

Crosses	Days to heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of Panicles per plant	Panicle length (cm)	Panicle weight (g)	Seed set %	1000 grains weight (g)	Grain yield/plant (g)	Harvest index (%)
Sakha101 × Sakha105	−3.60**	9.67**	14.75**	18.25**	2.10**	6.42**	0.74	6.74**	16.92**	0.87
Sakha101 × Giza 177	−2.62**	6.34**	48.62**	20.00**	10.00**	4.71**	1.33*	6.90**	29.49**	3.21**
Sakha101 × Sakha 104	−0.63	6.86**	11.08**	16.55**	4.13**	9.72**	3.08**	8.92**	37.12**	1.45**
Sakha101x Black rice 1	1.85**	−2.03**	28.79**	22.12**	9.28**	35.67**	−11.77**	5.66**	36.77**	28.95**
Sakha101x Black rice 2	0.84	−0.20	19.51**	26.05**	16.29**	21.34**	−8.35**	7.95**	24.87**	13.83**
Sakha101x Black rice 3	−1.67*	4.24**	3.52**	30.43**	11.41**	15.79**	−11.52**	7.18**	23.75**	15.38**
Sakha105 × Giza 177	2.11**	−0.85	10.73**	25.20**	5.72**	3.37**	1.96**	8.08**	33.21**	4.92**
Sakha105 × Sakha 104	0.68	−3.46**	25.74**	24.24**	4.93**	1.66**	2.70**	3.11**	20.75**	4.82**
Sakha105 × Black rice 1	−2.70**	3.07**	18.96**	37.74**	2.48**	31.90**	−12.41**	4.60**	41.78**	19.02**
Sakha105 × Black rice 2	0.54	5.13**	2.85**	39.29**	7.64**	13.63**	−8.46**	1.26**	28.87**	5.68**
Sakha105 × Black rice 3	0.00	3.93**	−5.92**	33.33**	5.41**	12.09**	−10.66**	7.97**	26.43**	6.95**
Giza 177 × Sakha 104	0.34	1.48**	3.23**	44.00**	2.83**	−2.99**	3.55**	4.87**	16.67**	−1.62**
Giza 177 × Black rice 1	3.78**	0.57	−7.82**	87.88**	−1.12**	27.65**	−12.64**	9.57**	42.73**	16.45**
Giza 177 × Black rice 2	1.62*	0.68	−3.44**	61.90**	12.66**	18.31**	−12.78**	7.14**	32.84**	9.62**
Giza 177 × Black rice 3	3.23**	−0.14	−17.13**	54.46**	9.10**	18.47**	−10.45**	6.35**	31.00**	5.94**
Sakha 104 × Black rice1	0.52	0.26	1.59*	48.15**	3.65**	12.07**	−14.45**	8.50**	38.11**	13.03**
Sakha 104 × Black rice 2	1.57*	−1.43**	−5.63**	57.89**	10.44**	9.60**	−6.99**	4.98**	28.17**	−0.83
Sakha 104 × Black rice 3	1.39*	−3.38**	−17.26**	63.64**	5.49**	−8.69**	−8.83**	2.90**	23.31**	0.78
Black rice1 × Black rice 2	2.48**	−0.13	49.79**	50.00**	11.50**	48.59**	1.28*	9.52**	37.75**	24.61**
Black rice1 × Black rice 3	2.50**	1.05*	26.36**	11.90**	8.44**	45.29**	1.35**	6.24**	55.73**	21.34**
Black rice 2 × Black rice 3	2.25**	1.43**	12.20**	8.89**	18.32**	26.65**	2.58**	8.35**	37.54**	14.05**

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

Table 6
Genetic parameters estimated for growth and yield characters in the 2017 season.

Genetic parameters and heritability	Days to heading (day)	Plant height (cm)	Flag leaf area (cm ²)	No. of panicle per plant	Panicle length (cm)	Panicle weight (g)	Seed set%	1000 grains weight (g)	Grain yield per plant (g)	Harvest index (%)
Additive variance (σ^2A)	8.40	3.20	4.58	4.49	0.89	0.11	0.68	0.60	23.16	6.96
Dominant variance (σ^2D)	2.20	8.36	25.16	19.66	1.11	0.15	40.70	0.92	37.68	10.35
Genotypic variance (σ^2G)	10.60	11.56	29.74	24.15	2.00	0.26	41.38	1.52	60.84	17.31
Environmental variance (σ^2E)	1.55	0.89	2.28	1.93	0.28	0.001	0.91	0.081	1.19	2.51
Phenotypic variance (σ^2Ph)	12.15	12.45	32.02	26.08	2.28	0.261	42.29	1.601	62.03	19.82
Broad sense heritability ($h^2b\%$)	87.24	92.85	92.87	92.59	87.71	99.61	97.84	94.94	98.08	87.33
Narrow sense heritability ($h^2n\%$)	69.13	25.70	14.30	17.21	39.03	42.14	1.60	37.47	37.33	35.11
Relative importance of $g c a\%$ *	79.24	27.68	15.40	18.59	44.5	42.30	1.64	39.47	38.06	40.20
Relative importance of $s c a\%$ **	20.75	72.31	84.59	81.40	55.5	57.69	98.35	60.52	60.74	59.79

* Relative importance of $g c a\% = \sigma^2A/\sigma^2G$.

** Relative importance of $s c a\% = \sigma^2D/\sigma^2G$.

breeding. When a breeding program is designed for earliness, GCA and SCA values should be negative to further progress; This showed that these two parents were effective general combiners for earliness, whereas the significant negative GCA effect seen for Black rice 1, 2, and 3 indicated that these two parents were effective general combiners for earliness; This implies that the parents were effective general combiners, but the crosses were effective specific combiners for the desired short stature of the plant (Zhou et al., 2021). Salgotra et al. (2009), Raju et al. (2014), and Waza et al. (2015) all showed similar findings for the GCA and SCA effects. In contrast, dominant genetic variation was the essential factor in the inheritance of these features.

Additionally, some researchers have reported the preponderance of dominant gene action for the major yield traits (Satyanarayana et al., 2000; Kumar et al., 2004; and Mirarab et al., 2011). In terms of heritability estimates, the greatest values determined in a broad sense for all traits varied between (87.24 %) for days to 50% heading and (99.61 %) for panicle weight, showing that the environment slightly influences these traits. On the other hand, the narrow-sense heritability value ranged from 1.60 % for seed set % to 69.13 % for days to heading, demonstrating that non-additive influences play a significant role in regulating these variables. Ahmadikhah (2008) similarly revealed that yield-related traits had a low heritability.

5. Conclusions

The management of yield and yield component traits, such as the number of panicles plant-1, 1000 grain weight, seed setting %, and non-additive genes, revealed that hybridization followed by intensive selection in subsequent generations would be useful for further improving these features. Three parents, namely Black rice 1, Black rice 2, Black rice 3, and Sakha 10, were effective general combiners for earliness and yield and thus might be used in future hybridization operations to introduce earliness and yield into elite rice lines. The F1 hybrids, namely the crosses Sakha 101 × Sakha 105, Sakha 101 × Giza 177, Sakha 101 × Black rice 3, Sakha 105 × Black rice 1, Giza 177 × Black rice 1, and Black rice 1 × Black rice 3, demonstrated the best performance for the traits tested with the desired heterosis over the mid parent. These promising populations could be employed in future breeding programs to generate rice genotypes with earliness and high yield.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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