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# Inheritance Analysis of Grain Yield and Contributing Traits in Rice Through Six Populations Under Normal and Water Deficit Conditions

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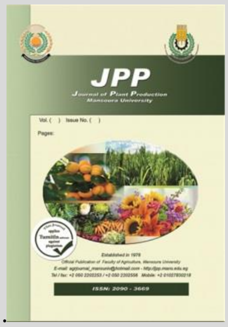


## ABSTRACT

Inheritance of yield and yield contributing traits for three crosses namely Sakha 108/IET 1444, Sakha 104/IRAT 170, and Sakha 107/Moroberekan were used to evaluate six populations including $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ for each cross. Scaling test results highlighted the importance of epistatic interactions for all the studied traits in the three crosses. Significant negative additive gene effects were observed under normal and water deficit conditions for most traits across the three crosses. There were some exceptions regarding the days to heading, which did not show significant effects for the first and second crosses under normal conditions, as well as for the first cross under water deficit conditions. However, all three crosses under normal conditions significantly affected grain yield per plant. In contrast, for the third cross under water deficit conditions, the effects were both significant and highly significant under positive gene action. The majority of traits exhibited positive and significant heterosis over the mid and better parents, except the second cross on fertility percentage and the third cross on heading date, which showed negative and highly significant heterosis. The heritability values in the narrow sense were found to be low to moderate for all the traits studied. These values ranged from 27.24% for grain yield per plant in the first cross to 57.74% for 100-grain weight in the third cross under normal conditions. Under water stress conditions, the dominance effect was found to play a significant role in the inheritance of these traits.

***Keywords***: Rice, scaling test, gene action, epistasis, and water deficit

## INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world and a significant food crop for over 50% of the global population. It is the main diet for most people in South and Southeast Asia. Rice grains provide approximately 23% of the world's energy and 16% of protein per capita (Surya 2024). Globally, rice is cultivated on over 160 million hectares, resulting in an annual production of about 740 million tons (Kumar *et al.* 2018). Rice is a semi-aquatic plant belonging to the grass family and is not well-suited to dry environments. It is more sensitive to water shortages than other important cereals in this family. To enhance productivity in aerobic or water-limited conditions, rice needs to adapt from its typical preference for flooded environments (Panda and Jijnasa 2021). One major abiotic stressor that restricts rice production globally is drought. Thirty percent of rice-growing regions suffer from water scarcity and moisture stress. Drought causes over 18 million tons of rice to be lost each year in rain-fed and irrigated areas, costing $650 million in lost revenue (Wassmann *et al.* 2009).

Breeding for water shortage tolerance has emerged as a major breeding priority for rice programs, particularly in Egypt because the River Nile provides a limited amount of water for irrigation. Water shortages occur in some rice-growing regions at different stages of growth, particularly at the terminal of irrigation canals in the northern Nile Delta. This lack of irrigation is one of the most serious constraints on rice production (Abdallah 2009). In the rice breeding program, enhancing tolerance to abiotic stress is highly desirable (Lee *et al.* 2017). Additionally, selecting drought tolerance in rice cultivars is considered a crucial trait (Rahman *et al.* 2022). Under water-limited conditions, grain yield and its component traits are significantly affected, particularly in sensitive rice genotypes. In contrast, tolerant genotypes possess mechanisms that help them endure drought stress (Gaballah *et al.* 2020). Hybridization is an essential method for improving stress tolerance in rice. Determining gene effects, heritability, and the identification of novel genes that can help plant breeding programs generate stress-tolerant rice all depend on screening the types of gene action in offspring. Selecting the best breeding techniques for genotype development programs requires knowledge of genetic components, heritability, heterosis, and genetic actions (Ahmed *et al.* 2023).

Genetic actions involve additive and dominant influences and their interactions, which are linked to breeding value (Begna 2021). Furthermore, the high genetic advance values and heritability indicate that additive gene action is predominant and that early generations can successfully carry out trait selection. Therefore, selecting genotypes based on these traits would be more successful for targeted plant selection (Admas *et al.* 2024). Furthermore, generation means analysis is a useful technique for determining if epistasis is present or absent and for measuring different aspects of genetic variance. To establish an effective breeding program, studying the genetics of yield and its component traits is crucial. Numerous morphological and agronomic traits, such as duration, plant height, number of panicles per plant, panicle length, number of filled grains

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per panicle, sterility percentage, 1000-grain weight, and grain yield per plant, were found to be significantly impacted by the analysis of additive and dominant genes. This study specifically aimed to estimate the type of gene action that regulates significant agronomic traits in rice populations under different conditions and to determine the best breeding selection methods for enhancing drought tolerance traits.

## MATERIALS AND METHODS

**Plant material and conditions**

This investigation was conducted during the three growing successive seasons of 2021, 2022, and 2023 at the experimental farm of Rice Research and Training Center Sakha, Kafr El-Sheikh, Egypt. The genetic resources utilized in this investigation represented six genetically diverse genotypes, i.e., Sakha 108, Sakha 104, Sakha 107, IET 1444, IRAT 170, and Moroberekan. The pedigree and characteristics of the parental rice genotypes are shown in Table 1. With the goal of generating the six experimental populations utilized in the present study, three crosses among the parental genotypes were carried out. The original three crosses were Sakha 108/IET 1444, Sakha 104/IRAT 170, and Sakha 107/Moroberekan, developed during the 2021 growing season.

In 2022, $F_1$ plants were produced as single plants after being selfed and backcrossed to each parent to collect $F_2$ and backcross seeds, the three crosses were recrossed again in the same season to produce their $F_1$ seeds. In 2023, two randomized complete block design (RCBD) experiments with three replicates were conducted. The first experiment was normally irrigated (4-day irrigation intervals), and the second was carried out under water deficit conditions (12-day irrigation intervals). Each experiment was sown, including the plants of $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ for each cross.

**Table 1. The pedigree and characteristics of parental rice genotypes**

| No | Genotype | Parentage | Origin | Drought reaction | Type |
|---|---|---|---|---|---|
| 1 | Sakha 108 | Sakha101/HR5824-B-3-2-3/Sakha101 | Egypt | Sensitive | Japonica |
| 2 | Sakha 104 | GZ 4096-8-1/GZ 4100-9-1 | Egypt | Moderate | Japonica |
| 3 | Sakha 107 | Giza177/BL1 | Egypt | Tolerant | Japonica |
| 4 | IET 1444 | TN 1/CO 29 | India | Tolerant | Indica |
| 5 | IRAT 170 | IRAT 13/Palawan | Côte d'Ivoire | Moderate | Indica |
| 6 | Moroberekan | Not available | Guinea | Tolerant | Japonica |

Each replication consisted of 10 rows of $F_2$ plants and four rows for the other populations from the three crosses. Each row was five meters long, with 20 x 20 cm spacing between rows and hills. Data were collected from individual guarded plants, 30 plants for $F_1$ generations, 100 for backcrosses, and 200 for $F_2$ generations of the six populations in each cross. The traits measured included heading date (day), plant height (cm), flag leaf area (cm²), panicle length (cm), number of panicles per plant, panicle weight (g), 100-grain weight (g), fertility percentage (%), and grain yield per plant (g). All recommended agricultural practices for rice production were applied on time.

**Statistical and genetic analysis**

Statistical and genetic parameters for each cross were calculated in each generation. A scaling test, as described by Mather (1949), was employed to assess the presence or absence of non-allelic interactions. The probability of interallic interaction was tested by calculating the variance of the scalls A, B, C, and D. By taking the square root of each of their variances, the standard errors for A, B, C, and D were determined. By dividing the effects of A, B, C, and D by their corresponding standard errors, the T-test was computed. According to the Gamble (1962) six-parameter model, the following types of gene effects were estimated: M=Mean = $F_2$, additive (a), dominance (d), additive x additive (aa), additive x dominance (ad), and dominance x dominance (dd).

The formula of Mather (1949) and Mather and Jinks (1982) was used to compare the F1 mean performance to the mid-parent and better-parent average values to assess the degree of heterosis revealed in individual crosses. Inbreeding depression was determined by Wynn *et al.* (1970) as the percentage difference between the $F_1$ and $F_2$ means. The standard error (S.E.) was computed as follows: $F_1$-Bp / $(VF1+VBp)^{1/2}$, the significance of these deviations was assessed using a T-test. S-E for inbreeding depression was estimated as follows: $F_1–F_2= (VF_1+VF_2)^{1/2}$. Both the broad and narrow senses of heritability were measured by Mather (1949), and Johnson *et al*. (1955) determined the predicted genetic gain from selection (Δg).

## RESULTS AND DISCUSSION

**Mean performance**

The mean performance of the three crosses for the six populations ($P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$) of the nine traits under study are presented in Table 2. Significant generational differences existed for all the studied traits, from normal irrigation to deficit irrigation conditions. The performance disparities among the three cross populations for all traits were notable. Considering all crosses provided earlyness by water shortage stress, the days to heading of populations varied between normal and water stress irrigation. The third cross (Sakha107/Moroberekan) was the earliest cross, with values of 95.30, 110.53, 98.97, 95.65, 99.65, and 108.87 days under normal conditions and 88.43, 106.20, 98.77, 94.93, 98.93, and 107.61 days under stressful conditions of water scarcity for $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ populations, respectively. Similar results were obtained by Solanke et al. (2019). Regarding plant height, the first cross (Sakha 108/IET 1444) indicated the shortest mean values under normal conditions, the $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ populations of plant heights were measured at 96.20 cm, 106.37 cm, 131.63 cm, 125.20 cm, 118.88 cm, and 121.23 cm, respectively. In contrast, under water-deficit conditions, the heights for the same trait were 80.13 cm, 77.63 cm, 104.23 cm, 107.73 cm, 92.80 cm, and 99.93 cm.

Concerning panicle length trait, the highest values were 22.34, 29.56, 33.27, 28.48, 26.56, and 30.5 cm for normal conditions, while under water deficit conditions the values 18.96, 23.63, 25.26, 21.57, 21.59 and 25.2 cm were recorded for $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$, respectively. Under normal irrigation, the number of panicles plant-1 trait had superior values of 21.57, 25.07, 31.03, 24.33, 24.21, and 28.21; however, under conditions of water scarcity, the values decreased, with the maximum values for six populations being 14.63, 18.97, 25.93, 17.67, 17.23, and

20.63, respectively. For panicle weight, the heaviest panicles for normal conditions were 4.48, 6.64, 6.72, 5.62, 5.15, and 6.51 g for the third cross, while the heaviest panicles under water deficit conditions were achieved with the third cross by 2.78, 4.09, 4.35, 3.66, 3.14 and 4.2 g values. Concerning 100-grain weight (g), the highest values obtained for six populations were 2.89, 3.36, 3.18, 2.98, 2.98, and 3.1 g under normal conditions, while under drought were 2.39, 2.89, 2.96, 2.66, 2.76 and 2.85 g, respectively.

**Table 2. Mean and variances of three crosses for grain yield and its component traits under both normal and water-deficit conditions**

| Trait | Cross | Mean and variation | $P_1$ | | $P_2$ | | $F_1$ | | $F_2$ | | $BC_1$ | | $BC_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | D | N | D | N | D | N | D | N | D | N | D |
| Heading date (day) | $C_1$ | $\bar{X}$ | 108.63 | 105.50 | 96.33 | 94.90 | 118.5 | 110.53 | 105.89 | 103.87 | 112.61 | 106.80 | 108.68 | 104.92 |
| | | $S^2$ | 2.17 | 1.98 | 1.75 | 2.16 | 2.81 | 2.40 | 36.15 | 49.78 | 34.67 | 42.41 | 27.44 | 42.75 |
| | $C_2$ | $\bar{X}$ | 103.60 | 95.97 | 94.67 | 93.33 | 110.93 | 109.63 | 106.91 | 105.03 | 109.8 | 108.37 | 100.55 | 100.05 |
| | | $S^2$ | 2.52 | 1.83 | 2.30 | 2.02 | 2.89 | 2.03 | 36.54 | 34.68 | 32.43 | 30.32 | 28.49 | 30.02 |
| | $C_3$ | $\bar{X}$ | 95.30 | 88.43 | 110.53 | 106.20 | 98.97 | 98.77 | 95.65 | 94.93 | 99.65 | 98.93 | 108.87 | 107.61 |
| | | $S^2$ | 1.67 | 2.39 | 2.33 | 2.58 | 2.38 | 1.56 | 40.18 | 40.48 | 33.55 | 35.95 | 30.85 | 38.73 |
| Plant height (cm) | $C_1$ | $\bar{X}$ | 96.20 | 80.13 | 106.37 | 77.63 | 131.63 | 104.23 | 125.21 | 107.73 | 118.88 | 92.80 | 121.23 | 99.93 |
| | | $S^2$ | 1.54 | 1.91 | 2.24 | 2.24 | 1.83 | 2.25 | 42.41 | 60.39 | 35.00 | 58.54 | 37.34 | 47.55 |
| | $C_2$ | $\bar{X}$ | 105.20 | 86.50 | 128.3 | 98.20 | 138.8 | 119.60 | 128.18 | 101.7 | 120.24 | 100.59 | 133.12 | 111.01 |
| | | $S^2$ | 1.48 | 1.98 | 2.56 | 2.17 | 2.86 | 2.04 | 50.19 | 55.90 | 39.13 | 48.84 | 35.97 | 52.23 |
| | $C_3$ | $\bar{X}$ | 103.80 | 79.27 | 150.60 | 115.63 | 166.6 | 122.60 | 127.71 | 106.95 | 121.21 | 95.63 | 144.52 | 118.61 |
| | | $S^2$ | 2.23 | 1.72 | 2.80 | 2.65 | 2.59 | 2.46 | 53.06 | 47.37 | 41.93 | 34.02 | 40.47 | 42.27 |
| Flag leaf area ($cm^2$) | $C_1$ | $\bar{X}$ | 31.30 | 19.27 | 51.70 | 30.17 | 58.43 | 33.37 | 46.30 | 28.54 | 38.76 | 27.25 | 53.53 | 30.97 |
| | | $S^2$ | 2.91 | 1.86 | 2.63 | 1.80 | 2.39 | 2.86 | 63.98 | 30.37 | 50.70 | 27.33 | 47.05 | 23.74 |
| | $C_2$ | $\bar{X}$ | 25.81 | 18.95 | 48.40 | 36.59 | 52.53 | 39.91 | 42.96 | 31.29 | 33.21 | 26.44 | 50.05 | 38.14 |
| | | $S^2$ | 2.50 | 1.58 | 2.87 | 2.04 | 2.26 | 2.04 | 58.77 | 25.21 | 47.04 | 19.72 | 50.63 | 22.59 |
| | $C_3$ | $\bar{X}$ | 28.03 | 16.63 | 60.93 | 49.57 | 55.60 | 45.43 | 44.51 | 36.07 | 35.6 | 25.21 | 50.89 | 39.48 |
| | | $S^2$ | 2.03 | 2.52 | 2.82 | 2.46 | 3.08 | 2.87 | 65.85 | 26.16 | 55.35 | 22.20 | 44.07 | 19.63 |
| Panicle length (cm) | $C_1$ | $\bar{X}$ | 22.34 | 15.81 | 26.84 | 20.93 | 28.70 | 24.00 | 26.29 | 20.21 | 24.67 | 20.06 | 27.53 | 22.62 |
| | | $S^2$ | 1.28 | 0.51 | 1.50 | 0.89 | 1.43 | 0.76 | 20.12 | 16.78 | 12.96 | 12.76 | 16.48 | 14.12 |
| | $C_2$ | $\bar{X}$ | 21.95 | 18.96 | 28.28 | 22.03 | 31.50 | 25.23 | 28.48 | 20.78 | 25.27 | 20.41 | 30.50 | 22.14 |
| | | $S^2$ | 1.63 | 0.77 | 1.08 | 0.72 | 1.29 | 1.03 | 19.62 | 16.65 | 15.65 | 13.59 | 17.85 | 15.32 |
| | $C_3$ | $\bar{X}$ | 21.90 | 18.07 | 29.56 | 23.63 | 33.27 | 25.26 | 26.88 | 21.57 | 26.56 | 21.59 | 29.99 | 25.20 |
| | | $S^2$ | 1.70 | 0.62 | 1.74 | 0.65 | 1.58 | 0.96 | 22.75 | 17.99 | 16.08 | 15.10 | 19.40 | 13.34 |
| Number of panicles $plant^{-1}$ | $C_1$ | $\bar{X}$ | 20.60 | 10.07 | 25.07 | 18.97 | 31.03 | 25.93 | 24.33 | 17.67 | 24.21 | 13.65 | 28.21 | 20.63 |
| | | $S^2$ | 2.59 | 0.69 | 2.62 | 0.86 | 1.90 | 2.13 | 36.99 | 22.49 | 30.52 | 18.18 | 32.12 | 18.56 |
| | $C_2$ | $\bar{X}$ | 21.57 | 13.43 | 12.33 | 10.20 | 23.67 | 18.57 | 18.30 | 13.34 | 22.53 | 17.23 | 14.48 | 10.97 |
| | | $S^2$ | 3.22 | 0.94 | 2.78 | 0.79 | 2.78 | 1.77 | 39.67 | 23.23 | 23.09 | 19.26 | 36.36 | 15.95 |
| | $C_3$ | $\bar{X}$ | 18.63 | 14.63 | 11.23 | 8.63 | 22.13 | 15.03 | 19.52 | 13.63 | 21.57 | 15.43 | 18.59 | 12.76 |
| | | $S^2$ | 2.79 | 0.93 | 1.91 | 0.65 | 3.02 | 2.03 | 35.12 | 24.29 | 27.14 | 19.17 | 29.87 | 20.64 |
| Panicle weight (g) | $C_1$ | $\bar{X}$ | 3.58 | 2.50 | 4.21 | 2.13 | 5.07 | 2.68 | 4.72 | 2.54 | 3.98 | 2.60 | 4.78 | 2.39 |
| | | $S^2$ | 0.09 | 0.01 | 0.09 | 0.01 | 0.05 | 0.02 | 1.02 | 0.30 | 0.96 | 0.26 | 0.70 | 0.29 |
| | $C_2$ | $\bar{X}$ | 4.48 | 2.78 | 5.82 | 3.97 | 6.14 | 4.27 | 5.05 | 3.64 | 5.15 | 2.91 | 6.06 | 3.84 |
| | | $S^2$ | 0.05 | 0.02 | 0.06 | 0.02 | 0.09 | 0.01 | 0.95 | 0.24 | 0.64 | 0.19 | 0.86 | 0.21 |
| | $C_3$ | $\bar{X}$ | 3.58 | 2.78 | 6.64 | 4.09 | 6.72 | 4.35 | 5.62 | 3.66 | 4.23 | 3.14 | 6.51 | 4.20 |
| | | $S^2$ | 0.07 | 0.01 | 0.10 | 0.02 | 0.10 | 0.01 | 1.08 | 0.36 | 0.87 | 0.32 | 0.98 | 0.29 |
| 100-grain weight (g) | $C_1$ | $\bar{X}$ | 2.89 | 2.39 | 2.36 | 1.94 | 2.69 | 2.46 | 2.57 | 2.19 | 2.70 | 2.21 | 2.46 | 2.29 |
| | | $S^2$ | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.18 | 0.18 | 0.14 | 0.14 | 0.15 | 0.15 |
| | $C_2$ | $\bar{X}$ | 2.61 | 2.36 | 3.12 | 2.89 | 3.18 | 2.96 | 2.95 | 2.66 | 2.86 | 2.49 | 3.10 | 2.85 |
| | | $S^2$ | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.14 | 0.19 | 0.11 | 0.17 | 0.12 | 0.14 |
| | $C_3$ | $\bar{X}$ | 2.69 | 2.31 | 3.36 | 2.85 | 3.04 | 2.79 | 2.98 | 2.60 | 2.98 | 2.76 | 3.08 | 2.75 |
| | | $S^2$ | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.17 | 0.17 | 0.15 | 0.16 | 0.10 | 0.15 |
| Fertility percentage (%) | $C_1$ | $\bar{X}$ | 92.13 | 74.53 | 91.13 | 79.13 | 94.89 | 81.53 | 91.19 | 80.05 | 92.51 | 78.20 | 92.06 | 79.66 |
| | | $S^2$ | 1.80 | 1.36 | 2.29 | 0.56 | 1.29 | 0.91 | 47.27 | 29.80 | 41.26 | 24.30 | 28.21 | 20.95 |
| | $C_2$ | $\bar{X}$ | 92.93 | 74.67 | 88.94 | 76.83 | 83.30 | 66.68 | 79.62 | 59.99 | 80.11 | 62.51 | 82.67 | 61.56 |
| | | $S^2$ | 1.97 | 0.99 | 2.10 | 0.99 | 1.60 | 0.98 | 56.17 | 24.17 | 44.29 | 19.49 | 40.88 | 18.22 |
| | $C_3$ | $\bar{X}$ | 92.51 | 81.21 | 93.82 | 88.78 | 90.85 | 85.65 | 88.89 | 79.00 | 88.24 | 80.65 | 89.57 | 83.61 |
| | | $S^2$ | 2.85 | 0.71 | 2.27 | 0.86 | 2.00 | 1.02 | 52.20 | 30.58 | 49.91 | 26.11 | 32.14 | 22.79 |
| Grain yield $plant^{-1}$ (g) | $C_1$ | $\bar{X}$ | 43.62 | 25.16 | 35.68 | 24.54 | 44.82 | 28.53 | 41.64 | 26.76 | 44.37 | 27.62 | 38.60 | 26.54 |
| | | $S^2$ | 1.98 | 0.79 | 1.83 | 0.86 | 2.84 | 0.91 | 42.86 | 26.70 | 41.11 | 25.47 | 32.93 | 23.32 |
| | $C_2$ | $\bar{X}$ | 43.91 | 29.58 | 37.89 | 25.84 | 46.81 | 32.95 | 41.51 | 30.23 | 39.62 | 25.63 | 35.31 | 30.09 |
| | | $S^2$ | 2.07 | 1.01 | 2.18 | 1.06 | 2.63 | 1.09 | 45.95 | 23.43 | 40.21 | 20.24 | 34.42 | 21.50 |
| | $C_3$ | $\bar{X}$ | 44.17 | 30.25 | 34.93 | 25.60 | 47.81 | 33.95 | 40.31 | 29.41 | 41.86 | 32.42 | 36.61 | 28.52 |
| | | $S^2$ | 2.15 | 0.95 | 2.02 | 0.91 | 2.16 | 1.03 | 47.33 | 27.66 | 43.28 | 23.4 | 36.86 | 25.26 |

**N: Normal condition; D: Water deficit condition; $C_1$: Sakha108/IET1444; $C_2$: Sakha104/IRAT170; $C_3$: Sakha107/Moroberekan**

The highest desirable values for fertility percentage were 92.93%, 93.82%, 94.89%, 91.19%, 92.51%, and 92.06% under normal conditions, while the best values under water deficit conditions were 81.21%, 88.78%, 85.65%, 80.05%, 80.65%, and 83.61%. The maximum values for grain yield plant$^{-1}$ were 44.17, 37.89, 47.81, 41.64, 44.37, and 38.6 g, while the best values under water shortage conditions were 30.25, 25.84, 33.95, 30.23, 32.42, and 30.09 g for $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$, and $BC_2$ populations, respectively. Days to heading is a crucial characteristic that should be examined in each generation, and the early segregating generation should be chosen based on its maturity days and panicle length, according to Ganapati et al. (2020).

**Yield and yield component inheritance**

The three crosses estimated scaling test parameters (A, B, and C) for the traits under study in both normal and water-deficit conditions are shown in Table 3. Scaling test parameters revealed substantial results that indicate the additive-dominance model is not enough for comprehending the gene effects present in the materials. These characteristics are inherited in large part due to epistasis contributions. The estimated parameters of the scaling test were significant for all the studied traits, with the possible exception of A scale at heading date in the first cross, number of panicles in the second and third crosses, panicle weight at the second cross, 100-grain weight at the first and second crosses, panicle length, fertility percentage, and grain yield per plant at the first cross under normal conditions. In contrast, the first cross of heading date, plant height, flag leaf area, panicle weight, panicle length, fertility percentage, and grain yield per plant, as well as the third cross of panicle number and grain yield per plant, were all affected by water deficiency. Additionally, the B scale includes several parameters for different crosses of plants. Under normal conditions, the following traits are considered insignificant: the second cross for plant height, the first cross for flag leaf area, the number of panicles, the weight of the panicles, the 100-grain weight for both the first and second crosses, the length of the panicles, and the fertility percentage for the first cross. In contrast, under water deficit conditions, the B scale includes the following parameters that are noteworthy: the heading date for the second cross, plant height for the third cross, the number of panicles and panicle weight for the first and third crosses, the 100-grain weight for the second and third crosses, the panicle length for the first and third crosses, the fertility percentage for the first cross, and the grain yield per plant for both the first and second crosses.

In the analysis of the C scale, the following evaluations were conducted: plant height was measured at the second cross, 100-grain weight at the third cross, panicle length at both the first and second crosses, and grain yield per plant at the first cross under normal conditions. Regarding the C scale related to heading date, assessments were made on the flag leaf area, the number of panicles at the third cross, panicle weight at the first cross, and grain yield per plant at both the first and second crosses, all under water deficit conditions. The findings indicate that the six-parameter model is effective in explaining the nature of gene action for these traits. In contrast, the A, B, and C scaling tests did not yield significant results for plant height, the number of panicles per plant, and grain yield per plant. Additionally, the interaction model did not clarify the type of gene action involved. These results align with previous reports of Hassan *et al.* (2023), where at least one of the computed parameters (A, B, or C) from the scaling test was significant for all the traits studied. This suggests that the genetic control of these characteristics is influenced by allelic interactions.

**Table 3. Scaling test of three rice crosses for the studied traits under normal and water-deficit conditions.**

| Trait | | Heading date (day) | | | Plant height (cm) | | | Flag leaf area (cm$^2$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ |
| Normal | A | -1.91 | 5.07** | 5.04** | 9.93** | -3.52* | -27.97** | -12.22** | -11.93** | -12.43** |
| | B | 2.53* | -4.51** | 8.23** | 4.45** | -0.86 | -28.16** | -3.07 | -0.84 | -14.76** |
| | C | -18.42** | 7.52** | -21.18** | 34.99** | 1.62 | -76.78** | -14.65** | -7.42** | -22.12** |
| Water-deficit | A | 0.57 | 13.13** | 12.67** | 1.23 | -4.93** | -10.61** | 1.86 | -5.98** | -11.65** |
| | B | 5.41** | -1.07 | 5.26** | 18.00** | 4.23* | -1.01 | -1.60 | -0.216 | -16.04** |
| | C | 14.00** | 19.54** | -1.46 | 64.67** | -17.10** | -12.31** | -2.00 | -10.19** | -12.78** |
| Trait | | Number of panicles plant$^{-1}$ | | | Panicle weight (g) | | | 100-grain weight (g) | | |
| | | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ |
| Normal | A | -3.21* | -0.17 | 2.38 | -0.70** | -0.33 | -1.85** | -0.18 | -0.08 | 0.22* |
| | B | 0.33 | -7.04** | 3.81** | 0.28 | 0.16 | -0.33 | -0.13 | -0.09 | -0.24** |
| | C | -10.40** | -8.03** | 3.95* | 0.97** | -2.40** | -1.20** | -0.35** | -0.31** | -0.23 |
| Water deficit | A | -8.69** | 2.45* | 1.19 | 0.02 | -1.25** | -0.85** | -0.42** | -0.34** | 0.41** |
| | B | -3.63** | -6.82** | 1.85 | -0.03 | -0.56** | -0.04 | -6.89** | -0.14 | -0.13 |
| | C | -10.23** | -7.41** | 1.20 | 0.16 | -0.72** | -0.93** | -7.55** | -0.53** | -0.34** |
| Trait | | Panicle length (cm) | | | Fertility percentage (%) | | | Grain yield plant$^{-1}$ (g) | | |
| | | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ |
| Normal | A | -1.69 | -2.92** | -2.05* | -2.01 | -16.01** | -6.86** | 0.31 | -11.48** | -8.27** |
| | B | -0.48 | 1.23 | -2.84** | -1.915 | -6.90** | -5.52** | -3.29* | -14.09** | -9.52** |
| | C | -1.42 | 0.70 | -10.45** | -8.29** | -29.99** | -12.43** | -2.39 | -9.36** | -13.46** |
| Water-deficit | A | 0.32 | -3.37** | -0.14 | 0.33 | -16.33** | -5.56** | 1.56 | -11.27** | 0.64 |
| | B | 0.32 | -2.98** | 1.50 | -1.34 | -20.39** | -7.21** | 0.01 | 1.38 | -2.52* |
| | C | -3.92** | -8.34** | -5.95** | 3.49* | -44.87** | -25.28** | 0.29 | -0.40 | -6.10** |

**$C_1$: Sakha108/IET1444; $C_2$: Sakha104/IRAT170; $C_3$: Sakha107/Moroberekan. * and ** significant at 0.05 and 0.01 levels of probability, respectively**

The estimated mean effect parameter (m) was found to be highly significant for all studied traits across all crosses, both under normal and water deficit conditions (Table 4). The means of the different generations were used to determine the various genetic effects (Kumar *et al.* 2018). Significant negative additive gene effects (a) were observed for most traits in three crosses under both normal and water deficit conditions. However, there were exceptions: for the first and second crosses under normal conditions, days to heading showed no significant effects, as did the first cross under water deficit. Additionally, the number of panicles for the second and third crosses did not demonstrate significant effects under either condition. In the case of panicle weight, a significant negative effect was observed only under drought conditions for the first cross. Similarly, the 100-grain weight for the first cross was significant only under normal growing conditions, while grain yield per plant was significant for all three crosses under the same conditions. In contrast, the third cross showed significant and highly significant positive gene action effects when subjected to water deficit conditions.

The additive gene action was found to be insignificant for the 100-grain weight in the first cross under water deficit conditions, as well as in the second cross under both normal and water deficit conditions. However, Simple pedigree selection can be used to effectively use the additive component of variance. A cost-effective and efficient approach would involve mass selection in the early generations, aimed at improving heterozygous populations by adjusting the frequencies of desirable genes, followed by single-plant selection from the resulting material. These findings are reported previously by Vinoth *et al.* (2015) and Kumar *et al.* (2017). The estimates of dominance effects were predominantly positive and highly significant for most crosses, with a few exceptions. Specifically, the traits related to heading date and plant height in the first cross, as well as the 100-grain weight in the first cross under water deficit conditions, did not show significant dominance effects. However, grain yield per plant was significantly negative under both normal and water deficit conditions, underscoring the importance of dominance gene effects in the inheritance of these traits. It is also important to note that no significant dominance gene action effects were observed in some crosses. These findings align with those reported by Sultana *et al.* (2016) regarding grains per panicle and 100-grain weight traits.

**Table 4. Type of gene action for studied traits of three rice crosses under normal and water-deficit conditions.**

| Trait | Cross | M | | a | | d | | aa | | ad | | dd | | Epistasis type | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| Heading date (day) | $C_1$ | 105.89$^{**}$ | 95.87$^{**}$ | 3.93$^{**}$ | -10.1$^{**}$ | 35.08$^{**}$ | -9.69$^{**}$ | 19.04$^{**}$ | -8.03$^{**}$ | -2.22$^{*}$ | -2.4$^{*}$ | -19.6$^{**}$ | 2.05 | D | d |
| | $C_2$ | 106.91$^{**}$ | 110.03$^{**}$ | 9.25$^{**}$ | 6.43$^{**}$ | 4.84 | 9.52$^{**}$ | -6.96$^{**}$ | -7.47$^{**}$ | 4.79$^{**}$ | 7.11$^{**}$ | 6.40 | -4.61 | C | d |
| | $C_3$ | 95.63$^{**}$ | 103.93$^{**}$ | -9.21$^{**}$ | -9.68$^{**}$ | 30.50$^{**}$ | 24.34$^{**}$ | 34.45$^{**}$ | 19.39$^{**}$ | -1.60 | 3.70$^{**}$ | -47.70$^{*}$ | -37.30$^{**}$ | D | d |
| Plant height (cm) | $C_1$ | 125.21$^{**}$ | 107.73$^{**}$ | -2.35$^{*}$ | -7.13$^{**}$ | 9.74$^{**}$ | -20.1$^{**}$ | -20.6$^{**}$ | -45.4$^{**}$ | 2.74$^{**}$ | -8.4$^{**}$ | 6.23 | 26.21$^{**}$ | C | d |
| | $C_2$ | 128.18$^{**}$ | 101.70$^{**}$ | -12.8$^{**}$ | -10.4$^{**}$ | 16.05$^{**}$ | 43.65$^{**}$ | -6.00$^{*}$ | 16.40$^{**}$ | -1.33 | -4.5$^{**}$ | 10.38$^{*}$ | -15.7$^{**}$ | C | d |
| | $C_3$ | 127.7$^{**}$ | 106.95$^{**}$ | -23.3$^{**}$ | -22.9$^{**}$ | 60.01$^{**}$ | 25.84$^{**}$ | 20.61$^{**}$ | 0.69 | 0.09 | -4.8$^{**}$ | 35.52$^{**}$ | 10.93$^{**}$ | C | c |
| Flag leaf area ($cm^2$) | $C_1$ | 46.30$^{**}$ | 28.54$^{**}$ | -14.7$^{**}$ | -3.72$^{**}$ | 16.30$^{**}$ | 10.92$^{**}$ | -0.63 | 2.26 | -4.5$^{**}$ | 1.73$^{*}$ | 15.91$^{**}$ | -2.52 | C | d |
| | $C_2$ | 42.96$^{**}$ | 31.29$^{**}$ | -16.8$^{**}$ | -11.7$^{**}$ | 10.08$^{**}$ | 16.13$^{**}$ | -5.35 | 3.99 | -5.5$^{**}$ | -2.8$^{**}$ | 18.12$^{**}$ | 2.21 | C | c |
| | $C_3$ | 44.51$^{**}$ | 36.07$^{**}$ | -15.3$^{**}$ | -14.2$^{**}$ | 6.05 | -2.58 | -5.07 | -14.9$^{**}$ | 1.17 | 2.20$^{**}$ | 32.26$^{**}$ | 42.60$^{**}$ | C | d |
| Panicle length (cm) | $C_1$ | 26.29$^{**}$ | 20.21$^{**}$ | -2.86$^{**}$ | -2.56$^{**}$ | 3.36 | 10.19$^{**}$ | -0.75 | 4.56$^{**}$ | -0.6 | 0.001 | 2.92 | -5.19 | C | d |
| | $C_2$ | 28.48$^{**}$ | 20.78$^{**}$ | -5.23$^{**}$ | -1.73$^{**}$ | 4.00$^{*}$ | 6.73$^{**}$ | -2.39 | 1.99 | -2.07$^{**}$ | -0.20 | 4.08 | 4.35 | C | c |
| | $C_3$ | 26.88$^{**}$ | 21.57$^{**}$ | -3.44$^{**}$ | -3.60$^{**}$ | 13.10$^{**}$ | 11.72$^{**}$ | 5.57$^{**}$ | 7.31$^{**}$ | 0.4 | -0.82 | -0.68 | -8.66$^{**}$ | D | d |
| Number of panicles plant$^{-1}$ | $C_1$ | 24.33$^{**}$ | 17.67$^{**}$ | -4.00$^{**}$ | -6.97$^{**}$ | 15.72$^{**}$ | 9.31$^{**}$ | 7.52$^{**}$ | -2.11 | -1.77 | -2.5$^{**}$ | -4.64 | 14.45$^{**}$ | D | c |
| | $C_2$ | 18.30$^{**}$ | 13.34$^{**}$ | 8.05$^{**}$ | 6.25$^{**}$ | 7.54$^{**}$ | 9.79$^{**}$ | 0.83 | 3.04 | 3.44$^{**}$ | 4.64$^{**}$ | 6.38 | 1.33 | C | c |
| | $C_3$ | 19.52$^{**}$ | 13.63$^{**}$ | 2.99$^{**}$ | 2.67$^{**}$ | 9.44$^{**}$ | 5.24$^{**}$ | 2.24 | 1.84 | -0.71 | -0.33 | -8.43$^{*}$ | -4.88 | D | d |
| Panicle weight (g) | $C_1$ | 4.72$^{**}$ | 2.54$^{**}$ | -0.80$^{**}$ | 0.21$^{*}$ | -0.21 | 0.2 | -1.38$^{**}$ | -0.16 | -0.49$^{**}$ | 0.02 | 1.79$^{**}$ | 0.16 | D | c |
| | $C_2$ | 5.05$^{**}$ | 3.64$^{**}$ | -0.91$^{**}$ | -0.94$^{**}$ | 3.22$^{**}$ | -0.19 | 2.23$^{**}$ | -1.09$^{**}$ | -0.25 | -0.3$^{**}$ | -2.07$^{**}$ | 2.90$^{**}$ | D | d |
| | $C_3$ | 5.62$^{**}$ | 3.66$^{**}$ | -2.29$^{**}$ | -1.06$^{**}$ | 0.63 | 0.96$^{**}$ | -0.98$^{*}$ | 0.04 | -0.76$^{**}$ | -0.4$^{**}$ | 3.17$^{**}$ | 0.84$^{*}$ | C | c |
| 100-grain weight (g) | $C_1$ | 2.57$^{**}$ | 2.19$^{**}$ | 0.24$^{**}$ | -0.07 | 0.11 | -3.00$^{**}$ | 0.04 | 0.24 | -0.03 | 3.23$^{**}$ | 0.26 | 7.07$^{**}$ | C | c |
| | $C_2$ | 2.95$^{**}$ | 2.66$^{**}$ | -0.24$^{**}$ | -0.37$^{**}$ | 0.46$^{**}$ | 0.38$^{*}$ | 0.14 | 0.05 | 0.01 | -0.1 | 0.03 | 0.43 | C | c |
| | $C_3$ | 2.98$^{**}$ | 2.60$^{**}$ | -0.1 | 0.001 | 0.23 | 0.84$^{**}$ | 0.21 | 0.62$^{**}$ | 0.23$^{**}$ | 0.27$^{**}$ | -0.19 | -0.91$^{**}$ | D | d |
| Fertility percentage (%) | $C_1$ | 91.19$^{**}$ | 80.05$^{**}$ | 0.45 | -1.46 | 7.63$^{**}$ | 0.19 | 4.37 | -4.50$^{*}$ | -0.05 | 0.84 | -0.45 | 5.50 | D | c |
| | $C_2$ | 79.62$^{**}$ | 59.99$^{**}$ | -2.56$^{*}$ | 0.95 | -0.54 | -0.92 | 7.09$^{*}$ | 8.15$^{**}$ | -4.55$^{**}$ | 2.03$^{**}$ | 15.81$^{**}$ | 28.56$^{**}$ | D | d |
| | $C_3$ | 88.89$^{**}$ | 79.00$^{**}$ | -1.33 | -2.96$^{**}$ | -2.26 | 13.17$^{**}$ | 0.06 | 12.51$^{**}$ | -0.67 | 0.83 | 12.32$^{**}$ | 0.26 | D | c |
| Grain yield plant$^{-1}$ (g) | $C_1$ | 41.64$^{**}$ | 26.76$^{**}$ | 5.77$^{**}$ | 1.08 | 4.58 | 4.96$^{*}$ | -0.59 | 1.28 | 1.8 | 0.78 | 3.57 | -2.85 | C | d |
| | $C_2$ | 41.51$^{**}$ | 30.23$^{**}$ | 4.32$^{**}$ | -4.46$^{**}$ | -10.29$^{**}$ | -4.25$^{*}$ | -16.20$^{**}$ | -9.49$^{**}$ | 1.31 | -6.33$^{**}$ | 41.76$^{**}$ | 19.38$^{**}$ | D | d |
| | $C_3$ | 40.31$^{**}$ | 29.41$^{**}$ | 5.25$^{**}$ | 3.90$^{**}$ | 3.93 | 10.24$^{**}$ | -4.33 | 4.22 | 0.63 | 1.58 | 22.11$^{**}$ | -2.34 | C | d |

**N: Normal condition; D: Water deficit condition; $C_1$: Sakha108/IET1444; $C_2$: Sakha104/IRAT170; $C_3$: Sakha107/Moroberekan; * and ** significant at 0.05 and 0.01 levels of probability, respectively**

Regarding the three types of epistasis, significant positive additive/additive epistasis was detected under normal conditions for several traits: heading date in the first and third crosses, plant height in the third cross, panicle length in the third cross, number of panicles per plant in the first cross, panicle weight in the second cross, and fertility percentage in the second cross. Concerning the water deficit condition, significant positive epistasis was found for heading date in the third cross, plant height in the second cross, panicle length in the first and third crosses, 100-grain weight in the third cross, and fertility percentage in the second and third crosses. On the other hand, significant negative additive/additive epistasis was identified for heading date in the first and second crosses under drought conditions and in the second cross under normal conditions. Additionally, negative epistasis was found for plant height in all three crosses under normal conditions and in the first cross under drought conditions. For the flag leaf area, negative epistasis was observed in the third cross under drought conditions. In terms of the number of panicles per plant, negative epistasis was observed in the first cross under drought conditions. For panicle weight, significant negative epistasis was noted in the first and third crosses under normal conditions, as well as in the second cross under drought conditions. Regarding fertility percentage, negative epistasis was identified in the first cross under water deficit conditions and in the second and third crosses under normal conditions for grain yield per plant. Additionally, it was found in the second cross under drought conditions. These findings suggest that additive/additive gene interactions play a significant role in the inheritance of these traits.

The duplicate form of epistasis combined with a non-allelic interaction component may delay the improvement of this trait through selection in the early generations. In these crosses, enhancement could be achieved by the cyclic breeding approach, which selects suitable recombinants and intercrosses them to pool the advantageous genes for creating the elite population. The findings of Chamundeswari *et al.* (2013) and Rani *et al.* (2015) were comparable. As a result, Vadivel *et al.* (2003) noted that the presence of non-additive gene action for grain yield and the majority of its yield components produced a high level of vigor in $F_1$, suggesting that heterosis might be used to increase yield. Furthermore, a less-than-additive or adverse effect was noted in the epistasis of additive-by-additive interactions among QTLs in the pyramiding lines (Tan *et al*. 2022).

In terms of the heading date for the second cross under both conditions, the following traits showed highly significant and positive additive/dominance type epistasis: plant height at the first cross under normal conditions, flag leaf area at the first and third crosses under water deficit conditions, number of panicles under both conditions, 100-grain weight at the first and third crosses under water deficit conditions and at the third cross under normal conditions, and fertility percentage at the second cross under water deficit conditions. It was discovered that the heading date at the first cross under both conditions, plant height at the first, second, and third crosses under water deficit conditions, flag leaf area at the first and second crosses under normal conditions and the second cross under water deficit conditions, panicle weight at the first and third crosses under normal conditions and the second and third crosses under drought conditions, fertility percentage at the second cross under normal conditions, and grain weight for the second cross under water deficit conditions all showed that the additive/dominance type of epistasis gene action was negative and significant. Similar results were found by Saleem *et al*. (2010); Hassan (2011); Khatab *et al.* (2019) and Ghidan and Khedr (2021).

Dominance/dominance type of epistasis, was found to be highly significant and positive for plant height in the second and third crosses under normal conditions. In contrast, the first and third crosses were evaluated under water deficit conditions. For the flag leaf area, there were significant and positive results in the first, second, and third crosses under normal conditions; however, the third cross exhibited different results under water deficit conditions. Additionally, the number of panicles per plant was recorded in the first cross under water deficit conditions, while panicle weight showed significant results in the first and third crosses under normal conditions, as well as in the second and third crosses under water deficit conditions. The 100-grain weight was notably significant in the first cross conducted under water deficit conditions. The fertility percentage showed a high level of significance in the second and third crosses under normal conditions, as well as in the second cross under water deficit conditions. Finally, grain weight was significant in both the second and third crosses under normal conditions and also in the second cross under water deficit conditions.

The negative and significant dominance/dominance type of epistatic gene action was observed for the heading date in the first and third crosses under normal conditions. In addition, under water deficit conditions in the third cross, dominance was noted for plant height in the second cross, panicle length in the third cross, number of panicles per plant in the third cross, panicle weight in the second cross under normal conditions, and 100-grain weight in the third cross under drought conditions. These findings indicate that dominance gene action plays a crucial role in the inheritance of these traits. These crosses showed a positive sign of dominance/dominance component, suggesting that they had an amplifying effect on the expression of that trait in all three rice crosses. The expression of these traits in these crosses was significantly influenced by the non-fixable gene effect, which may be taken advantage of through bi-parental mating under recurrent selection or by replacing the conventional method with the idea of population improvement.

The expression of these traits was reduced, as indicated by the negative dominance effect. However, the negative sign of the dominance component for heading date in the first and third crosses suggested a positive influence on early flowering in this crop. In contrast, the dominance component was positive for the other traits, indicating an increased expression across all three rice crosses. It was found that the additive/additive interaction significantly influenced most crosses more than the additive/dominance and dominance/dominance interactions under both normal and water deficit conditions (You *et al*. 2006). The study identified both duplicate and complementary epistasis in the examined traits. In cases of duplicate epistasis, it is difficult to identify genotypes that demonstrate higher levels of trait expression because the positive effects of one factor may be offset by the negative effects of another. In contrast, complementary epistasis indicates that selection in early generations could be beneficial. The presence of epistatic effects was noted, except for panicle length, all attributes exhibiting duplicate epistasis (Ganapati *et al*. 2020). This dominance of duplicate epistasis may delay single-plant selection (Solanke *et al*. 2019). Therefore, strategies such as biparental mating or diallel selective mating may be advantageous. Several cycles of promising crossing segregate in the $F_2$ generation and beyond could help incorporate desirable genes into a single genetic background.

**Heterosis, inbreeding depression, and potence ratio**

The percentage of $F_1$ hybrids that have increased or decreased compared to the mid-parent and heterobeltiosis, along with inbreeding depression and potence ratio for all studied traits under normal and water deficit conditions, is presented in Table 5. The heterosis with mid and better parents was noted, as most crosses exhibited positive and significant heterosis for most traits studied. However, the third cross for heading date and the second cross for fertility percentage showed significantly negative heterosis. Both of these crosses exhibit desirable characteristics in comparison to the other crosses, which did not show significant heterosis over the mid or better parent. Similar outcomes were achieved by Saravanan *et al*. (2008). Inbreeding depression is assessed by calculating the difference between the means of the $F_1$ and $F_2$ generations as a percentage of the $F_1$ mean. Various crosses exhibited a range of inbreeding depression values. For fertility percentage, the values ranged from 2.15% to 23.34% at the third cross, while for plant height, the range was also observed at the third cross. In other cases, the inbreeding depression values varied from -4.73% to 31.88% for the heading date at the first cross and for the number of panicles per plant at the first cross.

**Table 5. Heterosis over the mid and better parent, inbreeding depression percentage and potence ratio under normal and water stress conditions**

| Trait | Cross | Heterosis | | | | InbreedingDepression(%) | | Potence Ratio(%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | MP-N | MP-D | BP-N | BP-D | N | D | N | D |
| Heading date (day) | $C_1$ | 15.63** | -1.79 | 23.01** | 7.06** | 10.644 | -4.73 | 2.60 | 0.22 |
| | $C_2$ | 11.90** | 17.57** | 17.18** | 18.41** | 3.624 | 3.17 | 2.64 | -24.85 |
| | $C_3$ | -3.84* | 4.86** | -10.46* | -7.32** | 3.355 | 2.66 | 0.52 | -0.37 |
| Plant height (cm) | $C_1$ | 29.97** | 32.14** | 23.75** | 34.26** | 4.88 | -3.35 | -5.97 | 20.28 |
| | $C_2$ | 18.89** | 29.51** | 31.94** | 38.27** | 7.65 | 14.97 | -1.91 | -4.66 |
| | $C_3$ | 30.97** | 25.81** | 10.62** | 6.02** | 23.34 | 12.77 | -1.68 | -1.38 |
| Flag leaf area ($cm^2$) | $C_1$ | 40.80** | 35.02** | 13.02** | 10.62* | 20.76 | 14.47 | -1.66 | -1.59 |
| | $C_2$ | 41.58** | 43.71** | 8.54* | 9.07 | 18.21 | 21.59 | -1.37 | -1.38 |
| | $C_3$ | 25.00** | 37.26** | 98.38* | 173.15* | 19.95 | 20.60 | -0.68 | -0.75 |
| Panicle length (cm) | $C_1$ | 16.72** | 30.65** | 6.92 | 14.65** | 8.40 | 15.81 | -1.82 | -2.20 |
| | $C_2$ | 25.43** | 23.09** | 11.40* | 14.49** | 9.58 | 17.64 | -2.02 | -3.08 |
| | $C_3$ | 29.30** | 21.17** | 51.94* | 39.83 | 19.18 | 14.63 | -1.97 | -1.59 |
| Panicles plant$^{-1}$ | $C_1$ | 35.91** | 78.65** | 23.80** | 36.73** | 21.59 | 31.88 | -3.67 | -2.57 |
| | $C_2$ | 39.63** | 57.12** | 9.74 | 38.21** | 22.68 | 28.15 | 1.45 | 4.18 |
| | $C_3$ | 48.21** | 29.23* | 18.78 | 2.73 | 11.81 | 9.31 | 1.95 | 1.13 |
| Panicle weight (g) | $C_1$ | 30.11** | 15.60* | 20.48** | 25.55 | 6.79 | 5.26 | -3.77 | 1.97 |
| | $C_2$ | 19.19** | 26.61** | 5.51 | 7.74* | 17.83 | 14.72 | -1.48 | -1.52 |
| | $C_3$ | 31.55** | 26.66** | 87.57** | 56.38* | 16.47 | 15.85 | -1.06 | -1.40 |
| 100-grain weight (g) | $C_1$ | 2.66 | 13.52 | -6.89 | 26.84 | 4.56 | 10.88 | 0.26 | 1.29 |
| | $C_2$ | 10.92 | 12.80* | 1.92 | 2.47 | 7.38 | 10.12 | -1.24 | -1.27 |
| | $C_3$ | 0.77 | 8.21 | -9.29* | -1.99 | 2.27 | 6.87 | -0.07 | -0.79 |
| Fertility percentage (%) | $C_1$ | 3.56* | 6.11** | 4.13 | 3.03* | 3.90 | 1.81 | 6.54 | -2.04 |
| | $C_2$ | -8.39** | -11.9** | -10.36** | -13.2** | 4.42 | 10.02 | -3.83 | 8.39 |
| | $C_3$ | -2.49 | 0.77 | -1.80 | 5.47** | 2.15 | 7.76 | 3.52 | -0.17 |
| Grain yield plant$^{-1}$ (g) | $C_1$ | 13.03** | 14.80** | 25.61** | 16.23** | 7.10 | 6.19 | 1.3 | 12.01 |
| | $C_2$ | 14.43** | 18.93** | 6.58 | 11.41** | 11.31 | 8.26 | 1.96 | 2.81 |
| | $C_3$ | 20.88** | 21.56** | 8.23* | 12.22** | 15.68 | 13.36 | 1.79 | 2.59 |

**MP-N: mid-parent of normal condition; MP-D: mid-parent of water deficit condition; BP-N: better-parent of normal condition; BP-D: better-parent of water deficit condition; N: Normal condition; D: Water deficit condition; $C_1$: Sakha108/IET1444; $C_2$: Sakha104/IRAT170; $C_3$: Sakha107/Moroberekan. * and ** significant at 0.05 and 0.01 levels of probability, respectively**

According to Hanifei (2022), gene linkage in the materials can lead to differences between heterosis estimates and inbreeding depression. The potence ratio values were greater than one for most crosses across all studied traits under both conditions. However, some potence ratio values in certain crosses were less than one, indicating that partial dominance occurred in these cases. Aside from grain yield per plant, Abdallah (2009) demonstrated that the potence ratio exhibited over-dominance for all examined traits in the three crosses. In addition, Wang (2024) found that most crosses had potence ratio values for grain yield per plant exceeding one, showing over-dominance for the majority of crosses in the two experimental settings as well as in the combined data.

**Heritability and expected genetic advance**

Both broad and narrow sense heritability estimates, along with the expected genetic improvements from selecting all studied traits under normal and water deficit conditions, are shown in Table 6. In general, high heritability values were found for all the variables under study in the majority of crosses under both conditions. The fertility percentage in the second cross was 96.77%, while the first cross of 100-grain weight was 90.11% under normal conditions. Regarding water deficit conditions, the heritability values ranged from 89.75% for the flag leaf area in the third cross to 97.05% for fertility in the same cross. In contrast, the heritability values in a narrow sense were generally low to moderate for all the studied traits. These values ranged from 27.24% for grain yield per plant in the first cross to 57.74% for 100-grain weight in the third cross under normal conditions. When subjected to water deficit conditions, the heritability values ranged from 15.53% for the heading date in the third cross to 48.47% for the number of panicles per plant in the second cross. This variation suggests that the dominance effect played a significant role in the inheritance of these traits. A non-additive component of genetic variance dominated the expression of all the traits under study in both crosses under both conditions, as evidenced by the dominant genetic variance (1/4 H) being greater than the additive genetic variance (1/2 D) for all traits under study. These results have a close relationship to the earlier research conducted by Hassan *et al.* (2023). Increased estimates of heredity for sterility percentage, flag leaf angle, days to heading, and grain yield per plant were found by Gaballah and Abu El-Ezz (2019) in combination with high genetic advance, suggesting the presence of additive genes. High heritability and high genetic advance are key factors for predicting the outcomes of selecting the best individuals.

The expected genetic advance (GA) values for plant height in the first cross ranged from 3.15% to 35.56%. For the second cross, the number of panicles per plant varied from 1.96% to 36.08% under normal conditions. In the third cross, the GA values for the heading date and the number of panicles per plant were assessed under water deficit conditions. Most yield and yield-attributing traits showed high heritability, which was linked to significant genetic advances. This suggests that these traits exhibit additive gene action and gene addressing. Combining heritability estimates with genetic gain provides more useful information than using heritability values alone when predicting the outcomes of selection. The number of panicles per plant in the second cross under both normal and drought conditions showed significant genetic advance, suggesting that selection for these traits might be successful. According to Ghidan *et al.* (2019), Ganapati *et al*. (2020), and Aswin *et al*. (2021), heritability estimates combined with genetic advances upon selection were more useful in estimating the impact of selection than the former alone.

**Table 6. Estimates of genetic variance, heritability, and genetic advance for the three crosses in both normal and water-deficit conditions**

| Trait | Cross | Genetic variance | | | | Heritability | | | | GS | | GS% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1/2 D | | 1/4 H | | Broad sense | | Narrow sense | | | | | |
| | | N | D | N | D | N | D | N | D | N | D | N | D |
| Heading date (day) | $C_1$ | 10.20 | 14.41 | 23.57 | 33.14 | 93.4 | 95.51 | 28.21 | 28.94 | 3.49 | 4.21 | 3.30 | 4.39 |
| | $C_2$ | 12.15 | 9.03 | 21.74 | 23.68 | 92.74 | 94.29 | 33.24 | 26.02 | 4.14 | 3.16 | 3.87 | 2.87 |
| | $C_3$ | 15.95 | 6.29 | 22.04 | 32.17 | 94.56 | 95 | 39.7 | 15.53 | 5.18 | 2.04 | 5.42 | 1.96 |
| Plant height (cm) | $C_1$ | 12.47 | 14.69 | 28.07 | 43.54 | 95.62 | 96.41 | 29.42 | 24.32 | 3.95 | 3.89 | 3.15 | 3.61 |
| | $C_2$ | 25.28 | 10.74 | 22.48 | 43.11 | 95.14 | 96.32 | 50.36 | 19.20 | 7.35 | 2.96 | 5.73 | 2.91 |
| | $C_3$ | 23.73 | 18.44 | 26.78 | 26.6 | 95.18 | 95.1 | 44.73 | 38.94 | 6.71 | 5.52 | 5.26 | 5.16 |
| Flag leaf area ($cm^2$) | $C_1$ | 30.20 | 9.66 | 31.19 | 18.36 | 95.97 | 92.27 | 47.21 | 31.82 | 7.78 | 3.61 | 16.8 | 12.66 |
| | $C_2$ | 19.86 | 8.11 | 36.43 | 15.18 | 95.79 | 92.37 | 33.8 | 32.17 | 5.34 | 3.33 | 12.42 | 10.64 |
| | $C_3$ | 32.28 | 10.49 | 30.82 | 12.98 | 95.82 | 89.75 | 49.02 | 40.11 | 8.19 | 4.23 | 18.41 | 11.72 |
| Panicles $plant^{-1}$ | $C_1$ | 11.34 | 8.25 | 23.4 | 12.79 | 93.92 | 93.54 | 30.66 | 36.67 | 3.84 | 3.58 | 15.79 | 20.28 |
| | $C_2$ | 19.90 | 11.26 | 16.89 | 10.65 | 92.71 | 94.33 | 50.15 | 48.47 | 6.51 | 4.81 | 35.56 | 36.08 |
| | $C_3$ | 13.24 | 8.76 | 19.2 | 14.11 | 92.36 | 94.18 | 37.7 | 36.08 | 4.6 | 3.66 | 23.58 | 26.87 |
| Panicle weight (g) | $C_1$ | 0.39 | 0.06 | 0.57 | 0.23 | 93.09 | 94.24 | 37.91 | 18.52 | 0.79 | 0.21 | 16.74 | 8.26 |
| | $C_2$ | 0.41 | 0.08 | 0.47 | 0.14 | 92.21 | 93.31 | 42.82 | 34.47 | 0.86 | 0.35 | 17.06 | 9.57 |
| | $C_3$ | 0.31 | 0.11 | 0.67 | 0.24 | 91.29 | 95.89 | 28.78 | 29.42 | 0.62 | 0.36 | 10.97 | 9.97 |
| 100-grain weight (g) | $C_1$ | 0.07 | 0.07 | 0.09 | 0.1 | 90.11 | 93.48 | 39.88 | 40.51 | 0.35 | 0.36 | 13.55 | 16.25 |
| | $C_2$ | 0.05 | 0.07 | 0.08 | 0.1 | 93.93 | 90.54 | 39.39 | 35.16 | 0.3 | 0.31 | 10.29 | 11.79 |
| | $C_3$ | 0.1 | 0.04 | 0.06 | 0.12 | 91.28 | 93.32 | 57.74 | 21.87 | 0.49 | 0.19 | 16.54 | 7.19 |
| Panicle length (cm) | $C_1$ | 10.81 | 6.67 | 7.91 | 9.38 | 92.99 | 95.64 | 53.7 | 39.75 | 4.96 | 3.35 | 18.87 | 16.6 |
| | $C_2$ | 5.74 | 4.38 | 12.56 | 11.38 | 93.25 | 94.66 | 29.26 | 26.3 | 2.67 | 2.21 | 9.37 | 10.64 |
| | $C_3$ | 10.03 | 7.54 | 11.07 | 9.65 | 92.74 | 95.56 | 44.08 | 41.93 | 4.33 | 3.66 | 16.11 | 16.99 |
| Fertility percentage (%) | $C_1$ | 25.07 | 14.35 | 20.54 | 14.51 | 96.47 | 96.86 | 53.03 | 48.15 | 7.51 | 5.41 | 8.24 | 6.76 |
| | $C_2$ | 27.18 | 10.63 | 27.18 | 12.55 | 96.77 | 95.93 | 48.38 | 43.99 | 7.47 | 4.45 | 9.38 | 7.43 |
| | $C_3$ | 22.35 | 12.26 | 27.57 | 17.42 | 95.63 | 97.05 | 42.81 | 40.09 | 6.37 | 4.57 | 7.17 | 5.78 |
| Grain yield $plant^{-1}$ (g) | $C_1$ | 11.67 | 4.6 | 28.81 | 21.23 | 94.46 | 96.76 | 27.24 | 17.25 | 3.67 | 1.84 | 8.82 | 6.86 |
| | $C_2$ | 17.26 | 5.13 | 26.31 | 17.24 | 94.82 | 95.46 | 37.57 | 21.89 | 5.25 | 2.18 | 12.64 | 7.22 |
| | $C_3$ | 14.52 | 6.67 | 30.69 | 20.01 | 95.52 | 96.45 | 30.68 | 24.1 | 4.35 | 2.61 | 10.78 | 8.88 |

**N: Normal condition; D: Water deficit condition; C1: Sakha108/IET1444; C2: Sakha104/IRAT170; C3: Sakha107/Moroberekan; GS: Genetic advance**

# CONCLUSION

The scaling test results demonstrate that the additive-dominance model is insufficient to explain the genetic effects in the materials under investigation. A major factor in the inheritance of these characteristics is epistasis. With a few exceptions, most attributes across three crosses exhibited significant negative additive gene effects in both normal and water shortage conditions. The days to heading for the first and second crosses were measured under normal conditions, as well as for the first cross under drought conditions. Additionally, we recorded the number of panicles for the second and third crosses under both normal and water deficit conditions, along with the grain yield per plant for all three crosses under normal conditions. Notably, the third cross under water deficit conditions exhibited significant and highly significant effects attributed to positive gene action. Heterosis was observed in both mid-parent and better-parent values, as most crosses showed positive and significant heterosis for the majority of the traits studied. However, the third cross for heading date and the second cross for fertility percentage exhibited negative and highly significant heterosis, indicating that these two crosses are advantageous for both traits. In contrast, the remaining crosses did not demonstrate significant heterosis compared to the mid-/better-parent values.

Under both conditions, all of the characteristics under study showed high heritability values in a broad sense across the majority of crosses. Under normal conditions, the fertility percentage in the second cross was 96.77%, whereas the 100-grain weight for the first cross was 90.11%. On the other hand, all of the traits under study revealed low to moderate heritability values in the narrow sense, ranging from 27.24% for grain yield per plant in the first cross to 57.74% for 100-grain weight in the third cross under normal conditions. The findings showed that the dominance effect was a major factor in the inheritance of these traits under conditions of water shortage. Furthermore, for every trait under study, the dominance of genetic variation exceeded the additive genetic variance, indicating that non-additive components of genetic variance largely controlled the expression of these traits in both normal and water deficit conditions. The expected values for genetic advancement varied from 3.15% to 35.56% for plant height in the first cross and for the number of panicles per plant in the second cross under normal conditions. In contrast, under water deficit conditions, the values ranged from 1.96% to 36.08% for the heading date in the third cross and the number of panicles per plant in the second cross. Most traits related to yield and its contributing factors displayed high heritability along with significant genetic advancement, indicating the fixation of genes and the presence of additive gene action for these traits.

## REFERENCES


Abdallah AA (2009). Genetic studies on leaf rolling and some root traits under drought conditions in rice (*Oryza sativa* L.). African Journal of Biotechnology, 8(22), 6241-6248.

Admas A, Johanna Å, Osval A. *et al* (2024). Genomic selection in plant breeding: Key factors shaping two decades of progress, Molecular Plant, 17(4), 552-578.

Ahmed MS, Qamar M, Waqar S, Naeem A, Javaid RA, Tanveer SK, Hussain I (2023). Estimation of genetic components, heterosis and combining ability of elite Pakistani wheat varieties for yield attributing traits and stripe rust response. Vavilovskii Zhurnal Genet Selektsii, (6): 609-622.

Aswin M, Umarani R, Rajeswari S, Jeyaprakash P (2021). Genetic variability and association analysis in rice (*Oryza sativa* L.) germplasm based on biometrical and floral traits. Electronic Journal of Plant Breeding, 12(3), 912-917.

Begna T (2021). Combining ability and heterosis in plant improvement. Open J Plant Sci 6(1): 108-117.

Chamundeswari N, Sathyanarayana PV, Suryanarayana Y, Raja Reddy K (2013). Studies on inheritance of yield and yield components in rice. *Oryza*, 50(2):105-109.

Gaballah MM, Abu El-Ezz AF (2019). Genetic Behavior of Some Rice Genotypes under Normal and High Temperature Stress. Alexandria Science Exchange Journal, 40(2), 370–384.

Gaballah MM, Metwally AM, Skalicky M, Hassan MM, Brestic M, Sabagh AEl, Fayed AM (2020). Genetic Diversity of Selected Rice Genotypes under Water Stress Conditions. Plants, 10(27), 1-19.

Gamble EE (1962). Gene Effects in Corn (*Zea mays* L.) Relative Importance of Gene Effects for Plant Height and Certain Components Attributes of Yield. Canadian Journal of Plant Science, 42, 349-358.

Ganapati RK, Rasul MG, Sarker U, Singha A, Faruquee M (2020). Gene action of yield and yield contributing traits of submergence tolerant rice (*Oryza sativa* L.) in Bangladesh. Bulletin of the National Research Centre, 44(1).

Ghidan WF, El-Agoury RY, Hussein FA (2019). Utilization of combining ability and genetic components for yield and its contributing traits of some rice (*Oryza sativa* L.) genotypes. J. of Agricultural Chemistry and Biotechnology, Mansoura Univ., 10(12): 257-267.

Ghidan WF, Khedr RA (2021). Assessment of Some Agro-Physiological Traits and Genetic Markers in Rice (*Oryza sativa* L.) Under Normal and Water Stress Conditions. Journal of Plant Production. Mansoura University, 12(1), 73-86.

Hanifei M, Gholizadeh A, Khodadadi M, Mehravi S, Hanifeh M, Edwards D, Batley J. (2022). Dissection of Genetic Effects, Heterosis, and Inbreeding Depression for Phytochemical Traits in Coriander. Plants (Basel). Nov 2;11(21):2959.

Hassan HM (2011). Combining ability for some root, physiological and grain quality traits in rice ( *Oryza sativa* L.) under water deficit conditions. 37(2), 239-256.

Hassan HM, Hadifa AA, El-Leithy SA *et al* (2023). Variable level of genetic dominance controls important agronomic traits in rice populations under water deficit condition. PeerJ, 11, 1–27.

Johnson HW, Robinson HF, Comstock RE (1955). Estimation of genetic and environmental variability in soybeans. Agronomy J.47:314-322.

Khatab IA, El-Mouhamady ABA, Mariey SA, Elewa TA (2019). Assessment of Water Deficiency Tolerance Indices and their Relation with ISSR Markers in Barley ( *Hordeum vulgare* L .). Current Science International, 08(01), 83-100.

Kumar PS, Saravanan K, Sabesan T (2017). Generation mean analysis for yield and grain quality characters in rice (*Oryza sativa* L.). Plant Archives., 17(1):557-560.

Kumar SS, Latha S, Sudheer Kumar S (2018). Scaling and Joint Scaling tests for Quantitative Characters in Greengram (*Vigna radiata* (L.) Wilczek.). Journal of Pharmacognosy and Phytochemistry, 7(2), 185-190.

Lee KW, Rahman MA, Choi GJ *et al* (2017). Expression of small heat shock protein23 enhanced heat stress tolerance in transgenic alfalfa plants. Journal of Animal and Plant Sciences 27(4):1238-1244.

Mather K (1949). Biometrical Genetics. Dover Publication, Inc. London.

Mather K, Jinks JL (1982). Biometrical genetics. 3rd ed. Cambridge Univ. press, London, N.Y.

Panda D, Jijnasa B (2021). Flooding Tolerance in Rice: Focus on Mechanisms and Approaches, Rice Science, 28(1), 43-57.

Rahman MA, Woo JH, Lee S-H, *et al* (2022). Regulation of Na+/H+ exchangers, Na+/K+ transporters, and lignin biosynthesis genes, along with lignin accumulation, sodium extrusion, and antioxidant defense, confers salt tolerance in alfalfa. Frontiers in Plant Science 13:326.

Rani MG, PV, Satyanarayana ML, Ahmed YA, Rani VS Rao (2015) Gene action of elite rice lines for yield and lodging resistance related traits. Research on Crops; 2015. 16(4):689-697.

Saleem MY, JI, Mirza MA Haq (2010). Genetic basis of yield and some yield related traits in Basmati rice. Pakistan Journal of Botany, 42(2):955-961.

Saravanan K, Sabesan T, Kumar ST (2008). Heterosis for yield and yield componentsinrice (*Oryza sativa* L.). Advancesin Plant Sciences, 21(1):119-121.

Solanke AC, Patel PB, Patel PK (2019). Generation mean analysis for yield and it's contributing traits in aromatic rice (*Oryza sativa* L.) Anita. The Pharma Innovation Journal, 8(8), 5-9.

Sultana R, Ansari NA, Ramesha MS, Shankar AS, Murali Krishna K (2016). Generation mean analysis of quantitative traits in restorer lines of rice (*Oryza sativa* L.). Asian Journal of Bioscience, 11(1):151-161.

Surya R (2024). Fermented foods of Southeast Asia other than soybean-or seafood-based ones. J. Ethn. Food 11, 27.

Tan Q, Bu S, Chen G, *et al* (2022). Reconstruction of the High Stigma Exsertion Rate Trait in Rice by Pyramiding Multiple QTLs. Frontiers in Plant Science, 13(June), 1-10.

Vadivel K, Anitha Vasline Y, Saravanan KR (2003). Studies on combining ability and heterosis in rice (*Oryza sativa* L.). Madras Agric. J., 90(4-6), 228-23.

Vinoth R, Shailesh M, V, Ulaganathan G, Subhasini K, Baghyalakshmi RSR Krishnan ( 2015). Evaluation of genetic variability for yield and its component characters in rice (*Oryza sativa* L.) for Allahabad agro-climatic region. Biochemical and Cellular Archives; 2015. 15(1):189-192.

Wang C, Wang Z, Cai Y, Zhu Z, Yu D, Hong L, Wang Y, Lv W, Zhao Q, Si L, Liu K, Han B. (2024). A higher-yield hybrid rice is achieved by assimilating a dominant heterotic gene in inbred parental lines. Plant Biotechnol J., 22(6):1669-1680.

Wassmann SVK, Jagadish K, Sumfleth H et al (2009). Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation, Chapter 3, Advances in Agronomy, Academic Press,102, 91-133,

Wynn J.C., T.A.Emery and P.W. Rice (1970). Combining ability in arachis hypogeae Π. Field performance of F1 hybrids. Crop Sci.,10: 713-715.

You A, Lu X, Jin H *et al* (2006). Identification of Quantitative Trait Loci Across Recombinant Inbred Lines and Testcross Populations for Traits of Agronomic Importance in Rice. Genetics Society of America, 1300 (February), 1287-1300.

# التحليل الوراثي لمحصول الحبوب والصفات المرتبطة في الأرز باستخدام العشائر الستة تحت ظروف الري العادي ونقص المياه

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## الملخص

تم اجراء التحليل الوراثي لمحصول الحبوب والصفات المرتبطة به لثلاث هجن سخا 108/اي اي تي 1444، سخا 104/ايرات 170 و سخا 107/موروبروكان لتقييم ست عشائر لكل هجين كالتالي $P_1, P_2, F_1, F_2, BC_1, BC_2$ وأوضحت نتائج الإختبار أهمية التفوق لجميع الصفات المدروسة للهجن الثلاثة. كما لوحظ تأثيرات سلبية للفعل الجيني المضيف تحت ظروف الري العادي ونقص المياه ، بالرغم من ذلك وجد أنه لا يوجد تأثيرات معنوية لصفة التزهير للهجينين الأول والثاني تحت ظروف الري العادي والهجين الأول تحت ظروف نقص المياه. بالاضافة إلى ذلك كان هناك تأثير معنوي لصفة محصول الحبوب لجميع الهجن تحت ظروف الري العادي، وعلي الجانب الآخر أظهر الهجين الثالث معنوية تحت ظروف نفص المياه، حيث كان للفعل الجيني تأثير معنوي لغالبية الصفات. أظهرت قوه الهجين لمتوسط وأفضل الآباء معنوية ايجابية ماعدا الهجين الثالث لصفة التزهير والهجين الثاني للنسبة المئوية للخصوبة، وكانت درجة التوريث بالمعني الضيق منخفضة إلى معتدلة لجميع الصفات المدروسة حيث تراوحت القيم ما بين 27.24% لمحصول الحبوب للنبات الفردي في الهجين الأول إلى 57.74% لوزن 100 حبة في الهجبن الثالث تحت ظروف الري العادي في حين تحت ظروف نقص المياه فإن التأثير السيادي لعب دورًا معنويًا وهام في وراثة الصفات تحت الدراسة .

***الكلمات الدالة*** : الأرز ، اختبار سكالينج، الفعل الجيني ، التفوق و نقص المياه