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Improving Rice Genetic Resources by Conducting Differential Crossings to Create New Hybrids in Both Regular and Water- Deficient Conditions

Cross Mark

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ABSTRACT

Thirty-six genotypes (8 parents and 28 F_1s excluding reciprocals) were grown in a randomized complete block design (RCBD) with three replications at the Rice Research experimental farm, Sakha, Kafr El-Sheikh, Egypt, in 2022 and 2023 seasons. The ratio of GCA and SCA variances was greater than one for most of the studied traits, suggesting that additive and additive x additive types of gene actions were more significant in the inheritance of these traits. The genotypes IET1444, Wab880 SG 33 and Sakha107 were identified as the top general combiners for most of the studied traits. The crossings Wab880 SG 33 × IET1444 and IRAT112 × ARS.105-2-1-1-2 were identified as the most effective cross combinations for various root characteristics in conditions of water deprivation. The crossovers Wab880 SG 33 × IRAT112 and Sakha107 × IRAT112 were identified as the most effective cross combinations for the majority of agro-physiological attributes in conditions of water deficit. Giza177 × IRAT112 and Sakha107 × ARS.105-2-1-1-2 were identified as the most effective cross combinations for yield and its components traits under both situations, these crosses exhibited considerable and high Specific Combining Ability (SCA) in a favorable direction particularly under water stress conditions. Wab880 SG 33 × IRAT112 exhibited significant and favorable estimates of heterosis and heterobeltiosis for root and agro-physiological traits. Sakha107 × ARS.105-2-1-1-2 indicated the same for yield and its components traits in both situations.

***Keywords*:** *rice, genetics resources, Argo-morphological, physiological, yield, general combining ability, specialized combing ability, heterosis, water shortage.*

INTRODUCTION

Rice (*Oryza sativa* L.) is the second most crucial food crop globally and encounters substantial obstacles in production and yield consistency caused by drought stress, especially in rainfed regions. Developing drought-tolerance rice through breeding is challenging due of the complexity of component qualities, screening methods, and environmental interactions. Drought stress, resulting from water scarcity, significantly endangers rice farming, causing significant financial damages, particularly in the face of worldwide climate change. Rice agriculture in Egypt is often affected by dryness, particularly near the ends of canals, emphasizing the urgent requirement to drought-resistant types. Obstacles in developing drought-resistant rice involve sufficient knowledge about the genetic and combining capabilities of drought tolerance traits, as well as gaps in understanding physiological qualities and mechanisms connected to drought. The effectiveness of plant breeding initiatives focused on enhancing drought resistance in rice relies heavily on the careful choice of parents for crossbreeding and a comprehensive comprehension of gene activities affecting important features.

Drought resistance is a plant's ability to produce its highest economic output when water is scarce. This characteristic is complex and depends on a variety of morphological, biochemical, and physiological reactions and how they interact. Drought escape is when a plant can finish its life cycle before soil water deficits occur, while drought avoidance is the ability of plants to keep high tissue water potential even with low soil moisture. Drought tolerance refers to a plant's capacity to survive in conditions of reduced tissue water content, as defined by [(Zhu et al., 2020). Drought's detrimental effects on crop development and yield reduction are determined by elements like the degree, duration, and timing of the stress, as well as the plant's growth stage.

Plant root characteristics are essential for enhancing productivity in times of drought. The growth and productivity of crops in conditions of water scarcity depend on the structure and growth of the rice system. Forecasting rice yield under water scarcity requires taking into account characteristics like root mass (dry weight) and length (Comas et al., 2013). Different reactions are noted in root development traits when exposed to water stress. (Manivannan et al., 2007) Observed that rice root length increased under drought stress because of higher levels of abscisic acid in the roots. Rice varieties with broad and prolific root systems generally show improved adaptation to drought conditions. Deep root systems, coarse roots, extensive branching, and a high root to shoot ratio are crucial characteristics for drought tolerance in rice genotypes. Rice root morpho-physiological characteristics are crucial in influencing shoot development and total grain production in the presence of drought conditions.

Leaf growth is hindered by reduced water potential under drought stress circumstances. Impaired water transport from xylem to other cells, along with lower turgor pressure caused by water scarcity, results in insufficient cell growth and decreased leaf area crops. The changes appear as smaller leaves, withering leaves, decreased leaf area index, and hindered vascular system development (Rollins et al., 2013). Leaf rolling and premature

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senescence are notable traits that can be seen in plants experiencing drought stress. Several leaf characteristics, including larger flag leaf area, leaf area index, and leaf relative water content, have been used to identify drought-resistant genotypes (Hussain et al., 2018, Farooq et al., 2009, Mishra and Panda, 2017, Hassan, 2017). Photosynthesis, a vital metabolic activity essential for crop development and yield, is negatively impacted by water scarcity or drought conditions. Chlorophyll levels in leaves and the presence of water in the root zones are important elements that lead to decreased production in vulnerable rice varieties when exposed to drought. Water scarcity negatively affects different physiological traits of rice, resulting in reductions in relative water content and chlorophyll content (Panda et al., 2021, Zhu et al., 2020, Mishra et al., 2018).

During drought stress, different physiological processes are negatively impacted, leading plants to adjust to harsh conditions. Optimize physiological factors and processes are essential before implementing breeding programs to improve production in dry situations. Drought affects many growth phases of plants, resulting in decreased plant height, panicle length, number of panicles per plant, and grain fullness, while also increasing sterility percentage. Collectively, these factors greatly reduce grain production. This emphasizes the importance of understanding and dealing with the physiological characteristics of plants in drought conditions to develop methods for reducing negative impacts and increasing productivity in difficult environmental conditions (Hassan et al., 2013, Hassan, 2017, Hassan, 2013, Hassan et al., 2016, Hassan et al., 2023, Abdelaty et al., 2022).

Combining ability is the ability of a parent line in hybrid combinations. It plays a crucial role in choosing the best parents for hybrid combinations and comprehending the characteristics of genetic diversity. This technique is effective for evaluating the gene action related to quantitative traits (Baker, 1978). General combining ability (GCA) is defined as the average performance of a line within hybrid combinations, while specific combining ability (SCA) occurs when certain hybrid combinations perform either better or worse than expected based on the average performance of the parent inbred lines included. GCA in random people is related to additive gene effects, while SCA is connected to dominance and epistatic gene effects. GCA effects represent the heritable portion of genetic diversity that can be improved and are essential for creating superior genotypes. SCA is an inherent aspect of genetic diversity that cannot be altered and is beneficial for understanding hybrid performance. The GCA/SCA ratio is examined as a measure of genetic variability in a diallel study. It predicts the sort of genetic influence that regulates certain traits (Quick, 1978, Sayed, 1978). A high ratio indicates that the influence of the additive genes is dominant. A ratio below one indicates that nonadditive genes have a significant influence on determining a specific trait. When the genetic component of variance (GCA) exceeds the environmental component of variance (SCA), the additive genetic effects are more pronounced. Alternatively, non-additive or dominant genetic variant are common. A ratio closer to one indicates more additive genetic effects.

First introduced the concept of "heterosis" in 31. Heterosis, as a commercial concept, refers to the level of hybrid performance compared to the best parent line available (Flintham et al., 1997) stated that heterozygosity is a crucial element of heterosis and can occur when overdominance at a single locus is the primary factor contributing to heterosis. Heterosis is a crucial factor in plant enhancement, and research will persist across various plant species. It has been effectively used despite the fact that its genetics foundation remains mostly undetermined (Hallauer, 1999). This study focuses on the latest advancements in the physiological characteristics, root development, and production of rice in relation to drought tolerance. The current study aimed to assess the combining capacity of physiological, root and yield factors in order to find superior combiners for the development of a population with desirable genes for these qualities in rice.

MATERIALS AND METHODS

Botanical specimens and field traits

In the summer of 2022, a half diallel set was created using eight local and foreign rice genotypes: Sakha 107, Giza 177, Wab 880 SG 33, Sakha 105, IET 1444, Sakha 103, IRAT 112, and ARS. 105- 2- 1- 1- 2 excluding reciprocals in the Experimental Farm of Sakha Rice Research and Training Center farm in Sakha, Kafr El-Sheikh, Egypt. Parents and F1s were assessed in two distinct irrigation experiments, in the first experiment, conducted under normal conditions, irrigation occurred every four days at a rate of 6000 m^3/fed. In the second experiment, conducted under deficit conditions, irrigation took place every twelve days at a rate of 3500 m^3/fed was measured by the counter. The amount of water used was monitored using a water meter. Two studies were conducted using a randomized complete block design (RCBD) with three replications in the summer of 2023. Each genotype, including parents and F1, was planted in four rows in each replicate. The row was five meters long with spacing of 20 × 20 cm between rows and plants, individual seedlings that were 30 days old were transplanted each hill. The prescribed cultural practices were adhered to in both cases. For root measurements, 20 rice plants from each genotype were individually grown in separate plastic bags. The bag had a diameter of 20 cm and a height of 0.5 m with openings on the top and two sides. Bags were positioned in the basin treated with water deficiency. The studied root traits, root length (cm), root volume (cm^3) and root/soot ratio were scored at the maximum tillering stage. To measure these traits, the plastic bag containing the soil and roots was pulled out from the basins. The lowest visible root in the soil after removing the plastic bag was scored as the maximum root length (in centimeters). The body of soil and roots was cut from the basal node of the plant and the soil was washed away carefully to collect roots. The following characteristics were examined and measured: root length (cm), number of roots per plant, root volume (cm^3) and root/soot ratio, days to 50% heading, plant height (cm), chlorophyll content, panicle length (cm), number of panicles per plant, number of filled grains per panicle, sterility percentage, 1000-grain weight and grain yield per plant in grams. These measurements were conducted as per reference (IRRI, 1996).

Relative water content (R.W.C): was calculated using the method described in reference (Barrs and Weatherly, 1962). The flag leaf area(cm^2), measured in square centimeters, was determined during the flowering stage using the manual approach suggested by reference (Yoshida et al., 1962). Leaf rolling and leaf firing were quantified on a scale of 1-9 from plant leaves to assess drought tolerance. The data was collected using visual estimation following the procedure outlined by reference (De Datta et al., 1988).

Combining ability was assessed following the methodology outlined in reference (Griffing, 1956).

Significance Tests were conducted for both general and specific combining abilities using mean squares. The abbreviation "M.S." is often used to refer to a Master of Science degree. Exempli gratia and Master of Science. Master of Science (M.S.) Referred to as technique 2, model 1 in reference (Griffing, 1956). Heterosis was evaluated as the difference between the F1 mean value and the mean values of the mid-parent and better-parent, as recommended by references (Matzinger et al., 1962) and (Fonsecca and Patterson, 1968). The formulas used to calculate mid-parent (MP) and better-parent (BP) heterosis for all the traits are as follows:

$$\textbf{Heterosis over the mid} - \textbf{parent} = \frac{\textbf{F1} - \textbf{MP}}{\textbf{MP}} x100$$

$$\textbf{S.E.}(\textbf{F1} - \textbf{MP}) = \sqrt{\textbf{3Me} / \textbf{2r}}$$

$$\textbf{Heterosis over the better} - \textbf{parent} = \frac{\textbf{F1} - \textbf{BP}}{\textbf{BP}} x100$$

$$\textbf{S.E.}(\textbf{F1} - \textbf{BP}) = \sqrt{\textbf{2Me} / \textbf{r}}$$

Where, Me represents the error mean squares for parents and F1s from an individual environment; MP stands for mean mid-parent value, calculated as the average of P1 and P2; P1 denotes the mean performance of parent one; P2 indicates the mean performance of parent two; BP represents the mean of better-parent value; and r represents the number of replications.

RESULTS AND

Results

Analysis of variance (ANOVA):

The analysis of variance showed that mean squares for genotypes were significant for all rice traits except leaf rolling and leaf firing under normal conditions, and root/shoot ratio under both conditions (Tables 1 and 2). The variance attributed to genotypes was subdivided into parents. Significant differences were seen among parents for all traits except leaf rolling and leaf firing under normal settings, as well as root/shoot ratio under both situations. This suggests abroad genetic diversity among parents for most features. The mean squares for all feature showed significance except leaf rolling and leaf firing under normal conditions, and root/shoot ratio under both conditions. Parental comparisons using analysis of variance showed significant differences in all crosses, except for leaf rolling and leaf firing under normal conditions, and root/shoot ratio under both conditions. In F1 populations, the ratio of general combining ability (GCA) and specific combining ability (SCA) variances was greater than one for all root traits except number of roots per plant under water deficit conditions, and for all agro-physiological traits except no. Of days to 50% heading, plant height, sterility%, no. of panicles/plant, no. of filled grains/panicle and grain yield/plant under both conditions, leaf rolling and leaf firing under normal conditions, and chlorophyll content under water deficit conditions. This indicates that additive gene action predominates over non-additive gene action in these traits under both conditions. Non-additive effects were more noticeable in yield component qualities such as grain yield per plant, suggesting that enhancing their genetics under normal and water deficit situations was a challenging task.

Table 1. Mean average squares of diallel analysis for root and physiological parameters in both normal and water deficiency circumstances.

S.O.V		Reps.	Genotypes	Parents	Crosses	Pa. *vs*. Cr.	Error	GCA	SCA	Error	GCA/SCA
	d.f	2	35	7	27	1	70	7	28	70	---
Root length (cm)	N	0.62	70.03**	90.18**	66.18**	32.89**	1.54	108.8**	1.97*	0.51	5.52
	D	1.78	35.28**	50.36**	29.60**	82.88**	0.98	52.00**	1.70*	0.33	3.05
Root volume (cm^3)	N	19.53	230.6**	386.3**	129.2**	1880.0**	9.38	275.6**	27.19**	3.13	1.01
	D	16	170.5**	310.2**	117.9**	613.3**	8.99	219.3**	16.23**	3.0	1.35
No. of roots/plant	N	12.84	5122.0**	11537**	3479.0**	4595.0**	10.7	7639**	224.5**	3.57	3.40
	D	13.45	663.8**	660.6**	586.0**	2787.0**	8.99	723.9**	95.64**	3.0	0.75
Root/shoot ratio	N	0.002	0.1	0.19	0.08	0.02	0.001	0.16	0.001	0.0005	16.0
	D	0.003	0.08	0.13	0.06	0.02	0.001	0.12	0.001	0.0005	12.0
Leaf rolling	N	1.03	0.73	0.86	0.68	1.17	0.22	0.69	0.13	0.07	0.53
	D	2.03	3.91**	5.09**	3.26**	13.1**	0.2	5.54**	0.25	0.07	2.21
Leaf firing	N	1.58	0.58	0.64	0.3	7.71**	0.18	0.21	0.19	0.06	0.11
	D	2.26	1.99**	2.52*	1.88*	9.37**	0.19	2.49*	0.21	0.06	1.18
Flag leaf area (cm^2)	N	10.36	21.57**	354.1**	182.7**	60.80**	4.58	336.3**	4.90**	1.53	6.86
	D	8.21	161.4**	245.2**	144.8**	20.72**	3.9	257.1**	2.97**	1.3	8.65
Relative water content	N	5.02	68.35**	128.0**	54.70**	19.53**	1.53	101.8**	3.03**	0.51	3.35
	D	3.83	93.46**	163.9**	78.64**	0.01	1	137.1**	4.64**	0.33	2.95
Chlorophyll content	N	7.19	21.09**	29.69**	18.05**	43.01**	3.93	28.85**	1.58	1.31	1.82
	D	18.36	20.72**	27.99**	18.81**	21.29**	5.35	22.96**	2.89**	1.78	0.79

*** and ** are statistically significant at the 0.05 and 0.01 probability levels, respectively.**

Table 2. Mean squares of diallel analysis for yield and its related features in both normal and water deficiency conditions.

S.O.V		Reps.	Genotypes	Parents	Crosses	Pa. *vs*. Cr.	Error	GCA	SCA	Error	GCA/SCA
	d.f	2	35	7	27	1	70	7	28	70	---
Days to 50% heading (day)	N	6.86	41.15**	38.10**	43.44**	0.6	5.36	26.33**	10.56**	1.79	0.24
	D	7.11	56.46**	62.36**	55.47**	42.00**	3.91	45.19**	12.23**	1.3	0.36
Plant height (cm)	N	6.7	260.75**	482.86**	182.43**	820.76**	9.99	228.62**	51.49**	3.33	0.44
	D	17.33	453.51**	507.21**	374.89**	2200.3**	9.28	438.75**	79.28**	3.09	0.55
Panicle length (cm)	N	4.46	15.85**	23.28**	13.04**	39.70**	1.34	19.44**	1.74*	0.45	1.11
	D	1.76	18.15**	22.91**	15.45**	57.79**	0.98	24.07**	1.55	0.33	1.55
Sterility %	N	5.19	122.0**	61.4**	120.0**	625.0**	1.4	58.2**	36.6**	0.47	0.15
	D	3.83	258.0**	404.0**	218.0**	332.0**	1.0	191.0**	60.0**	0.33	0.31
No. of panicles/plant	N	1.44	63.09**	12.57**	55.94**	609.52**	1.14	41.41**	15.93**	0.38	0.25
	D	1.78	17.59**	16.23**	8.96**	260.0**	0.98	11.69**	4.41**	0.33	0.26
No. of filled grains/ panicle	N	28.44	1284.56**	1307.09**	1325.12**	31.72**	15.64	495.37**	411.39**	5.21	0.12
	D	2.4	918.53**	1352.04**	806.34**	913.11**	9.6	648.23**	220.66**	3.2	0.29
1000-grain weight (g)	N	3.37	28.73**	60.42**	21.19**	10.33**	1.31	43.08**	1.20	0.44	3.59
	D	1.78	27.51**	58.66**	18.94**	41.01**	0.98	37.99**	1.97*	0.33	1.92
Grain yield/plant (g)	N	21.79	202.73**	120.64**	117.44**	3080.0**	10	135.32**	50.64**	3.33	0.26
	D	14.7	125.43**	164.04**	84.14**	969.92**	8.71	117.71**	22.83**	2.9	0.51

*** and ** are statistically significant at the 0.05 and 0.01 probability levels.**

Analysis of root, physiological and yield characteristics in both normal and water deficiency conditions:

Figures (1 and 2) indicate that Wab880 SG33 exhibited the highest values for root and most of physiological traits in normal and water deficit conditions. Meanwhile, Sakha 107 showed the highest values for root/shoot ratio and all physiological traits except flag leaf area in both conditions. The IET 1444 rice genotype had the greatest root length, volume, number of roots per plant, root-to-shoot ratio, leaf rolling and leaf firing under both conditions. IRAT112 rice genotype exhibited the highest root-to-shoot ratio, leaf rolling, flag leaf area, and relative water content under both circumstances. The results indicate that Wab880 SG33 and IET1444 were the top performing rice genotypes for root and physiological parameters in both normal and water stress conditions. The tallest plants favored by rice breeders under water deficit conditions were found in Wab880 SG33, followed by IRAT 112 and ARS 105-2-1-1-2. Conversely, the shortest and earliest plants were seen in Giza 177 and Sakha 103 rice varieties under both normal and water deficit conditions. Among the rice cultivars, IET 1444 and Wab880 SG33 were the most recent. IRAT 112, IET 1444, and Wab880 SG33 had the longest panicle lengths of 29.0 and 23.5 cm, 23.8 and 21.7 cm, and 23.3 and 21.1 cm, respectively, under normal and water deficiency circumstances. WAB880 SG33 had the lowest sterility percentage, followed by IET 1444 and ARS 105-2-1-1-2 rice genotypes, under both normal and water shortage conditions when compared to other cultivated parents. IET 1444 had the highest number of panicles per plant and number of filled grains per panicle, followed by Giza 177, in both normal and water shortage circumstances. WAB880 SG33 was identified as the rice cultivar with the highest grain weight, weighing 32.6 and 31.0 g/1000 grains in regular and water deficient circumstances, respectively. The average grain yield values of the parents ranged from 17 to 37 g/plant for Giza177 and from 39 to 53 g/plant for IET1444 under normal and water deficiency circumstances, as shown in Figures 3 and 4.

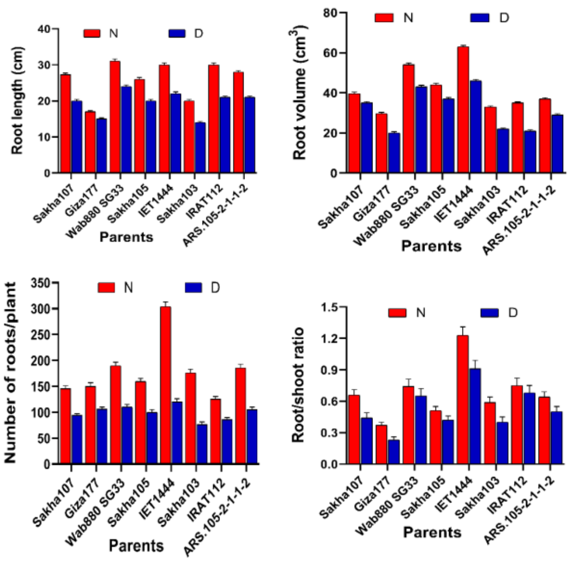

Figure 1. Average parental performance for root characteristics in both normal and water deficiency circumstances.

The average performance of the characters analyzed for both parents and their F1 crosses may be found in Tables 3, 4, 5, and 6. Sakha107 × IET1444 and Wab880 SG 33 × IET1444 showed the longest root length, greatest root volume, numerous roots, and the highest root-to-shoot ratio. IET1444, used as the male parent in both cases, proved to be a beneficial contributor for enhancing root characteristics. Furthermore, in the rice crosses Wab880 SG 33 × IET1444 and Wab880 SG 33 × IRAT112, various leaf traits were observed. The former had low leaf rolling and firing values but high flag leaf area and relative water content values in both conditions. The latter had low leaf firing values but high while the mean values of Wab880 SG 33 × IRAT112, rice cross were low for leaf firing, high for leaf area index and relative water content values. Wab 880 SG 33 was a female parent in both crosses and showed potential as a donor for enhancing leaf traits. Among the two rice crosses, Sakha 107 × Wab 880 SG 33 and Sakha 107 × IRAT 112, which both involved the top general combiner, Sakha107 exhibited a higher Chlorophyll content compared to itself as a parent.

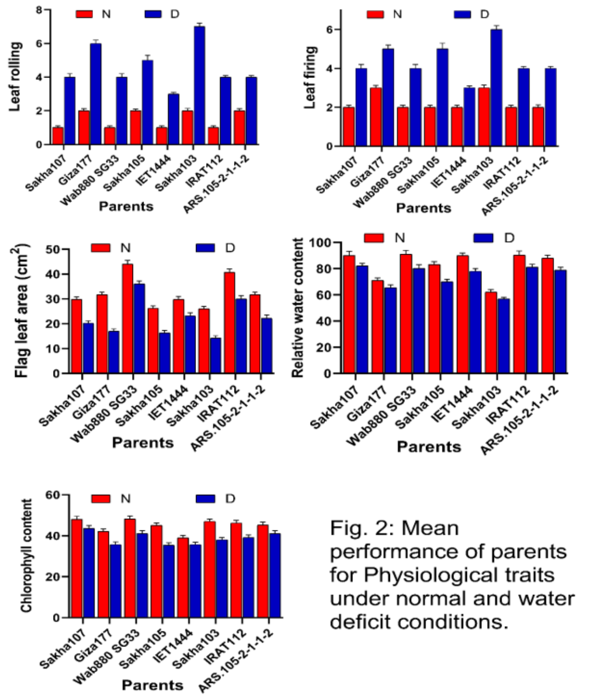

Fig. 2: Mean performance of parents for Physiological traits under normal and water deficit conditions.

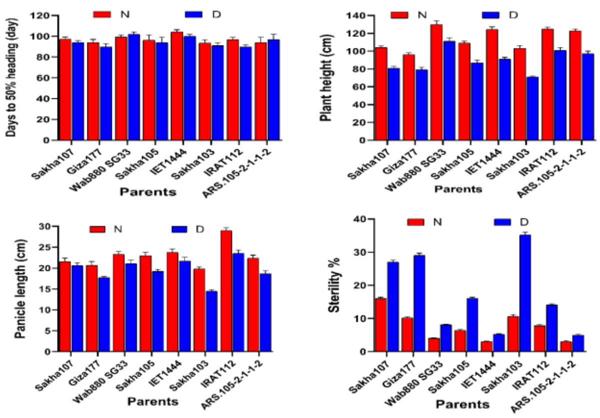

Fig. 3. Average parental performance for vegetative features in regular and water deficient environments.

Most rice crosses matured in less than 100 days, particularly in times of water scarcity, making them ideal for identifying early maturing rice varieties. The F1 mean values of plant height ranged from 80 cm for (Giza177 × IET1444) to 115 cm for (Sakha107 × Wab880 SG 33) rice crosses in situations of water deficit. The plant height of twenty-two rice crosses under water deficit conditions was ranged from 80 to 110.30 cm, meeting the desired criteria set by rice breeders for optimal plant height under water stress to prevent lodging and facilitate mechanical harvesting. The hybrids IET1444 × IRAT112 and IET1444 × ARS.105-2-1-1-2, as well as Sakha105 × IRAT112, exhibited the longest panicles in both environments. The rice crosses Sakha105 × ARS.105-2-1-1-2, Sakha107 × Wab880 SG 33 and Sakha107 × Sakha105 exhibited the lowest estimated levels of sterility % under both conditions. High 1000-grain weight was recorded for the crosses Wab880 SG 33 × Sakha105, Wab880 SG 33 × IRAT112, and Giza177 × Wab880 SG 33 in both circumstances. In two rice crosses (Sakha107 × ARS.105-2-1-1-2 and Sakha105 × ARS.105-2-1-1-2), traits such as grain yield/plant, number of panicles/plant and number of filled grains/panicles were higher than the highest parent in both conditions. The male parent, ARS.105-2-1-1-2, showed higher values for panicle number, filled grains, and grain yield compared to the female parent, ARS.105-2-1-1-2. Over-dominance played a significant role in the inheritance of these traits in these crosses under both conditions as shown in Tables 5 and 6.

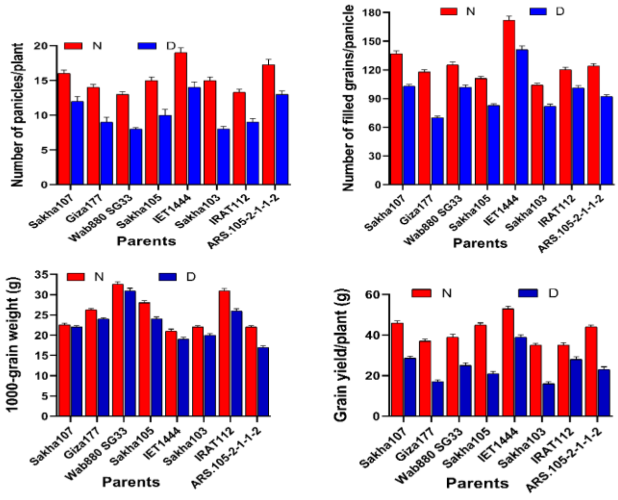

Fig. 4. Average performance of parents for yield characteristics in regular and water deficient environments.

Table 3. Mean performance of crosses in terms of root length, root volume, number of roots per plant, and root/shoot ratio under both normal and water deficiency situations.

Traits	Root length (cm)		Root volume (cm^3)		No. of roots/plant		Root/shoot ratio	
Crosses	N	D	N	D	N	D	N	D
Sakha 107	27.30	20.00	39.60	35.00	145.30	94.00	0.66	0.44
Giza 177	17.00	15.00	29.60	20.00	150.00	106.00	0.37	0.23
Wab880 SG 33	31.00	24.00	54.00	43.00	189.60	110.00	0.74	0.65
Sakha 105	26.00	20.00	44.00	37.00	159.30	100.00	0.51	0.42
IET 1444	30.00	22.00	63.00	46.00	304.00	120.00	1.23	0.91
Sakha 103	20.00	14.00	33.00	22.00	176.00	76.30	0.59	0.40
IRAT 112	30.00	21.00	35.00	21.00	125.30	85.60	0.75	0.68
ARS. 105-2-1-1-2	28.00	21.00	37.00	29.00	185.60	105.00	0.64	0.50
Sakha107 × Giza177	23.00	19.00	40.60	30.00	217.00	120.00	0.49	0.40
Sakha107 × Wab880 SG 33	33.30	24.00	53.60	42.00	203.60	103.00	0.68	0.51
Sakha107 × Sakha 105	29.00	23.00	56.00	41.00	223.60	109.00	0.62	0.45
Sakha107 × IET1444	35.00	27.00	60.00	44.00	284.60	110.00	0.97	0.82
Sakha107 × Sakha103	24.00	19.00	48.00	30.00	215.00	85.30	0.61	0.41
Sakha107 × IRAT112	34.00	25.00	47.00	34.00	191.60	100.00	0.78	0.54
Sakha107 × ARS.105-2-1-1-2	30.00	24.00	50.00	35.60	252.30	106.00	0.64	0.51
Giza177 × Wab880 SG 33	25.00	21.00	46.00	34.00	178.00	97.60	0.59	0.47
Giza177 × Sakha105	22.00	20.00	52.00	39.00	183.00	109.60	0.48	0.32
Giza177 × IET1444	24.00	20.00	56.60	41.00	202.30	130.00	0.89	0.67
Giza177 × Sakha103	18.30	16.00	42.00	29.00	183.00	93.00	0.46	0.35
Giza177 × IRAT112	25.00	22.00	44.00	26.00	168.30	100.00	0.63	0.51
Giza177 × ARS.105-2-1-1-2	23.00	19.00	47.00	29.00	216.00	126.00	0.52	0.39
Wab880 SG 33 × Sakha105	28.00	24.00	60.00	42.00	153.60	94.30	0.68	0.52
Wab880 SG 33 × IET1444	34.00	27.00	63.00	50.00	259.00	130.00	0.96	0.89
Wab880 SG 33 × Sakha103	26.00	22.00	51.00	33.00	199.00	102.30	0.68	0.54
Wab880 SG 33 × IRAT112	36.00	29.00	45.00	35.00	163.60	111.60	0.78	0.70
Wab880 SG 33 × ARS.105-2-1-1-2	33.00	25.00	49.60	41.00	203.60	125.00	0.72	0.68
Sakha 105 × IET1444	29.30	24.00	66.00	52.00	220.60	113.60	0.88	0.75
Sakha 105 × Sakha103	22.00	18.00	51.30	37.30	188.00	89.30	0.61	0.41
Sakha 105 × IRAT112	30.00	25.00	54.00	40.00	148.60	98.00	0.78	0.53
Sakha 105 × ARS.105-2-1-1-2	29.00	23.00	57.30	42.00	203.30	123.00	0.64	0.54
IET1444 × Sakha103	23.00	18.00	52.00	34.00	240.30	112.30	0.87	0.70
IET1444 × IRAT112	35.00	27.00	56.30	37.00	212.30	125.00	1.08	0.84
IET1444 × ARS.105-2-1-1-2	31.00	24.00	61.00	40.00	280.30	133.00	0.98	0.79
Sakha103 × IRAT112	26.00	21.00	44.00	29.00	189.00	97.00	0.73	0.50
Sakha103 × ARS.105-2-1-1-2	24.30	19.00	49.00	38.00	219.60	120.00	0.66	0.48
IRAT112 × ARS.105-2-1-1-2	31.00	24.00	51.00	41.00	185.00	132.30	0.74	0.70
L.S.D: 0.05	2.03	1.61	5.00	4.9	5.34	4.90	0.07	0.07
L.S.D: 0.01	2.70	2.15	6.65	6.51	7.10	6.51	0.09	0.09

Table 4. Mean performance of crosses for leaf rolling, leaf firing, flag leaf area, relative water content, and chlorophyll content in both normal and water deficiency circumstances.

Traits	Leaf rolling		Leaf firing		Flag leaf area (cm^2)		Relative water content		Chlorophyll content	
Crosses	N	D	N	D	N	D	N	D	N	D
Sakha 107	1.00	4.00	2.00	4.00	29.83	20.20	90.16	82.13	48.03	43.56
Giza 177	2.00	6.00	3.00	5.00	31.73	17.00	71.06	65.63	42.10	35.70
Wab880 SG 33	1.00	4.00	2.00	4.00	44.06	36.03	91.03	80.10	48.23	41.16
Sakha 105	2.00	5.00	2.00	5.00	26.23	16.26	83.30	70.03	45.06	35.33
IET 1444	1.00	3.00	2.00	3.00	29.80	23.20	90.03	78.13	39.03	35.73
Sakha 103	2.00	7.00	3.00	6.00	26.00	14.26	62.10	57.03	47.03	38.03
IRAT 112	1.00	4.00	2.00	4.00	40.73	30.03	90.46	81.26	46.23	39.16
ARS. 105-2-1-1-2	2.00	4.00	2.00	4.00	31.73	22.20	88.16	79.06	45.26	41.10
Sakha107 × Giza177	1.33	4.66	1.66	3.66	34.20	18.30	86.66	77.06	46.00	38.53
Sakha107 × Wab880 SG 33	1.33	2.66	1.66	3.66	38.23	30.23	93.13	84.00	51.00	43.00
Sakha107 × Sakha 105	2.33	3.66	1.66	3.66	32.16	18.20	85.06	76.16	46.00	38.23
Sakha107 × IET1444	1.33	2.66	1.00	2.66	32.13	24.13	91.13	80.13	45.00	40.16
Sakha107 × Sakha103	2.33	4.66	1.66	4.66	28.00	16.06	77.26	68.16	50.00	42.13
Sakha107 × IRAT112	1.33	2.66	1.66	2.66	35.80	24.03	93.23	85.06	51.00	43.10
Sakha107 × ARS.105-2-1-1-2	1.33	2.66	1.66	2.66	34.20	23.06	91.26	81.30	47.00	42.90
Giza177 × Wab880 SG 33	2.33	4.66	1.00	3.66	40.04	24.16	85.23	73.10	46.00	37.10
Giza177 × Sakha105	2.33	4.66	1.66	4.66	31.06	19.16	76.53	68.03	44.00	36.26
Giza177 × IET1444	2.33	3.66	1.66	4.00	33.03	20.03	83.43	74.26	43.00	37.53
Giza177 × Sakha103	2.33	5.66	2.66	4.66	27.80	15.26	68.30	63.16	46.00	40.06
Giza177 × IRAT112	2.33	4.66	1.66	3.66	35.10	22.03	84.26	76.13	48.00	40.76
Giza177 × ARS.105-2-1-1-2	2.33	4.66	1.66	3.66	33.23	19.10	79.13	72.26	47.00	42.66
Wab880 SG 33 × Sakha105	2.33	3.66	1.66	3.66	35.20	21.03	88.20	77.00	49.00	42.80
Wab880 SG 33 × IET1444	1.33	2.00	1.66	2.66	39.60	31.06	95.90	83.20	43.00	38.60
Wab880 SG 33 × Sakha103	2.33	4.66	1.00	4.66	32.20	18.26	79.06	69.00	51.00	39.16
Wab880 SG 33 × IRAT112	1.33	2.66	1.66	2.66	46.00	37.13	93.00	85.00	49.00	40.60
Wab880 SG 33 × ARS.105-2-1-1-2	1.33	2.66	1.66	3.66	35.06	28.00	92.56	82.30	47.00	42.10
Sakha 105 × IET1444	1.66	3.66	1.66	3.66	27.26	19.16	88.16	74.10	43.00	38.13
Sakha 105 × Sakha103	1.66	5.66	1.66	4.66	26.76	18.06	72.20	61.00	48.00	37.20
Sakha 105 × IRAT112	1.66	3.66	1.00	3.66	35.80	25.10	87.26	76.06	47.00	37.76
Sakha 105 × ARS.105-2-1-1-2	1.66	3.66	1.66	3.66	30.06	20.16	85.00	75.00	47.00	40.06
IET1444 × Sakha103	1.66	4.66	1.66	3.66	29.00	17.16	79.13	67.30	43.00	34.00
IET1444 × IRAT112	1.00	1.33	1.66	2.66	34.93	26.26	94.00	79.26	44.00	36.66
IET1444 × ARS.105-2-1-1-2	1.00	2.66	1.66	2.66	34.00	25.23	93.26	81.00	43.00	38.20
Sakha103 × IRAT112	1.66	4.66	1.66	4.66	34.23	23.06	70.13	65.00	49.00	41.13
Sakha103 × ARS.105-2-1-1-2	1.66	4.66	1.66	4.66	29.13	17.13	77.50	68.13	48.00	43.00
IRAT112 × ARS.105-2-1-1-2	1.33	2.66	1.66	3.33	34.83	27.10	92.63	84.16	47.00	42.30
L.S.D: 0.05	0.76	0.73	0.70	0.72	2.02	1.63	3.50	3.23	0.76	0.73
L.S.D: 0.01	1.01	0.97	0.93	0.95	2.69	2.17	4.65	4.29	1.01	0.97

Table 5. Mean performance of crosses in terms of days to 50% heading, plant height, panicle length, and sterility percentage, in both normal and water deficiency situations.

Traits	Days to 50% heading (day)		Plant height (cm)		Panicle length (cm)		Sterility %	
Crosses	N	D	N	D	N	D	N	D
Sakha 107	97.3	94	104	81	21.60	20.60	16.00	27.00
Giza 177	94	90	96	79	20.70	17.70	10.20	29.00
Wab880 SG 33	99.3	102	130	111	23.30	21.10	4.00	8.10
Sakha 105	96.3	94	109	87	23.00	19.20	6.40	16.10
IET 1444	104.3	100	124.3	91	23.80	21.70	3.00	5.20
Sakha 103	93.6	91	103.3	71	19.80	14.50	10.70	35.20
IRAT 112	97	90	125	101	29.00	23.50	7.80	14.10
ARS. 105-2-1-1-2	94	97	123	97	22.40	18.70	3.10	5.00
Sakha107 × Giza177	88	90	110	88	22.50	21.40	33.70	45.00
Sakha107 × Wab880 SG 33	97	98	130	115	25.30	23.30	6.20	14.10
Sakha107 × Sakha 105	94	92	128	104	23.10	22.40	7.00	13.10
Sakha107 × IET1444	90	92	106	87	24.30	23.50	22.60	35.20
Sakha107 × Sakha103	97.6	95	110	85	22.20	19.80	17.10	25.00
Sakha107 × IRAT112	101	97	115	91	26.00	23.50	12.00	18.10
Sakha107 × ARS.105-2-1-1-2	97	104	131	110	23.80	22.00	12.30	15.20
Giza177 × Wab880 SG 33	98	97	125	112	23.60	22.80	18.60	22.00
Giza177 × Sakha105	94	98	123.3	113	22.30	20.00	16.20	25.00
Giza177 × IET1444	92.3	91	110	80	24.70	22.70	10.10	15.00
Giza177 × Sakha103	96.3	93	105	85	22.50	17.90	15.30	37.20
Giza177 × IRAT112	99.3	94	117	95	24.30	20.60	13.00	19.30
Giza177 × ARS.105-2-1-1-2	90	91	115	86	20.00	18.20	24.10	30.10
Wab880 SG 33 × Sakha105	97	94	125	114	24.60	22.80	22.90	36.00
Wab880 SG 33 × IET1444	103	105	126	112	25.30	23.90	14.20	18.00
Wab880 SG 33 × Sakha103	100	97	125	100	24.00	17.50	12.20	20.00
Wab880 SG 33 × IRAT112	102	98	130	112	26.40	23.60	10.10	16.10
Wab880 SG 33 × ARS.105-2-1-1-2	100	100	122	107	24.20	22.00	10.10	18.00
Sakha 105 × IET1444	91	94	122.6	102	24.80	21.90	9.20	13.30
Sakha 105 × Sakha103	98.6	96	116.3	92	21.80	16.70	13.10	24.20
Sakha 105 × IRAT112	98.3	93	128.3	110	28.00	23.40	9.20	28.10
Sakha 105 × ARS.105-2-1-1-2	101	107	126	108	25.40	22.50	7.20	9.10
IET1444 × Sakha103	98.3	95	129.6	104	22.70	18.90	10.10	19.20
IET1444 × IRAT112	99	95	120	106	30.10	24.50	8.00	16.00
IET1444 × ARS.105-2-1-1-2	96.6	102	126.3	110	27.60	23.70	16.20	21.00
Sakha103 × IRAT112	98.3	94	127	94	24.90	19.50	9.00	23.30
Sakha103 × ARS.105-2-1-1-2	96.3	99	117.6	85	23.10	17.80	7.20	18.00
IRAT112 × ARS.105-2-1-1-2	96	94	121.6	110	25.60	21.90	9.30	13.00
L.S.D: 0.05	3.78	3.23	5.16	4.97	1.89	1.61	1.93	1.64
L.S.D: 0.01	5.03	4.30	6.86	6.61	2.52	2.15	2.57	2.17

Table 6. Mean performance of crosses in terms of panicles per plant, full grains per panicle, 1000-grain weight, and grain yield per plant under both normal and water shortage situations.

Traits	No. of panicles/plant		No. of filled grains/panicle		1000-grain weight (g)		Grain yield/ plant (g)	
Crosses	N	D	N	D	N	D	N	D
Sakha 107	16.00	12.00	137	103	22.60	22.00	46.00	28.60
Giza 177	14.00	9.00	118	70	26.30	24.00	37.00	17.00
Wab880 SG 33	13.00	8.00	125	102	32.60	31.00	39.00	25.00
Sakha 105	15.00	10.00	111	83	28.00	24.00	45.00	21.00
IET 1444	19.00	14.00	172	141	21.00	19.00	53.00	39.00
Sakha 103	15.00	8.00	104	82	22.00	20.00	35.00	16.00
IRAT 112	13.30	9.00	120	101	31.00	26.00	35.00	28.00
ARS. 105-2-1-1-2	17.30	13.00	124	92	22.00	17.00	44.00	23.00
Sakha107 × Giza177	20.00	15.00	101	77	25.00	23.00	60.30	25.00
Sakha107 × Wab880 SG 33	26.00	16.00	160	122	27.60	24.00	63.30	38.00
Sakha107 × Sakha 105	28.00	13.00	127	112	26.30	25.00	62.00	33.00
Sakha107 × IET1444	25.00	19.00	140	120	26.00	25.00	61.00	43.00
Sakha107 × Sakha103	18.00	12.00	126	103	25.00	23.00	53.00	26.00
Sakha107 × IRAT112	17.00	13.00	145	117	29.00	27.00	57.30	39.00
Sakha107 × ARS.105-2-1-1-2	28.00	18.00	179	131	24.00	22.00	62.00	39.00
Giza177 × Wab880 SG 33	20.00	14.00	142	125	30.00	27.00	54.00	33.00
Giza177 × Sakha105	19.00	12.00	141	99	27.00	24.00	48.00	24.00
Giza177 × IET1444	21.00	15.00	100	74	24.30	22.00	47.00	29.00
Giza177 × Sakha103	16.00	12.00	125	89	24.00	22.00	43.30	20.60
Giza177 × IRAT112	17.00	13.00	131	93	28.60	27.00	49.30	35.00
Giza177 × ARS.105-2-1-1-2	28.00	13.00	83	78	23.00	21.00	53.00	26.00
Wab880 SG 33 × Sakha105	19.00	14.00	132	95	31.00	29.00	61.00	34.00
Wab880 SG 33 × IET1444	21.00	16.00	111	99	29.00	28.00	60.00	39.00
Wab880 SG 33 × Sakha103	17.00	12.00	128	92	28.30	26.00	54.00	31.00
Wab880 SG 33 × IRAT112	20.00	13.00	132	115	34.00	30.00	53.00	36.00
Wab880 SG 33 × ARS.105-2-1-1-2	25.00	17.00	122	103	26.00	25.00	59.00	34.00
Sakha 105 × IET1444	22.00	12.00	91	84	26.00	25.00	60.00	27.00
Sakha 105 × Sakha103	18.00	13.00	109	87	25.00	22.00	54.00	29.00
Sakha 105 × IRAT112	17.00	14.00	126	94	29.00	27.00	56.00	34.00
Sakha 105 × ARS.105-2-1-1-2	30.00	17.00	160	129	24.60	23.00	61.60	39.00
IET1444 × Sakha103	17.30	14.00	149	114	23.00	21.00	42.00	30.00
IET1444 × IRAT112	18.60	15.00	158	121	26.60	25.00	54.00	33.00
IET1444 × ARS.105-2-1-1-2	28.00	16.00	126	122	24.00	22.00	58.00	36.00
Sakha103 × IRAT112	17.60	12.00	110	94	26.00	23.00	44.00	27.00
Sakha103 × ARS.105-2-1-1-2	17.30	14.00	118	97	23.00	21.00	46.60	29.00
IRAT112 × ARS.105-2-1-1-2	18.30	15.00	126	105	25.00	23.00	51.60	33.00
L.S.D: 0.05	1.74	1.61	6.46	5.06	1.87	1.61	5.16	4.82
L.S.D: 0.01	2.32	2.15	8.59	6.73	2.49	2.15	6.87	6.41

Effects of general and specialized combining ability on root, physiological, and yield attributes under normal and water deficiency situations.

The GCA impacts estimations showed that the parent Sakha 107 exhibited strong combining ability for various traits including plant height, No. of panicles/plant, No. of filled grains/panicle, grain yield/plant, relative water content, and chlorophyll content in both circumstances as depicted in Figures 5, 6, 7, and 8. Giza 177 parent may exhibit up to a 50% increase in heading and plant height under both conditions. Furthermore, Wab880-SG33 exhibited good combining abilities for several traits such as sterility %, No. of filled grains/ panicle, 1000-grain weight, root length, flag leaf area, relative water content, and chlorophyll content in both environments. The father Sakha 105 demonstrated effective genetic recombination for the number of root/plant under various situations. In addition, IET1444 was the best general combiner for panicle length, sterility %, No. of panicles/plant, No. of full grains/ panicle, grain yield/plant, all root features, leaf rolling and relative water content under both conditions. Parents with high mean values showed minimal GCA effects, and those with low mean values showed large GCA effects. Both intrinsic and GCA impacts should be considered while selecting parents. The parent IET 1444 was chosen as the top performer due to its high mean values and significant general combining ability (GCA) for all root traits in both circumstances. It also exhibited strong general combining ability for these traits. None of the parents were deemed suitable for all the qualities. Therefore, it would be beneficial to do numerous crossings between the parents IET1444, Wab880-SG33, and Sakha107 in order to select superior genotypes in the segregating generations as shown in table 3. Estimates of general combining ability impacts are a crucial measure of the capacity of parental lines to produce high quality breeding populations. A minimal or negative combining ability effect suggests a limited capacity to pass on its genetic advantages to hybrids. The biggest negative values have minimal consequences, save for sterility percentage, length in days, plant height, leaf rolling and leaf firing features. Furthermore, the IRAT112 rice tester was an effective general combiner for enhancing several traits such as panicle length, sterility percentage, 1000-grain weight, root length, root volume, flag leaf area and relative water content under different situations. Table (3) clearly showed that Sakha107, IET 1444, and Wab880-SG33 were identified as effective general combiners for several features in various situations.

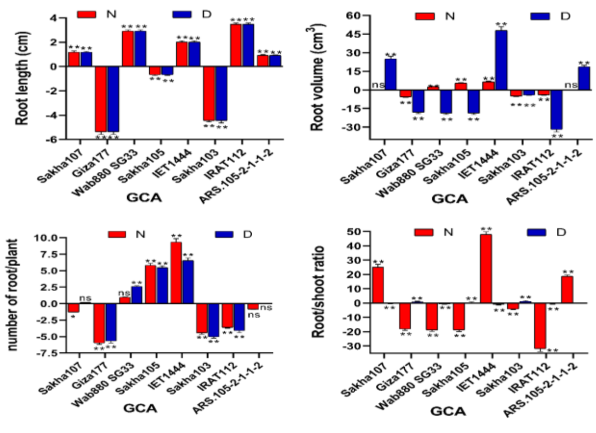

Figure 5. General combining ability effects for root characteristics in normal and water deficiency settings.

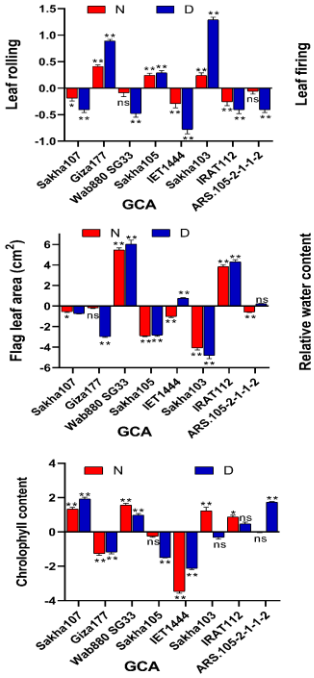

Fig. 6: General combining ability effects for physiological traits under normal and water deficit conditions.

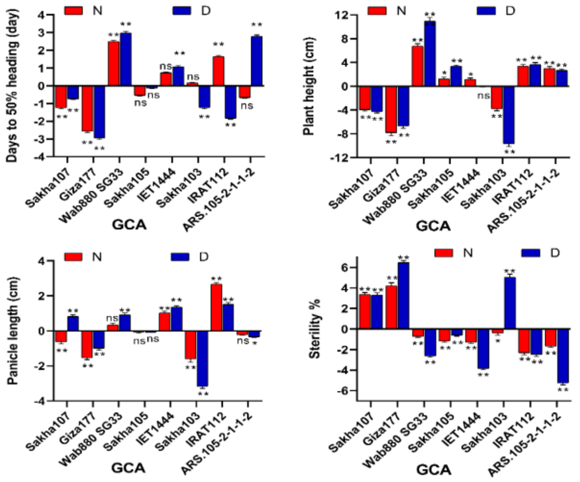

Figure 7. General combining ability effects on vegetative features in both normal and water deficiency circumstances.

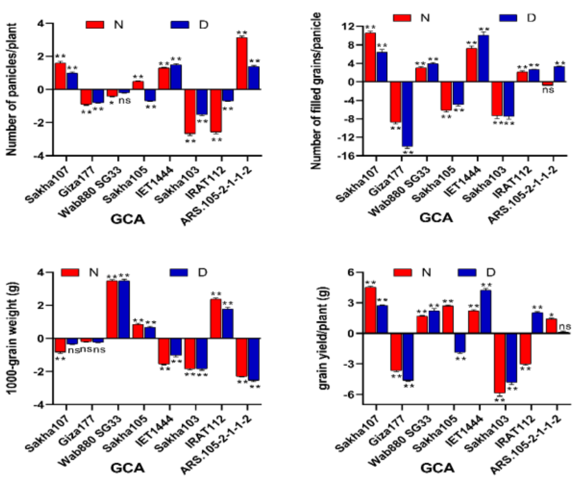

Figure 8. General combining ability effects on yield attributes in normal and water deficiency settings.

Figures 5, 6, 7, and 8 display grain yield per plant, root characteristics, and physiological factors. The parent IET144 was chosen as the best one due to its high mean values for many root and physiological qualities, as well as being a strong general combiner for these traits under both conditions. Similarly, the Sakha 107 rice parent is likewise considered excellent for certain yield components, root characteristics, and physiological qualities under both circumstances.

The high specific combining ability effects were a result of dominance and epistatic interaction between the crossing parents non-fixable genes. The same can serve as an indicator to assess the effectiveness of a specific crossbreeding combination in utilizing heterosis. Table (7, 8, 9, 10) demonstrates that five out of 18 combinations had significant beneficial SCA impacts for many investigated attributes, particularly under water deficit conditions, Sakha 107 × ARS. 105-2-1-1-2, Giza 177 × IET 1444, Wab880 SG 33 × IET 1444, Wab880 SG 33 × IRAT 112 and IRAT 112 × ARS.105-2-1-1-2. Most of these were obtained from previous cross-breeding. The Sakha 107 x ARS.105-2-1-1-2 hybrid showed superior performance in various aspects such as panicles per plant, filled grains per panicle, grain production per plant, root length, and resistance to leaf rolling and firing under conditions of water deficiency. The hybrid Giza 177 × IET 1444 showed the most effective cross combinations for enhancing short plant height, lengthening panicle length, increasing root/shoot ratio, and reducing sterility under water deficit conditions. The cross combination Wab880 SG 33 × IET 1444 was shown to be the most effective for enhancing 1000-grain weight, root length, root numbers and volumes, leaf rolling, and relative water content in circumstances of water deficiency. The cross combination Wab880 SG 33 × IRAT 112 has shown notable positive benefits on specific traits like as 1000-grain weight, root length, leaf firing, flag leaf area, and relative water content. The cross combination IRAT 112 × ARS.105-2-1-1-2 showed strong specific combining ability (SCA) and involved at least one parent with good general combining ability (GCA) for all root characteristics, leaf rolling, and criterion for selection superior hybrids. The crosses Sakha 107 × Wab880 SG 33, Sakha 107 × IRAT112, Sakha 107 × ARS.105-2-1-1-2, Sakha177 × Sakha105, Wab880 SG 33 × Sakha105, Wab880 SG 33 × sakha103, Sakha105 × Sakha103, and Sakha105 × IRAT112 showed positive SCA effects for grain yield per plant in both conditions.

Hybrid vigor and hybrid belt effect on root, physiological, and yield characteristics in both normal and water- deficit environments:

Many crosses showed significant levels of heterosis and heterobeltiosis favoring root, physiological, and yield traits under both normal and water deficit conditions. Table 11 to 18 displays the estimations of heterosis and heterobeltiosis for root, physiological, and yield parameters. Significant positive heterosis and heterobeltiosis were observed in root length for the crosses Sakha 107 × ARS.105-2-1-1-2, Wab 880 SG 33 × IET 1444, and Wab 880 SG 33 × IRAT 112 in rice. High significant positive estimates of heterosis were found in root volume for Sakha 177 × IET 1444, Sakha 103 × ARS.105-2-1-1-2, and IRAT 112 × ARS.105-2-1-1-2 crosses. The highest estimated values of heterosis and heterobeltiosis were observed in specific crosses for root length under both conditions. Conversely, highly significant and negative estimates of heterobeltiosis were obtained in other crosses for root/shoot ratio under normal and water deficit conditions. Table 5 clearly demonstrates that the cross between Wab 880 SG 33 and IET 1444 displayed the highest levels of heterosis and heterobeltiosis (-42.86% and -33.33%, respectively) for leaf rolling when subjected to water deficiency circumstances.

Table 7. Specific combining ability effects for root features in both normal and water deficiency environments.

Traits	Root length (cm)		Root volume (cm^3)		No. of roots/plant		Root/shoot ratio	
Crosses	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-0.37	0.01	-1.79	-0.6	6.86**	15.34**	-0.03	0.04*
Sakha107 × Wab880 SG 33	1.66**	-0.29	4.24**	3.10*	-5.70**	2.77	-0.02	-0.04*
Sakha107 × Sakha 105	0.93	1.01*	1.74	-0.73	14.33**	9.47**	0.01	0.01
Sakha107 × IET1444	1.23*	0.91*	2.21	1.2	8.53**	-5.23**	0.02	0.02
Sakha107 × Sakha103	-0.31	0.61	3.98**	-1.23	-8.97**	-5.70**	-0.01	-0.01
Sakha107 × IRAT112	1.76**	0.21	2.18	1.8	-4.64**	0.64	0.04*	-0.02
Sakha107 × ARS.105-2-1-1-2	0.33	1.71**	2.41	-0.6	5.40**	-9.36**	-0.02	0.01
Giza177 × Wab880 SG 33	-8.11**	-6.19**	-15.0**	-13.03**	-16.27**	-0.93	-0.20**	-0.24**
Giza177 × Sakha105	0.49	1.11*	2.44	3.13*	16.76**	3.44*	0	-0.03
Giza177 × IET1444	-0.21	0.01	3.58*	4.07**	-30.70**	8.07**	0.07*	0.05**
Giza177 × Sakha103	0.59	0.71	2.68	3.63*	2.13	-4.73**	-0.03	0.02
Giza177 × IRAT112	-0.67	0.31	3.88**	-0.33	15.13**	-6.06**	0.02	0.03
Giza177 × ARS.105-2-1-1-2	-0.11	-0.19	4.11**	-1.4	12.16**	3.94**	-0.01	-0.03
Wab880 SG 33 × Sakha105	-1.81**	-0.19	4.48**	-2.17	-11.80**	-7.46**	0.02	-0.02
Wab880 SG 33 × IET1444	1.49*	1.71**	2.94*	4.77**	26.73**	12.50**	-0.04*	-0.03
Wab880 SG 33 × Sakha103	-0.04	1.41**	4.71**	-0.67	18.90**	9.04**	0.01	0.01
Wab880 SG 33 × IRAT112	2.03**	2.01**	-2.09	0.37	11.23**	10.04**	-0.01	0.02
Wab880 SG 33 × ARS.105-2-1-1-2	1.59**	0.51	-0.19	2.3	0.6	7.37**	0.01	0.06**
Sakha 105 × IET1444	0.43	1.01**	1.11	3.93**	-11.57**	-3.13*	-0.03	0.05**
Sakha 105 × Sakha103	-0.44	-0.29	0.21	0.83	7.93**	-3.26*	0.03	0
Sakha 105 × IRAT112	-0.37	0.31	2.08	2.53	-3.74*	-2.93*	0.08**	-0.03
Sakha 105 × ARS.105-2-1-1-2	1.19*	0.81	2.64	0.47	0.3	6.07**	0.02	0.04*
IET1444 × Sakha103	-2.14**	-1.39**	-2.66	-3.57*	-6.54**	4.04**	-0.05**	0.02
IET1444 × IRAT112	1.93**	1.21**	0.88	-1.53	-6.87**	8.37**	0.04*	0.01
IET1444 × ARS.105-2-1-1-2	0.49	0.71	2.78	-2.6	10.50**	0.37	0.02	0.02
Sakha103 × IRAT112	-0.61	-0.09	2.31	2.03	21.96**	4.57**	0.02	-0.04*
Sakha103 × ARS.105-2-1-1-2	0.29	0.41	4.54**	6.97**	2	11.57**	0.03	-0.01
IRAT112 × ARS.105-2-1-1-2	-0.97	-0.99**	5.74**	9.00**	-5.00**	15.57**	-0.01	0.06**
SE(Sij):0.05	1.13	0.9	2.79	2.73	2.98	2.73	0.04	0.04
SE(Sij):0.01	1.51	1.2	3.71	3.63	3.96	3.63	0.05	0.05
SE(Sij-Skj)):0.05	1.82	1.44	4.48	4.38	4.78	4.38	0.06	0.06
SE(Sij-Skj)):0.01	2.42	1.91	5.95	5.82	6.35	5.82	0.08	0.08

*** and ** refer to statistically significant at the 0.05 and 0.01 probability levels, respectively.**

Table 8. Specific combining ability effects for physiological traits in both normal and water deficiency conditions.

Traits	Leaf rolling		Leaf firing		Flag leaf area (cm^2)		Relative water content		Chlorophyll content	
Crosses	N	D	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-0.58**	0.21	-0.23	-0.24	1.62**	-0.42	4.04**	1.92*	-0.38	-1.78
Sakha107 × Wab880 SG 33	-0.08	-0.42*	0.13	0.29	0	2.53**	0.16	1	1.79	0.55
Sakha107 × Sakha 105	0.59**	-0.19	0.07	-0.21	2.30**	-0.65	-1.89	-0.2	-1.38	-1.76
Sakha107 × IET1444	0.12	-0.12	-0.60**	-0.24	0.39	1.68**	-1.43	-1.04	0.83	0.81
Sakha107 × Sakha103	0.59**	-0.19	-0.23	0.19	-0.7	-0.8	0.43	-1.04	1.13	0.98
Sakha107 × IRAT112	0.09	-0.49*	0.07	-0.57**	-0.81	-1.96**	1.63	2.12*	0.49	1.16
Sakha107 × ARS.105-2-1-1-2	-0.11	-0.49*	0	-0.67**	2.01**	1.14*	0.44	-0.55	-0.62	-0.32
Giza177 × Wab880 SG 33	-0.01	1.61**	1.17**	0.99**	-6.86**	-8.47**	-12.66**	-9.28**	-4.52**	-3.66**
Giza177 × Sakha105	-0.01	-0.49*	-0.23	0.16	0.84	2.55**	-1.18	-0.24	-0.79	-0.64
Giza177 × IET1444	0.52*	-0.42*	-0.23	0.46*	0.93	-0.19	0.11	1.18	1.42	1.27
Giza177 × Sakha103	-0.01	-0.49*	0.47*	-0.44*	-1.26*	0.64	0.71	2.05*	-0.28	2
Giza177 × IRAT112	0.49*	0.21	-0.23	-0.21	-1.86**	-1.72**	1.91	1.28	2.08*	1.91
Giza177 × ARS.105-2-1-1-2	0.29	0.21	-0.3	-0.31	0.69	-0.59	-2.45**	-1.5	1.97*	2.53*
Wab880 SG 33 × Sakha105	0.49*	-0.12	0.13	-0.31	-0.68	-4.57**	0.14	0.87	1.38	3.76**
Wab880 SG 33 × IET1444	0.02	-0.72**	0.13	-0.34	1.85**	1.86**	2.23*	2.26*	-1.41	0.2
Wab880 SG 33 × Sakha103	0.49*	-0.12	-0.83**	0.09	-2.51**	-5.35**	1.13	0.03	1.89*	-1.04
Wab880 SG 33 × IRAT112	-0.01	-0.42*	0.13	-0.67**	3.39**	4.39**	0.29	2.29*	0.25	-0.39
Wab880 SG 33×ARS.105-2-1-1-2	-0.21	-0.42*	0.07	0.23	-3.13**	-0.68	0.64	0.69	-0.86	-0.17
Sakha 105 × IET1444	0.02	0.18	0.07	0.16	-2.12**	-1.19*	0.51	-0.2	0.42	2.19*
Sakha 105 × Sakha103	-0.51*	0.11	-0.23	-0.41*	0.42	3.30**	0.27	-1.33	0.72	-0.55
Sakha 105 × IRAT112	-0.01	-0.19	-0.60**	-0.17	1.55**	1.21**	0.57	0	0.08	-0.77
Sakha 105 ×ARS.105-2-1-1-2	-0.21	-0.19	0	-0.27	0.24	0.34	-0.92	0.02	0.98	0.25
IET1444 × Sakha103	0.02	0.18	-0.23	-0.44*	0.78	-1.20*	1.6	0.16	-1.07	-3.11**
IET1444 × IRAT112	-0.14	-0.12	0.07	-0.21	-1.19*	-1.23**	1.7	-1.61	0.29	-1.23
IET1444 × ARS.105-2-1-1-2	-0.34	-0.12	0	-0.31	2.29**	1.80**	1.74	1.21	0.18	-0.98
Sakha103 × IRAT112	-0.01	-0.19	-0.23	0.23	1.15*	1.16*	-6.44**	-3.91**	0.59	1.43
Sakha103 × ARS.105-2-1-1-2	-0.21	-0.19	-0.3	0.13	0.47	-0.71	1.71	0.32	0.48	2.02
IRAT112 × ARS.105-2-1-1-2	-0.04	-0.49*	0	0.03	-1.73**	0.13	2.07*	2.61**	-0.16	0.53
SE(Sij):0.05	0.43	0.41	0.39	0.4	1.13	0.91	1.95	1.8	1.8	2.11
SE(Sij):0.01	0.57	0.54	0.52	0.53	1.5	1.21	2.59	2.39	2.4	2.8
SE(Sij-Skj)):0.05	0.68	0.66	0.62	0.64	1.8	1.46	3.12	2.88	2.9	3.38
SE(Sij-Skj)):0.01	0.9	0.87	0.82	0.85	2.39	1.94	4.14	3.83	3.85	4.49

*** and ** refer to statistically significant at the 0.05 and 0.01 probability levels, respectively.**

Table 9. Specific combining ability effects for Agronomic features under both normal and water deficiency environments.

Traits	Days to 50% heading (day)		Plant height (cm)		Panicle length (cm)		Sterility %	
Crosses	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-5.04**	-2.27*	2.26	0.76	0.57	0.58	13.98**	14.49**
Sakha107 × Wab880 SG 33	-1.11	-0.17	7.69**	9.16**	1.49**	0.57	-8.62**	-7.29**
Sakha107 × Sakha 105	-1.08	-3.07**	11.23**	6.72**	-0.27	0.67	-7.33**	-10.36**
Sakha107 × IET1444	-6.34**	-4.27**	-12.74**	-6.88**	-0.2	0.33	8.41**	14.99**
Sakha107 × Sakha103	1.89	1.03	-1.74	0.72	0.32	1.17*	1.96**	-4.08**
Sakha107 × IRAT112	3.72**	3.63**	-3.91**	-6.61**	-0.13	0.18	-1.16*	-3.46**
Sakha107 × ARS.105-2-1-1-2	2.06	6.03**	12.43**	13.42**	0.62	0.53	-1.56**	-3.61**
Giza177 × Wab880 SG 33	-2.78**	-5.97**	-22.44**	-23.44**	-2.16**	-3.22**	-5.45**	4.41**
Giza177 × Sakha105	0.26	5.13**	10.43**	18.12**	-0.12	0.14	0.99	-1.68**
Giza177 × IET1444	-2.68*	-3.07**	-2.87	-11.48**	1.11*	1.34**	-5.00**	-8.34**
Giza177 × Sakha103	1.89	1.23	-2.87	3.12*	1.57**	1.08*	-0.68	4.89**
Giza177 × IRAT112	3.39**	2.83**	1.96	-0.21	-0.92	-0.91*	-1.0	-5.49**
Giza177 × ARS.105-2-1-1-2	-3.61**	-4.77**	0.29	-8.18**	-2.34**	-1.46**	9.45**	8.08**
Wab880 SG 33 × Sakha105	-1.81	-4.77**	-2.47	1.52	0.23	0.97*	12.63**	18.42**
Wab880 SG 33 × IET1444	2.92**	5.03**	-1.44	2.92*	-0.13	0.63	4.03**	3.77**
Wab880 SG 33 × Sakha103	0.82	-0.67	2.56	0.52	1.22*	-1.23**	1.12*	-3.14**
Wab880 SG 33 × IRAT112	1.32	0.93	0.39	-0.81	-0.63	0.18	1.0	0.41
Wab880 SG 33 × ARS.105-2-1-1-2	1.66	-1.67	-7.27**	-4.78**	0.05	0.43	0.34	5.14**
Sakha 105 × IET1444	-6.04**	-2.87**	0.76	0.49	-0.26	-0.37	-0.44	-3.03**
Sakha 105 × Sakha103	2.19*	1.43	-0.57	0.09	-0.64	-1.03*	2.52**	-1.05*
Sakha 105 × IRAT112	0.36	-0.97	4.26**	5.09**	1.38*	0.98*	0.5	10.40**
Sakha 105 × ARS.105-2-1-1-2	5.02**	8.43**	2.26	3.79**	1.59**	1.93**	-2.09**	-5.84**
IET1444 × Sakha103	0.59	-0.77	12.79**	15.82**	-0.84	-0.27	-0.36	-2.74**
IET1444 × IRAT112	-0.24	-0.17	-4.04**	4.16**	2.34**	0.64	-0.55	1.58**
IET1444 × ARS.105-2-1-1-2	-0.24	2.23*	2.63	9.19**	2.69**	1.69**	7.05**	9.36**
Sakha103 × IRAT112	-0.34	1.13	7.96**	1.76	-0.27	0.18	-0.4	-0.06
Sakha103 × ARS.105-2-1-1-2	-0.01	1.53	-1.04	-6.21**	0.85	0.33	-2.85**	-2.53**
IRAT112 × ARS.105-2-1-1-2	-1.84	-2.87**	-4.21**	5.79**	-0.94	-0.26	1.10*	-0.05
SE(Sij):0.05	2.11	1.8	2.88	2.77	1.06	0.9	1.08	0.91
SE(Sij):0.01	2.8	2.4	3.83	3.69	1.4	1.2	1.43	1.21
SE(Sij-Skj)):0.05	2.1	2.88	4.62	4.44	1.7	1.44	1.72	1.46
SE(Sij-Skj)):0.01	2.79	3.83	6.14	5.9	2.26	1.91	2.28	1.94

*** and ** refer to statistically significant at the 0.05 and 0.01 probability levels.**

Table 10. Specific combining ability effects for yield and its component qualities in both normal and water deficiency conditions.

Traits	No. of panicles/plant		No. of filled grains/panicle		1000-grain weight (g)		Grain yield/plant (g)	
Crosses	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-0.48	1.47**	-28.19**	-17.15**	-0.27	-0.48	7.73**	-3.45*
Sakha107 × Wab880 SG 33	5.02**	1.87**	19.01**	9.89**	-1.27*	-3.18**	5.39**	2.72*
Sakha107 × Sakha 105	6.12**	-0.63	-4.79**	8.75**	0.03	0.62	3.03*	1.82
Sakha107 × IET1444	2.32**	3.17**	-5.19**	1.75	2.10**	2.32**	2.49	5.72**
Sakha107 × Sakha103	-0.71	-0.83	-4.59*	2.32	1.36*	1.12*	2.59	-2.25
Sakha107 × IRAT112	-1.81**	-0.63	4.91**	6.19**	1.16*	1.52**	4.09**	3.92**
Sakha107 × ARS.105-2-1-1-2	3.49**	2.27**	41.81**	19.49**	0.83	0.82	4.29**	5.82**
Giza177 × Wab880 SG 33	-4.48**	-3.33**	-3.69*	-21.65**	-3.24**	-3.28**	-12.74**	-10.91**
Giza177 × Sakha105	-0.38	0.17	28.51**	16.22**	0.06	-0.48	-2.77	0.19
Giza177 × IET1444	0.82	0.97*	-25.89**	-23.45**	-0.2	-0.78	-3.31*	-0.91
Giza177 × Sakha103	-0.21	0.97*	13.71**	8.79**	-0.27	0.02	1.13	-0.21
Giza177 × IRAT112	0.69	1.17*	10.21**	2.65	0.2	1.42**	4.29**	7.29**
Giza177 × ARS.105-2-1-1-2	5.99**	-0.93*	-34.89**	-13.05**	-0.8	-0.28	3.49*	0.19
Wab880 SG 33 × Sakha105	-0.88	1.57**	7.71**	-5.75**	0.4	0.82	4.89**	3.35*
Wab880 SG 33 × IET1444	0.32	1.37**	-26.69**	-16.75**	0.8	1.52**	4.36**	2.25
Wab880 SG 33 × Sakha103	0.29	0.37	4.91**	-6.18**	0.4	0.32	6.46**	3.29*
Wab880 SG 33 × IRAT112	3.19**	0.57	-0.59	6.69**	1.86**	0.72	2.63	1.45
Wab880 SG 33 × ARS.105-2-1-1-2	2.49**	2.47**	-7.69**	-6.01**	-1.47**	0.02	4.16**	1.35
Sakha 105 × IET1444	0.42	-2.13**	-37.49**	-22.88**	0.43	1.32**	3.33*	-5.65**
Sakha 105 × Sakha103	0.39	1.87**	-4.89**	-1.98	-0.3	-0.88	5.43**	5.39**
Sakha 105 × IRAT112	-0.71	2.07**	2.61	-5.45**	-0.5	0.52	4.59**	3.55*
Sakha 105 × ARS.105-2-1-1-2	6.59**	0.97*	16.51**	28.85**	-0.17	0.82	5.79**	2.45
IET1444 × Sakha103	-1.08*	0.67	21.71**	9.69**	0.1	-0.18	-6.11**	0.29
IET1444 × IRAT112	0.16	0.87	21.21**	6.55**	-0.44	0.22	3.06*	-3.55*
IET1444 × ARS.105-2-1-1-2	3.79**	-0.23	-7.89**	6.85**	1.56**	1.52**	2.59	1.35
Sakha103 × IRAT112	3.12**	0.87	-12.19**	-2.55	-0.84	-0.98*	1.16	-0.51
Sakha103 × ARS.105-2-1-1-2	-2.91**	0.77	-1.29	-0.58	0.83	1.32**	-0.64	3.39*
IRAT112 × ARS.105-2-1-1-2	-2.01**	0.97*	-2.79	-2.71	-1.37*	-0.28	1.53	0.55
SE(Sij):0.05	0.97	0.9	3.6	2.82	1.04	0.9	2.88	2.69
SE(Sij):0.01	1.29	1.2	4.79	3.75	1.39	1.2	3.88	3.58
SE(Sij-Skj)):0.05	1.56	1.44	5.78	4.52	1.68	1.44	4.62	4.32
SE(Sij-Skj)):0.01	2.07	1.91	7.68	6.01	2.23	1.91	6.14	5.74

*** and ** refer to statistically significant at the 0.05 and 0.01 probability levels, respectively.**

Table 11. Estimates of heterosis as a divergence from mid and better parent for the number of roots per plant and root volume under normal and water deficiency conditions.

Traits	No. of roots/plant				Root volume (cm^3)			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	3.76**	8.57**	-15.85**	-5.00**	17.31**	9.09**	2.52	-14.29**
Sakha107 × Wab880 SG 33	14.29**	9.09**	7.53**	0	28.29**	16.67**	21.97**	13.51**
Sakha107 × Sakha 105	8.75**	15.00**	6.10**	15.00**	19.57**	5.13*	3.7	-4.65
Sakha107 × IET1444	11.63**	14.29**	6.67**	9.09**	16.88**	8.64**	-4.76	-4.35
Sakha107 × Sakha103	1.41	11.76**	-12.20**	-5.00**	32.11**	5.26*	21.01**	-14.29**
Sakha107 × IRAT112	12.71**	8.70**	3.03**	-3.85**	25.89**	21.43**	18.49**	-2.86
Sakha107 × ARS.105-2-1-1-2	8.43**	17.07**	7.14**	14.29**	30.43**	11.46**	26.05**	1.9
Giza177 × Wab880 SG 33	4.17**	7.69**	-19.35**	-12.50**	24.89**	19.30**	4.55	-8.11**
Giza177 × Sakha105	2.33*	14.29**	-15.38**	0	24.30**	23.81**	-3.7	-9.30**
Giza177 × IET1444	2.13*	8.11**	-20.00**	-9.09**	22.30**	24.24**	-10.05**	-10.87**
Giza177 × Sakha103	-0.9	10.34**	-8.33**	6.67**	34.04**	38.10**	27.27**	31.82**
Giza177 × IRAT112	0	7.32**	-24.24**	-15.38**	36.08**	26.83**	25.71**	23.81**
Giza177 × ARS.105-2-1-1-2	2.22*	5.56**	-17.86**	-9.52**	41.00**	18.37**	27.03**	0
Wab880 SG 33 × Sakha105	-1.75	9.09**	-9.68**	0	24.49**	5.00*	12.96**	-2.33
Wab880 SG 33 × IET1444	11.48**	17.39**	9.68**	12.50**	17.76**	20.48**	0	8.70**
Wab880 SG 33 × Sakha103	1.96*	15.79**	-16.13**	-8.33**	32.47**	11.86**	15.91**	-10.81**
Wab880 SG 33 × IRAT112	12.50**	16.00**	9.09**	11.54**	13.92**	20.69**	2.27	-5.41*
Wab880 SG 33 × ARS.105-2-1-1-2	11.86**	11.11**	6.45**	4.17**	22.63**	24.24**	12.88**	10.81**
Sakha 105 × IET1444	4.76**	14.29**	-2.22	9.09**	12.82**	16.85**	4.76	13.04**
Sakha 105 × Sakha103	-4.35**	5.88**	-15.38**	-10.00**	18.01**	14.87**	-4.94	-13.18**
Sakha 105 × IRAT112	1.69	8.70**	-9.09**	-3.85**	21.35**	25.00**	0	-6.98**
Sakha 105 × ARS.105-2-1-1-2	7.41**	12.20**	3.57**	9.52**	26.01**	16.67**	6.17*	-2.33
IET1444 × Sakha103	-8.00**	0	-23.33**	-18.18**	8.33**	0	-17.46**	-26.09**
IET1444 × IRAT112	11.11**	12.50**	6.06**	3.85**	14.97**	10.45**	-10.58**	-19.57**
IET1444 × ARS.105-2-1-1-2	6.90**	11.63**	3.33**	9.09**	22.00**	6.67**	-3.17	-13.04**
Sakha103 × IRAT112	-1.89*	5.00**	-21.21**	-19.23**	29.41**	34.88**	25.71**	31.82**
Sakha103 × ARS.105-2-1-1-2	1.39	8.57**	-13.10**	-9.52**	40.00**	49.02**	32.43**	31.03**
IRAT112 × ARS.105-2-1-1-2	1.64	2.13**	-6.06**	-7.69**	41.67**	64.00**	37.84**	41.38**
L.S.D: 0.05	1.76	1.4	2.03	1.61	4.33	4.24	5	4.9
L.S.D: 0.01	2.34	1.86	2.7	2.15	5.76	5.64	6.65	6.51

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

Table 12. Estimates of heterosis as a divergence from mid and better parent for root length and root/shoot ratio under normal and water deficiency conditions.

Traits	Root length (cm)				Root/shoot ratio			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	9.78**	20.00**	-11.55**	13.21**	-4.85**	18.81**	-25.76**	-9.77**
Sakha107 × Wab880 SG 33	5.80*	11.96**	-16.98**	9.57**	-2.86**	-5.78**	-8.11**	-20.92**
Sakha107 × Sakha 105	10.54**	12.37**	-8.83**	9.00**	21.57**	4.62**	21.57**	2.26**
Sakha107 × IET1444	3.64	2.8	-6.36*	-8.33**	3.00**	7.39**	-20.87**	-20.15**
Sakha107 × Sakha103	2.06	0.2	-12.36**	-9.22**	-2.40**	-1.98**	-7.58**	-6.77**
Sakha107 × IRAT112	3.42	11.32**	-21.88**	6.38*	10.64**	-2.96**	4.00**	-20.00**
Sakha107 × ARS.105-2-1-1-2	6.69**	1.44	2.85	-7.83**	-2.04**	9.15**	-3.03**	2.65**
Giza177 × Wab880 SG 33	18.67**	-0.34	18.67**	-7.86**	6.31**	7.17**	-20.27**	-27.55**
Giza177 × Sakha105	22.41**	6.47**	14.85**	3.46	9.09**	-1.02**	-5.88**	-23.62**
Giza177 × IET1444	-10.87**	15.04**	-33.44**	8.33**	11.25**	17.54**	-27.64**	-26.37**
Giza177 × Sakha103	12.27**	2.01	3.98	-12.26**	-4.17**	11.11**	-22.03**	-12.50**
Giza177 × IRAT112	22.28**	4.35*	12.22**	-5.66*	12.50**	11.68**	-16.00**	-25.37**
Giza177 × ARS.105-2-1-1-2	14.39**	14.03**	-5.12	9.57**	2.30**	6.36**	-19.59**	-22.52**
Wab880 SG 33 × Sakha105	2.79	-0.7	-3.56	-5.67*	8.80**	-2.79**	-8.11**	-19.90**
Wab880 SG 33 × IET1444	16.75**	23.81**	-14.80**	8.33**	-2.54**	1.07**	-21.95**	-13.19**
Wab880 SG 33 × Sakha103	26.08**	23.05**	13.07**	13.70**	2.26**	2.53**	-8.11**	-17.35**
Wab880 SG 33 × IRAT112	23.52**	27.13**	17.18**	24.07**	4.70**	4.74**	4.00**	2.44**
Wab880 SG 33 × ARS.105-2-1-1-2	10.89**	21.95**	-10.54**	8.70**	3.85**	17.58**	-2.70**	35.10**
Sakha 105 × IET1444	-4.75*	3.33	-27.41**	-5.28*	1.53	13.00**	-28.18**	-17.22**
Sakha 105 × Sakha103	12.13**	1.32	6.82*	-10.67**	11.52**	-0.40**	3.95**	-3.15**
Sakha 105 × IRAT112	4.45	5.57*	-6.69*	-2	23.81**	-3.61**	4.00**	-21.95**
Sakha 105 × ARS.105-2-1-1-2	5.08*	14.42**	-10.69**	6.96**	11.24**	16.55**	-0.52**	7.28**
IET1444 × Sakha103	0.14	14.43**	-20.94**	-6.39*	-4.40**	7.38**	-29.27**	-22.71**
IET1444 × IRAT112	-1.09	21.56**	-30.15**	4.17	9.43**	5.44**	-11.92**	-7.69**
IET1444 × ARS.105-2-1-1-2	5.45*	13.19**	-7.79**	10.83**	4.80**	11.79**	-20.05**	-13.19**
Sakha103 × IRAT112	25.44**	19.75**	7.39**	13.23**	8.96**	-7.08**	-2.67**	-26.34**
Sakha103 × ARS.105-2-1-1-2	8.84**	25.44**	-3.51	4.35	6.74**	6.27**	2.06**	-4.64**
IRAT112 × ARS.105-2-1-1-2	4.82*	31.89**	-18.74**	15.07**	6.44**	17.98**	-0.89**	2.44**
L.S.D: 0.05	4.63	4.24	5.34	4.9	0.06	0.06	0.07	0.07
L.S.D: 0.01	6.15	5.64	7.1	6.51	0.08	0.08	0.09	0.09

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

Table 13. Estimates of heterosis as a departure from a mid and better parent for leaf rolling and leaf firing under normal and water deficiency conditions.

Traits	Leaf rolling				Leaf firing			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-11.11**	-6.67**	33.33**	16.67**	-33.33**	-18.52**	-16.67**	-8.33**
Sakha107 × Wab880 SG 33	33.33**	-33.33**	33.33**	-33.33**	-16.67**	-8.33**	-16.67**	-8.33**
Sakha107 × Sakha 105	55.56**	-18.52**	133.33**	-8.33**	-16.67**	-18.52**	-16.67**	-8.33**
Sakha107 × IET1444	33.33**	-23.81**	33.33**	-11.11**	-50.00**	-23.81**	-50.00**	-11.11**
Sakha107 × Sakha103	55.56**	-15.15**	133.33**	16.67**	-33.33**	-6.67**	-16.67**	16.67**
Sakha107 × IRAT112	33.33**	-33.33**	33.33**	-33.33**	-16.67**	-33.33**	-16.67**	-33.33**
Sakha107 × ARS.105-2-1-1-2	-11.11**	-33.33**	33.33**	-33.33**	-16.67**	-33.33**	-16.67**	-33.33**
Giza177 × Wab880 SG 33	55.56**	-6.67**	133.33**	16.67**	-60.00**	-18.52**	-50.00**	-8.33**
Giza177 × Sakha105	16.67**	-15.15**	16.67**	-6.67**	-33.33**	-6.67**	-16.67**	-6.67**
Giza177 × IET1444	55.56**	-18.52**	133.33**	22.22**	-33.33**	0	-16.67**	33.33**
Giza177 × Sakha103	16.67**	-12.82**	16.67**	-5.56**	-11.11**	-15.15**	-11.11**	-6.67**
Giza177 × IRAT112	55.56**	-6.67**	133.33**	16.67**	-33.33**	-18.52**	-16.67**	-8.33**
Giza177 × ARS.105-2-1-1-2	16.67**	-6.67**	16.67**	16.67**	-33.33**	-18.52**	-16.67**	-8.33**
Wab880 SG 33 × Sakha105	55.56**	-18.52**	133.33**	-8.33**	-16.67**	-18.52**	-16.67**	-8.33**
Wab880 SG 33 × IET1444	33.33**	-42.86**	33.33**	-33.33**	-16.67**	-23.81**	-16.67**	-11.11**
Wab880 SG 33 × Sakha103	55.56**	-15.15**	133.33**	16.67**	-60.00**	-6.67**	-50.00**	16.67**
Wab880 SG 33 × IRAT112	33.33**	-33.33**	33.33**	-33.33**	-16.67**	-33.33**	-16.67**	-33.33**
Wab880 SG 33 × ARS.105-2-1-1-2	-11.11**	-33.33**	33.33**	-33.33**	-16.67**	-8.33**	-16.67**	-8.33**
Sakha 105 × IET1444	11.11**	-8.33**	66.67**	22.22**	-16.67**	-8.33**	-16.67**	22.22**
Sakha 105 × Sakha103	-16.67**	-5.56**	-16.67**	13.33**	-33.33**	-15.15**	-16.67**	-6.67**
Sakha 105 × IRAT112	11.11**	-18.52**	66.67**	-8.33**	-50.00**	-18.52**	-50.00**	-8.33**
Sakha 105 × ARS.105-2-1-1-2	-16.67**	-18.52**	-16.67**	-8.33**	-16.67**	-8.33**	-16.67**	-8.33**
IET1444 × Sakha103	11.11**	-6.67**	66.67**	55.56**	-33.33**	-18.52**	-16.67**	22.22**
IET1444 × IRAT112	0	-23.81**	0	-11.11**	-16.67**	-23.81**	-16.67**	-11.11**
IET1444 × ARS.105-2-1-1-2	-33.33**	-23.81**	0	-11.11**	-16.67**	-23.81**	-16.67**	-11.11**
Sakha103 × IRAT112	11.11**	-15.15**	66.67**	16.67**	-33.33**	-6.67**	-16.67**	16.67**
Sakha103 × ARS.105-2-1-1-2	-16.67**	-15.15**	-16.67**	16.67**	-33.33**	-6.67**	-16.67**	16.67**
IRAT112 × ARS.105-2-1-1-2	-11.11**	-33.33**	33.33**	-33.33**	-16.67**	-16.67**	-16.67**	-16.67**
L.S.D: 0.05	0.66	0.63	0.76	0.73	0.61	0.62	0.7	0.72
L.S.D: 0.01	0.88	0.84	1.01	0.97	0.81	0.83	0.93	0.95

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

Table 14. Estimates of heterosis for flag leaf traits like as relative water content and chlorophyll content, compared to mid and better parent values, in both normal and water shortage situations.

Traits	Flag Leaf area (cm^2)				Relative water content				Chlorophyll content			
Heterosis	MP		BP		MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D	N	D	N	D
Sakha107 × Giza177	11.10**	-1.61*	7.77**	-9.41**	7.50**	4.31**	-3.88*	-6.17**	2.07	-2.78	-4.23*	-11.55**
Sakha107 × Wab880 SG 33	3.47**	7.53**	-13.24**	-16.10**	2.8	3.55*	2.31	2.27	5.96**	1.49	5.74**	-1.3
Sakha107 × Sakha 105	14.74**	-0.18	7.82**	-9.90**	-1.92	0.11	-5.66**	-7.26**	-1.18	-3.08	-4.23*	-12.24**
Sakha107 × IET1444	7.77**	11.21**	7.71**	4.02**	1.15	0	1.07	-2.44	3.37*	1.3	-6.32**	-7.80**
Sakha107 × Sakha103	0.3	-6.77**	-6.15**	-20.46**	1.49	-2.04	-14.31**	-17.00**	5.19**	3.27*	4.09*	-3.29
Sakha107 × IRAT112	1.46	-4.31**	-12.11**	-19.98**	3.23*	4.12**	3.06	3.57*	3.96**	4.19*	2.01	-1.07
Sakha107 × ARS.105-2-1-1-2	11.10**	8.81**	7.77**	3.90**	2.36	0.87	1.22	-1.01	0.75	1.34	-2.15	-1.53
Giza177 × Wab880 SG 33	5.65**	-8.86**	-9.14**	-32.93**	5.16**	0.32	-6.37**	-8.74**	1.85	-3.47*	-4.63**	-9.88**
Giza177 × Sakha105	7.19**	15.23**	-2.10*	12.75**	-0.84	0.29	-8.12**	-2.86	0.96	2.11	-2.37	1.59
Giza177 × IET1444	7.37**	-0.33	4.10**	-13.65**	3.58*	3.32*	-7.33**	-4.95**	6.00**	5.09**	2.14	5.04**
Giza177 × Sakha103	-3.70**	-2.35**	-12.39**	-10.20**	9.98**	2.99*	9.98**	-3.76*	3.22*	8.68**	-2.2	5.35**
Giza177 × IRAT112	-3.13**	-6.31**	-13.83**	-26.64**	4.33**	3.65*	-6.85**	-6.32**	8.68**	8.90**	3.82*	4.09*
Giza177 × ARS.105-2-1-1-2	4.73**	-2.55**	4.73**	-13.96**	-0.61	-0.12	-10.25**	-8.60**	7.59**	11.11**	3.83*	3.81*
Wab880 SG 33 × Sakha105	0.14	-19.57**	-20.12**	-41.63**	1.19	2.58	-3.11	-3.87*	5.04**	11.90**	1.59	3.97*
Wab880 SG 33 × IET1444	7.22**	4.90**	-10.14**	-13.78**	5.93**	5.16**	5.35**	3.87*	-1.45	0.39	-10.85**	-6.23**
Wab880 SG 33 × Sakha103	-8.09**	-27.37**	-26.93**	-49.31**	3.27*	0.63	-13.15**	-13.86**	7.07**	-1.09	5.74**	-4.86*
Wab880 SG 33 × IRAT112	8.49**	12.41**	4.39**	3.05**	2.48	5.35**	2.16	4.59**	3.74*	1.08	1.59	-1.38
Wab880 SG 33×ARS.105-2-1-1-2	-7.48**	-3.84**	-20.42**	-22.29**	3.31*	3.41*	1.68	2.75	0.53	2.35	-2.56	2.27
Sakha 105 × IET1444	-2.68**	-2.87**	-8.50**	-17.39**	1.73	0.02	-2.07	-5.16**	2.26	7.32**	-4.59**	6.72**
Sakha 105 × Sakha103	2.49**	18.34**	2.03*	11.07**	-0.69	-3.99**	-13.33**	-12.90**	4.23**	1.41	2.06	-2.19
Sakha 105 × IRAT112	6.92**	8.42**	-12.11**	-16.43**	0.44	0.55	-3.54*	-6.40**	2.96*	1.39	1.66	-3.57
Sakha 105 × ARS.105-2-1-1-2	3.74**	4.85**	-5.25**	-9.16**	-0.86	0.6	-3.59*	-5.14**	4.06**	4.84**	3.83*	-2.51
IET1444 × Sakha103	3.94**	-8.36**	-2.68*	-26.01**	4.03**	-0.42	-12.11**	-13.87**	-0.08	-7.82**	-8.58**	-10.60**
IET1444 × IRAT112	-0.95	-1.31	-14.24**	-12.54**	4.16**	-0.54	3.91*	-2.46	3.21*	-2.09	-4.83**	-6.38**
IET1444 × ARS.105-2-1-1-2	10.51**	11.16**	7.14**	8.76**	4.68**	3.05*	3.59*	2.45	2.02	-0.56	-5.01**	-7.06**
Sakha103 × IRAT112	2.60**	4.14**	-15.96**	-23.20**	-8.06**	-6.00**	-22.48**	-20.02**	5.08**	6.56**	4.18*	5.02**
Sakha103 × ARS.105-2-1-1-2	0.92	-6.03**	-8.19**	-22.82**	3.15*	0.12	-12.10**	-13.83**	4.01**	8.68**	2.06	4.62*
IRAT112 × ARS.105-2-1-1-2	-3.86**	3.77**	-14.48**	-9.77**	3.71*	4.99**	2.39	3.57*	2.73	8.00**	1.66	8.00**
L.S.D: 0.05	1.75	1.42	2.02	1.63	3.03	2.79	3.5	3.23	2.8	3.27	3.24	3.78
L.S.D: 0.01	2.33	1.88	2.69	2.17	4.03	3.72	4.65	4.29	3.73	4.35	4.3	5.02

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

Table 15. Estimates of heterosis as a departure from mid and better parent days to 50% heading and plant height under normal and water deficiency conditions.

Traits	Days to 50% heading (day)				Plant height (cm)			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	4.85**	18.81**	-25.76**	-9.77**	10.00**	10.00**	14.58**	11.39**
Sakha107 × Wab880 SG 33	-2.86	-5.78**	-8.11**	-20.92**	11.11**	18.75**	25.00**	40.74**
Sakha107 × Sakha 105	21.57**	4.62**	21.57**	2.26**	20.19**	23.81**	23.08**	28.40**
Sakha107 × IET1444	3	7.39**	-20.87**	-20.15**	-8.91**	1.16	0	7.41**
Sakha107 × Sakha103	-2.4	-1.98	-7.58**	-6.77**	6.11**	11.84**	6.45*	19.72**
Sakha107 × IRAT112	10.64**	-2.96*	4.00*	-20.00**	0.44	0	10.58**	12.35**
Sakha107 × ARS.105-2-1-1-2	-2.04	9.15**	-3.03	2.65**	15.42**	23.60**	25.96**	35.80**
Giza177 × Wab880 SG 33	6.31**	7.17**	-20.27**	-27.55**	10.62**	17.89**	30.21**	41.77**
Giza177 × Sakha105	9.09**	-1.02	-5.88**	-23.62**	20.33**	36.14**	28.47**	43.04**
Giza177 × IET1444	11.25**	17.54**	-27.64**	-26.37**	-0.15	-5.88**	14.58**	1.27
Giza177 × Sakha103	-4.17*	11.11**	-22.03**	-12.5**	5.35*	13.33**	9.38**	19.72**
Giza177 × IRAT112	12.50**	11.68**	-16.00**	-25.37**	5.88*	5.56*	21.88**	20.25**
Giza177 × ARS.105-2-1-1-2	2.3	6.36**	-19.59**	-22.52**	5.02*	-2.27	19.79**	8.86**
Wab880 SG 33 × Sakha105	8.80**	-2.79	-8.11**	-19.9**	4.60*	15.15**	14.68**	31.03**
Wab880 SG 33 × IET1444	-2.54	1.07	-21.95**	-13.19**	-0.92	10.89**	1.34	23.08**
Wab880 SG 33 × Sakha103	2.26	2.53	-8.11**	-17.35**	7.14**	9.89**	20.97**	40.85**
Wab880 SG 33 × IRAT112	4.70**	4.74**	4.00*	2.44	1.96	5.66*	4	10.89**
Wab880 SG 33 × ARS.105-2-1-1-2	3.85*	17.58**	-2.70	35.10**	-3.56	2.88	-0.81	10.31**
Sakha 105 × IET1444	1.53	13.00**	-28.18**	-17.22**	5.14*	14.61**	12.54**	17.24**
Sakha 105 × Sakha103	11.52**	-0.4	3.95*	-3.15	9.58**	16.46**	12.58**	29.58**
Sakha 105 × IRAT112	23.81**	-3.61*	4.00*	-21.95**	9.69**	17.38**	17.74**	26.82**
Sakha 105 × ARS.105-2-1-1-2	11.24**	16.55**	-0.52	7.28**	8.62**	17.39**	15.60**	24.14**
IET1444 × Sakha103	-4.40**	7.38**	-29.27**	-22.71**	13.91**	28.81**	25.48**	46.95**
IET1444 × IRAT112	9.43**	5.44**	-11.92**	-7.69**	-3.74	10.42**	-3.49	16.48**
IET1444 × ARS.105-2-1-1-2	4.80**	11.79**	-20.05**	-13.19**	2.16	17.02**	2.71	20.88**
Sakha103 × IRAT112	8.96**	-7.08**	-2.67	-26.34**	11.24**	9.30**	22.90**	32.39**
Sakha103 × ARS.105-2-1-1-2	6.74**	6.27**	2.06	-4.64**	3.98	1.19	13.87**	19.72**
IRAT112 × ARS.105-2-1-1-2	6.44**	17.98**	-0.89	2.44	-1.88	11.45**	-1.08	13.75**
L.S.D: 0.05	3.27	2.8	3.78	3.23	4.47	4.31	5.16	4.97
L.S.D: 0.01	4.35	3.72	5.03	4.3	5.94	5.73	6.86	6.61

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

Table 16. Estimates of heterosis as a departure from mid and better parent for panicle length and sterility percentage under normal and water deficiency conditions.

Traits	Panicle length (cm)				Sterility %			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	6.22**	11.75**	4.01**	3.88**	33.33**	42.86**	25.00**	25.00**
Sakha107 × Wab880 SG 33	12.61**	11.75**	8.58**	10.43**	79.31**	60.00**	62.50**	33.33**
Sakha107 × Sakha 105	3.66**	12.56**	0.58	8.74**	80.65**	18.18**	75.00**	8.33**
Sakha107 × IET1444	6.97**	11.11**	2.10*	8.29**	42.86**	46.15**	31.58**	35.71**
Sakha107 × Sakha103	7.16**	12.82**	2.62**	-3.88**	16.13**	20.00**	12.50**	0
Sakha107 × IRAT112	2.70**	6.58**	-10.34**	0	15.91**	23.81**	6.25**	8.33**
Sakha107 × ARS.105-2-1-1-2	8.40**	11.96**	6.55**	6.80**	68.00**	44.00**	61.54**	38.46**
Giza177 × Wab880 SG 33	7.19**	17.53**	1.29	8.06**	48.15**	64.71**	42.86**	55.56**
Giza177 × Sakha105	2.29**	8.76**	-2.75**	4.51**	31.03**	26.32**	26.67**	20.00**
Giza177 × IET1444	10.93**	15.23**	3.78**	4.61**	27.27**	30.43**	10.53**	7.14**
Giza177 × Sakha103	11.18**	11.18**	8.68**	1.13	10.34**	41.18**	6.67**	33.33**
Giza177 × IRAT112	-2.28**	0	-16.21**	-12.34**	24.39**	44.44**	21.43**	44.44**
Giza177 × ARS.105-2-1-1-2	-7.26**	0	-10.71**	-2.67**	78.72**	18.18**	61.54**	0
Wab880 SG 33 × Sakha105	6.26**	13.15**	5.58**	8.06**	35.71**	55.56**	26.67**	40.00**
Wab880 SG 33 × IET1444	7.57**	11.68**	6.44**	10.14**	31.25**	45.45**	10.53**	14.29**
Wab880 SG 33 × Sakha103	11.68**	-1.69*	3.29**	-17.06**	21.43**	50.00**	13.33**	50.00**
Wab880 SG 33 × IRAT112	1.21	5.83**	-8.74**	0.43	51.90**	52.94**	50.00**	44.44**
Wab880 SG 33 × ARS.105-2-1-1-2	6.20**	10.55**	4.15**	4.27**	64.84**	61.90**	44.23**	30.77**
Sakha 105 × IET1444	5.98**	7.09**	4.20**	0.92	29.41**	0	15.79**	-14.29**
Sakha 105 × Sakha103	1.87*	-0.89	-5.22**	-13.02**	20.00**	44.44**	20.00**	30.00**
Sakha 105 × IRAT112	7.95**	9.60**	-3.22**	-0.43	20.00**	47.37**	13.33**	40.00**
Sakha 105 × ARS.105-2-1-1-2	11.89**	18.73**	10.43**	17.19**	85.57**	30.43**	73.08**	15.38**
IET1444 × Sakha103	4.13**	4.42**	-4.62**	-12.90**	1.96*	27.27**	-8.77**	0
IET1444 × IRAT112	14.14**	8.41**	3.91**	4.26**	15.46**	30.43**	-1.75*	7.14**
IET1444 × ARS.105-2-1-1-2	19.48**	17.33**	15.97**	9.22**	54.13**	18.52**	47.37**	14.29**
Sakha103 × IRAT112	2.05*	2.63**	-14.14**	-17.02**	24.71**	41.18**	17.78**	33.33**
Sakha103 × ARS.105-2-1-1-2	9.64**	7.23**	3.27**	-4.81**	7.22**	33.33**	0	7.69**
IRAT112 × ARS.105-2-1-1-2	-0.39	3.79**	-11.72**	-6.81**	19.57**	36.36**	5.77**	15.38**
L.S.D: 0.05	1.64	1.4	1.89	1.61	1.51	1.4	1.74	1.61
L.S.D: 0.01	2.18	1.86	2. 52	2.15	2.01	1.86	2.32	2.15

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

Table 17. Estimates of heterosis as a deviation from mid and better parent for the number of panicles per plant and number of filled grains per panicle under normal and water deficit conditions.

Traits	No. of panicles/plant				No. of filled grains/panicle			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	-20.78**	-8.88**	-26.28**	-22.22**	2.04*	0	-5.06**	-4.17**
Sakha107 × Wab880 SG 33	22.14**	21.39**	16.79**	19.61**	0	-9.43**	-15.31**	-22.58**
Sakha107 × Sakha 105	2.42	23.08**	-7.30*	13.13**	3.95**	8.70**	-5.95**	4.17**
Sakha107 × IET1444	-9.39**	0	-18.60**	-14.89**	19.08**	21.95**	14.71**	13.64**
Sakha107 × Sakha103	4.56	13.81**	-8.03*	4.04	11.94**	9.52**	10.29**	4.55**
Sakha107 × IRAT112	12.84**	16.81**	5.84	15.46**	8.07**	12.50**	-6.45**	3.85**
Sakha107 × ARS.105-2-1-1-2	37.16**	37.17**	30.66**	32.32**	7.46**	12.82**	5.88**	0
Giza177 × Wab880 SG 33	16.87**	45.35**	13.60**	22.55**	1.69*	-1.82*	-8.16**	-12.90**
Giza177 × Sakha105	23.14**	29.41**	19.49**	19.28**	-0.61	0	-3.57**	0
Giza177 × IET1444	-31.03**	-29.54**	-41.86**	-47.28**	2.82**	2.33**	-7.59**	-8.33**
Giza177 × Sakha103	12.61**	17.11**	5.93	8.54**	-0.69	0	-8.86**	-8.33**
Giza177 × IRAT112	10.08**	8.56**	9.17**	-8.22**	0	8.00**	-7.53**	3.85**
Giza177 × ARS.105-2-1-1-2	-31.40**	-3.7	-33.06**	-15.22**	-4.83**	2.44**	-12.66**	-12.50**
Wab880 SG 33 × Sakha105	11.86**	2.7	5.6	-6.86**	2.20**	5.45**	-5.10**	-6.45**
Wab880 SG 33 × IET1444	-25.25**	-18.52**	-35.47**	-29.79**	8.07**	12.00**	-11.22**	-9.68**
Wab880 SG 33 × Sakha103	11.79**	0	2.4	-9.80**	3.66**	1.96**	-13.27**	-16.13**
Wab880 SG 33 × IRAT112	7.76**	13.11**	5.6	12.75**	6.81**	5.26**	4.08**	-3.23**
Wab880 SG 33 × ARS.105-2-1-1-2	-2.01	6.19**	-2.4	0.98	-4.88**	4.17**	-20.41**	-19.35**
Sakha 105 × IET1444	-35.69**	-25.00**	-47.09**	-40.43**	6.12**	16.28**	-7.14**	4.17**
Sakha 105 × Sakha103	1.4	5.86**	-1.8	5.22*	0	0	-10.71**	-8.33**
Sakha 105 × IRAT112	9.09**	1.99	5	-7.24**	-1.69*	8.00**	-6.45**	3.85**
Sakha 105 × ARS.105-2-1-1-2	16.60**	47.43**	10.48**	40.22**	-1.33	12.20**	-11.90**	-4.17**
IET1444 × Sakha103	7.97**	2.24	-13.37**	-19.15**	6.98**	7.69**	4.55**	5.00**
IET1444 × IRAT112	8.22**	-0.14	-8.14*	-14.18**	2.56**	11.11**	-13.98**	-3.85**
IET1444 × ARS.105-2-1-1-2	-14.86**	4.72*	-26.74**	-13.48**	11.63**	22.22**	9.09**	15.79**
Sakha103 × IRAT112	-1.79	2.91	-8.33*	-6.91**	-1.89*	0	-16.13**	-11.54**
Sakha103 × ARS.105-2-1-1-2	3.51	11.49**	-4.84	5.43*	4.55**	13.51**	4.55**	5.00**
IRAT112 × ARS.105-2-1-1-2	3.28	8.62**	1.61	3.62	-5.66**	6.98**	-19.35**	-11.54**
L.S.D: 0.05	5.59	4.38	6.46	5.06	1.62	1.4	1.87	1.61
L.S.D: 0.01	7.44	5.83	8.59	6.73	2.16	1.86	2.49	2.15

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

Table 18. Estimates of heterosis as a divergence from mid and better parent for 1000-grain weight and grain output per plant in both normal and water shortage circumstances.

Traits	1000-grain weight (g)				Grain yield/plant (g)			
Heterosis	MP		BP		MP		BP	
Conditions	N	D	N	D	N	D	N	D
Sakha107 × Giza177	156.52**	60.60**	229.62**	66.44**	45.38**	9.49**	31.16**	-12.79**
Sakha107 × Wab880 SG 33	-38.17**	-19.46**	53.92**	74.00**	49.02**	41.61**	37.68**	32.56**
Sakha107 × Sakha 105	-37.49**	-39.16**	9.04**	-18.70**	36.26**	32.89**	34.78**	15.12**
Sakha107 × IET1444	137.35**	117.82**	645.61**	567.07**	23.23**	27.09**	15.09**	10.26**
Sakha107 × Sakha103	27.64**	-19.54**	59.32**	-7.42**	30.86**	16.42**	15.22**	-9.30**
Sakha107 × IRAT112	1.15	-11.90**	54.70**	28.24**	41.56**	37.65**	24.64**	36.05**
Sakha107 × ARS.105-2-1-1-2	28.36**	-4.95**	295.61**	202.51**	37.78**	50.97**	34.78**	36.05**
Giza177 × Wab880 SG 33	161.40**	18.80**	361.93**	171.01**	42.11**	57.14**	38.46**	32.00**
Giza177 × Sakha105	94.29**	10.54**	151.14**	54.45**	17.07**	26.32**	6.67*	14.29**
Giza177 × IET1444	52.22**	-12.19**	232.24**	185.30**	4.44	3.57	-11.32**	-25.64**
Giza177 × Sakha103	45.97**	15.74**	49.56**	28.07**	20.37**	29.17**	17.12**	29.17**
Giza177 × IRAT112	44.94**	-10.68**	67.52**	36.24**	37.04**	55.56**	33.33**	25.00**
Giza177 × ARS.105-2-1-1-2	262.32**	76.63**	677.06**	496.63**	30.86**	30.00**	20.45**	13.04**
Wab880 SG 33 × Sakha105	337.24**	195.81**	468.13**	341.54**	45.24**	47.83**	35.56**	36.00**
Wab880 SG 33 × IET1444	301.88**	169.06**	367.76**	242.15**	30.43**	21.88**	13.21**	0
Wab880 SG 33 × Sakha103	65.20**	-7.50**	202.23**	146.12**	45.95**	51.22**	38.46**	24.00**
Wab880 SG 33 × IRAT112	71.78**	44.27**	151.86**	97.47**	43.24**	35.85**	35.90**	28.57**
Wab880 SG 33 × ARS.105-2-1-1-2	184.05**	173.79**	226.37**	258.06**	42.17**	41.67**	34.09**	36.00**
Sakha 105 × IET1444	95.65**	24.05**	205.48**	152.05**	22.45**	-10.00**	13.21**	-30.77**
Sakha 105 × Sakha103	52.83**	-5.87**	103.51**	49.51**	35.00**	56.76**	20.00**	38.10**
Sakha 105 × IRAT112	29.09**	85.37**	42.56**	98.59**	40.00**	38.78**	24.44**	21.43**
Sakha 105 × ARS.105-2-1-1-2	51.69**	-13.94**	133.23**	81.04**	38.58**	40.91**	37.04**	34.78**
IET1444 × Sakha103	47.14**	-5.06**	233.33**	264.04**	-4.55*	9.09**	-20.75**	-23.08**
IET1444 × IRAT112	48.22**	64.87**	164.25**	203.47**	22.73**	-1.49	1.89	-15.38**
IET1444 × ARS.105-2-1-1-2	429.43**	307.87**	435.53**	317.44**	19.59**	16.13**	9.43**	-7.69**
Sakha103 × IRAT112	-2.16	-5.67**	16.24**	64.47**	25.71**	22.73**	25.71**	-3.57
Sakha103 × ARS.105-2-1-1-2	4.98**	-10.29**	133.65**	257.99**	18.14**	48.72**	6.06*	26.09**
IRAT112 × ARS.105-2-1-1-2	70.49**	35.67**	199.04**	158.26**	30.80**	29.41**	17.42**	17.86**
L.S.D: 0.05	1.67	1.42	1.93	1.64	4.47	4.17	5.16	4.82
L.S.D: 0.01	2.22	1.88	2.57	2.17	5.95	5.55	6.87	6.41

The symbols * and ** indicate statistical significance at the 0.05 and 0.01 probability levels, respectively.

Sakha 107 × IRAT 112, Sakha 107 × ARS.105-2-1-1-2, and Wab 880 SG 33 × IRAT 112 crosses exhibited considerable heterosis and heterobeltiosis in a favorable negative direction for MP and BP under both conditions in leaf firing. The crosses Sakha 107 × IRAT 112, Wab 880 SG 33 × IRAT 112, and IET1444 × ARS.105-2-1-1-2 showed the most improvement in flag leaf area under both conditions. The greatest levels of heterosis were observed in the crosses Giza177 × Sakha103 (9.98%) under normal conditions, Wab880 SG 33 × IET1444 under both conditions, and Wab880 SG 33 × IRAT112 (5.35 and 4.59%) under water deficit conditions for relative water content. The crosses Giza177 × ARS.105-2-1-1-2, Wab880 SG 33 × Sakha105, and Giza177 × IRAT112 showed the highest levels of heterosis in improving Chlorophyll content. Notably, Giza177 × Sakha103, Sakha105 × IET1444, and IRAT112 × ARS.105-2-1-1-2 exhibited the highest estimated values for Chlorophyll content under water deficit conditions. Our investigation found that there were significantly positive estimates of heterosis in yield and its components traits under normal and water deficit conditions for various crosses, such as Giza 177 × Wab 880 SG 33, Sakha 107 × IET 1444, Sakha 107 × IRAT 112, Sakha 107 × ARS.105-2-1-1-2, Giza 177 × Wab 880 SG 33, and Wab 880 SG 33 × ARS.105-2-1-1-2. highly significantly negative estimations of heterosis were reported as a deviation from mid-parent (MP) and better parent (BP) during water deficiency conditions for days to 50% heading in certain crosses such Giza 177 × Wab 880 SG 33, IET 1444 × Sakha 103, and Sakha 103 × IRAT 112.

Assessing the drought responses of 8 rice genotypes by root, agro-physiological, and yield evaluation using a heatmap.

We assessed the performance of 8 rice varieties under both normal watering conditions and water constraints. We assessed the impact of drought on plants by examining various traits, including root length (RL), root volume (RV), number of roots per plant (NR), root/shoot ratio (RSR), leaf rolling (LR), leaf firing (LF), flag leaf area (FLA), relative water content (RWC), chlorophyll content (CC), days to 50% heading (HD), plant height (PH), panicle length (PL), sterility percentage (ST), number of panicles per plant (NP), panicle weight (PW), 100-grain weight (TGW), number of filled grains per panicle (NFG), and grain yield/plant (GY). We conducted hierarchical clustering to find the key characteristics for evaluating rice's drought tolerance. This analysis was based on root, physiological, morphological, and yield data, and the results were visualized in a heatmap. The heatmap shows how the 8 genotypes, with their physiological, morphological, and yield features, grouped together hierarchically when grown under normal or water deficiency conditions. The genotypes were classified into primary clusters under both conditions, each of which was further separated into three (I, II, and III) in each condition, demonstrating genetic diversity among them (Fig. 9).

The genotypes were classified into two main groups, with the first group being subdivided into two subgroups (I and II). Subgroup I consisted of six genotypes in normal conditions: ARS.105-2-1-1-2, Wab880SG33, Sakha105, Sakha103, Giza177, and Sakha107. Under water deficit conditions, there were five genotypes: IRAT112, Sakha107, Sakha105, Wab880SG33, and ARS.105-2-1-1-2. Subgroup II included one genotype, IRAT112, in normal conditions and two genotypes, Sakha103, and Giza177, under water deficit conditions (Fig. 9). The second group had a single subgroup (III) with the genotype IET1444 exhibiting greater drought tolerance under both conditions.

Additionally, a hierarchical clustering analysis was conducted on physiological, morphological, and yield parameters, revealing four unique groups labeled a, b, c, and d under normal conditions and a, b, c under water deficiency conditions at the top of Fig. 9. Five traits, including days to 50% heading (HD), plant height (PH), number of filled grains/panicle (NFG), number of roots/plant (NR), and relative water content (RWC), were closely associated with each other under both normal and water deficit conditions. This relationship was highlighted in the heatmap by their clustering in groups b and c, as shown at the top of figure 9.

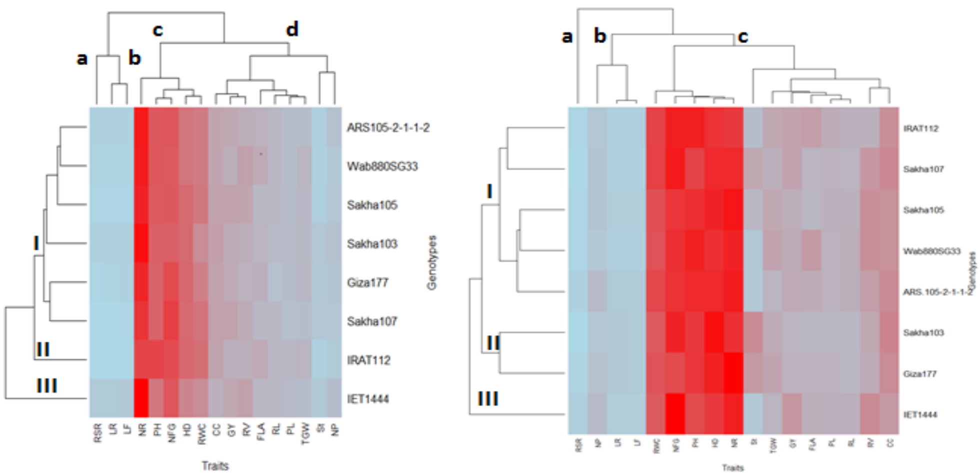

Figure 9. Heatmap and hierarchical clustering analysis were conducted on root, Agro-morphological, and yield variables of 8 rice genotypes under both normal and water deficiency conditions. Clustering analysis was conducted on rice genotypes and various traits including root length *(RL)*, root volume (RV), number of roots per plant *(NR)*, root/shoot ratio *(RSR)*, days to 50% heading (*HD)*, plant height *(PH*), panicle length *(PL)*, sterility percentage *(St)*, number of panicles per plant *(NP)*, 1000-grain weight *(TGW)*, number of filled grains per panicle *(NFG)*, grain yield *(GY)*, leaf rolling *(LR)*, leaf firing (*LF)*, flag leaf area *(FLA)*, relative water content (RWC), and chlorophyll content *(CC)*.

Discussion

Rice breeders utilize diallel crosses to provide substantial genetic variety and variation. They can choose certain genotypes in breeding programs to enhance various qualities under both biotic and abiotic stress situations. This study involved performing diallel crosses among eight genotypes, some of which exhibit traits associated with resistance to water scarcity for root, agro-physiological, and yield characteristics. This was done to produce new genotypes with advantageous characteristics that surpass those of their parents in the same features. These can be used in breeding programs to continually enhance rice yield under water-deficient situations. The data indicated that both general combining ability (GCA) and specialized combining ability (SCA) variations were statistically significant ($p \leq 0.01$) for most variables in F1 rice populations. This highlights the significance of both additive and non-additive genetic variations in influencing the performance of attributes tested under various settings. The results indicated that selection approaches relying on the aggregation of additive effects could be effectively enhance yield-related attributes. The current results aligned closely with previous research on the impact of varying temperature conditions on the root system, yield, and physiological characteristics of rice in both scenarios. Similar results for the general combining ability (GCA) and specific combining ability (SCA) variants were also seen in rice populations, as reported in previous studies (Hassan et al., 2012b). The GCA/SCA ratio was less than one for various traits such as days to 50% heading, plant height, sterility percentage, number of panicles per plant, number of filled grains per panicle, and grain yield per plant. This indicates a prevalence of dominance gene action in the inheritance of these traits under both conditions. The study found that Wab880 SG33 followed by IET1444 and IRAT112 were the most effective rice genotypes for root and physiological traits in both normal and water stress conditions. Therefore, rice breeders should consider using them as donors to enhance new rice varieties in breeding programs focusing on water deficit conditions. IET1444, Sakha 107 and IRAT 112 were identified as the most promising rice genotypes for yield and its components attributes under water stress conditions. Rice breeders may consider using them as donors to enhance new rice varieties that are tolerant to water deficiency in their breeding programs. The findings were consistent with those described in references (Hassan, 2013, Hassan et al., 2023, Hassan et al., 2012a, Sultan et al., 2013, Nessreen et al., 2015, Daher et al., 2023)

Among two rice crosses, Sakha 107 × Wab 880 SG 33 and Sakha 107 × IRAT 112, both including the superior general combiner Sakha107 as the female parent, Sakha107 had the highest Chlorophyll content compared to itself as the highest content parent. The results obtained align with those documented in references (Hassan et al., 2016, Gaballah et al., 2021). Among two rice crosses, Sakha 107 × Wab 880 SG 33 and Sakha 107 × IRAT 112, both including the general combiner Sakha107, the female parent Sakha 107 had the highest Chlorophyll content compared to the other parent (Sakha107). The results obtained align with those documented in references (Hassan et al., 2011, Gaballah et al., 2021).

Rice breeders consistently aim to enhance early maturity as a common strategy to address water shortages. This study uncovers the existence of advantageous genes at an early stage. Rice breeders can improve this attribute by including these genotypes into breeding programs. Some genotypes matured in less than 110 days, particularly under water deficiency conditions, making them appropriate for selecting early maturing rice genotypes. The hybrids Giza177 × IET1444 and Sakha107 × Wab880 SG 33 exhibited semi-dwarf stem characteristics, making them well-suited for breeding in conditions of water constraint. Two rice crosses, Sakha107 × ARS.105-2-1-1-2 and Sakha105 × ARS.105-2-1-1-2, showed that the male parent, ARS.105-2-1-1-2, had a high number of panicles, filled grains, and the heaviest grain yield compared to the other parent. This suggests that over-dominance played a significant role in the inheritance of these traits in these specific crosses under both conditions.

Some parents with high mean values had low GCA impacts. Therefore, both individual performance and general combining ability effects should be considered while choosing parents. The parent IET144 was chosen as the best one because to its high mean values for most root and physiological traits, and its effectiveness as a general combiner for these features under both situations. Similarly, the Sakha 107 rice parent is considered excellent for various yield components, root characteristics, and physiological qualities in both situations. The same outcomes were previously achieved by references (Dash et al., 2018, Hassan et al., 2012a, Daher et al., 2023, Hassan et al., 2016, Kushal et al., 2023). The specific combining ability (SCA) is considered the most reliable criterion for selecting superior hybrids. The crosses Sakha 107 × Wab880 SG 33, Sakha 107 × IRAT112, Sakha 107 × ARS.105-2-1-1-2, Sakha177 × Sakha105, Wab880 SG 33 × Sakha105, Wab880 SG 33 × sakha103, Sakha105 × Sakha103, and Sakha105 × IRAT112 showed positive SCA effects for grain yield per plant in both conditions. The hybrids examined included various parental combinations, such as high x high, high x low and low x low. This indicates the genetic interactions involving either additive x additive, additive x dominance and/or dominance x dominance were the most common. The crosses may be superior due to complementary and duplicate gene interactions. Therefore, hybrids are anticipated to yield favorable offspring and can be effectively utilized in breeding initiatives. Previous studies have found similar results as published by references (Panda et al., 2021, Gupta et al., 2020, Kumari Priyanka, 2014, Hassan et al., 2016).

Based on the above discussion, it can be inferred that the crosses Wab880 SG 33 × IRAT112 exhibit heterosis in root and Agro-physiological properties. Therefore, it can be utilized in future generations to enhance the majority of these analyzed characteristics. The same outcomes were achieved using references (MOHAN et al., 2021, Rohit et al., 2022, Sunny et al., 2021). The presence of strong hybrid vigor in various crosses regarding grain production indicates that a hybrid breeding program could be beneficially conducted for rice under water deficit conditions. The crosses, Sakha107 × ARS.105-2-1-1-2, exhibit heterosis in various characteristics, particularly grain yield. Therefore, it can be utilized in future generations to enhance the majority of the features that were examined. Multiple scientists including those referenced in citations (Hassan et al., 2011, Kushal et al., 2023, Rohit et al., 2022), reported comparable findings.

CONCLUSION

Drought is a tough phenomenon that can significantly decrease agricultural productivity and potentially jeopardize food security. Rice, the primary staple crop, is significantly impacted by water deficit stress. Among the twenty-eight rice hybrids examined, the cross pairings Wab880 SG 33 × IET1444 and IRAT112 × ARS.105-2-1-1-2 were identified as the most effective for root characteristics under conditions of water deficit. The crossovers Wab880 SG 33 × IRAT112 and

Sakha107 × IRAT112 were identified as the most effective cross combinations for the majority of agro-physiological attributes in conditions of water deficit. The cross combinations Giza177 × IRAT112 and Sakha107 × ARS.105-2-1-1-2 were identified as the most optimal for yield and its components traits in both situations. The parents IET1444, Wab880 SG 33, and Sakha107 rice genotypes were identified as the best general combiners based on their highly substantial GCA impacts for root, agro-physiological, and yield traits examined under both conditions. The heterotic cross Wab880 SG 33 × IRAT112 showed superior performance in root and agro-physiological traits, while Sakha107 × ARS.105-2-1-1-2 excelled in yield and its components traits under both situations. Significant estimates of heterosis and heterobeltiosis were observed in Wab880 SG 33 × IRAT112 for root and agro-physiological traits. The variation in better parent heterosis across different crosses can be attributed to the diverse genetic backgrounds of the parents. The parents and hybrids showing favorable significant GCA and SCA effects, along with high values of relative heterosis and heterobeltiosis, should undergo additional testing to enhance the breeding program for water scarcity stress.

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تحسين المصادر الوراثيه للأرز من خلال إجراء التهجينات التفاضليه لإنتاج هجن جديده تحت ظروف الرى المنتظم وندرة المياه.

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الملخـص

تم زراعة ٣٦ تركيب وراثى (٨ آباء و ٢٨ هجين) بإستخدام تصميم القطاعات الكاملة العشوائية فى ثلاث مكررات بنظام التهجين التبادلى بدون الهجن العكسية وذلك فى تجربة قيمت فى المزرعة البحثية لقسم بحوث الأرز سخا – كفر الشيخ – مصر وذلك خلال موسمى زراعة الأرز ٢٠٢٢ – ٢٠٢٣ وذلك بهدف دراسة تحسين المصادر الوراثيه للأرز من خلال إجراء التهجينات التفاضلية لإنتاج هجن جديدة تحت ظروف الرى المنتظم وندرة المياه. أوضحت النتائج أن النسبة بين كل من تباين القدرة العامة على التآلف و تباين القدرة الخاصة على التآلف أكبر من الواحد الصحيح دل ذلك على أهمية الفعل الجينى المضيف والفعل الجينى المضيف × المضيف فى التحكم فى السلوك الوراثى لمعظم الصفات المدروسة. كما أوضحت تأثيرات القدرة العامة على الإئتلاف أن الأباء أى إى تى ١٤٤٤ , واب ٨٨٠ إس جى ٣٣ و سخا ١٠٧ كانوا أفضل الأباء فى معظم الصفات المدروسة. كانت الهجن واب ٨٨٠ إس جى ٣٣ × أى إى تى ١٤٤٤ وإرات ١١٢ × أ أر إس ١٠٥- ٢- ١- ١- ٢ لمعظم صفات الجذور, واب ٨٨٠ إس جى ٣٣ × إرات ١١٢ وسخا ١٠٧ × إرات ١١٢ لمعظم الصفات الفسيولوجيه وكذلك جيزه ١٧٧× إرات ١١٢و سخا ١٠٧ × أ أر إس ١٠٥- ٢- ١- ١- ٢ لمعظم صفات المحصول ومكوناته كانوا جميعا" افضل الهجن قدره خاصه على التالف تحت ظرف ندرة المياه. أظهر الهجين واب ٨٨٠ إس جى ٣٣ × إرات ١١٢ معنوية عالية وموجبة كإنحراف عن قيم متوسط وأفضل الأبوين لمعظم صفات الجذور والصفات الفسيولوجيه كذلك أظهر الهجين سخا ١٠٧ × أ أر إس ١٠٥- ٢- ١- ١- ٢ معنويه عاليه وموجبه لصفات المحصول ومكوناته تحت الظروف العادية وظروف ندرة المياه.