Agronomic and Genetic Insights into Rice (*Oryza sativa* L.) Genotype Responses to Wastewater Irrigation

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ABSTRACT

The quality of irrigation water, the use of tolerant rice varieties, and soil fertility are key factors in rice growth and yield production. To tackle water shortages, rice breeders are developing new varieties suited for different conditions. This study evaluated ten rice genotypes irrigated with wastewater from the El-Khiry Drain and freshwater supplied to paddy fields. The analysis of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}) showed that wastewater had higher levels of electrical conductivity (EC), pH, and certain ions compared to freshwater. ANOVA indicated significant differences among traits under both irrigation conditions, with higher ion concentrations negatively affecting yield in Japonica varieties like Giza 171, Giza 177, Sakha 108, and Sakha 101. In contrast, genotypes such as Sakha 104, Giza 182, Giza 178, Giza 183, and Egyptian Yasmin thrived under both conditions. Moreover, wastewater irrigation led to increased stemborer populations, resulting in yield reductions of 11.27% to 30.87%. The most tolerant varieties were Giza 178, Sakha 104, Sakha 101, Egyptian Yasmin, and Giza 183. High heritability values were observed for all studied traits, with phenotypic coefficients of variation (PCV) exceeding genotypic coefficients (GCV). Genetic analyses indicated close relationships among tolerant genotypes. Understanding and managing soil and irrigation water characteristics are vital for sustainable rice production, enabling farmers to assess water quality effectively.

Keywords: water quality, EC, pH, rice genotypes, quantitative traits, genetic parameters.

INTRODUCTION

Rice (*Oryza sativa* L.) is the main food for half of the world population, especially in Asia and Africa. Climatic change in the world restricted the increase of rice all over the world (Rezk et al., 2025a), at a time when the demand for rice continues to rise due to rapid population growth (Rezk et al., 2025a). One of the main constraints in increasing rice yield worldwide is the shortage and declining quality of irrigation water (Ugalahi et al., 2016). Which led to the use of water seas after manipulations and treated, recycled industrial wastewater and agricultural wastewater, which is considered the most stable and safe among these different types of water for irrigating rice (Hester et al., 2022). However, the use of agricultural drainage water over time causes soil deterioration and erosion because it is reached by high levels of salt compared with fresh water (El-Hitya et al., 2024).

The major salt elements, such as cations (Na^+, K^+, Ca^{++}, and Mg^{++}) and anions (Cl, CO_3, HCO_3, and SO_4), which were in irrigation water or soil, will affect all growth stages in the rice plant, and the increase of these elements leads to the inhibition of absorption of other important elements and thus leads to decreased yield (Mohamed et al., 2016; Li et al., 2023). Additionally, electrical conductivity (EC) and pH concentration were also main factors in fertile soil and good indicators of which crops are suitable for growing in this area. Therefore, the chemical components analysis of irrigation water and soil is very important,

especially for the area, which is irrigated by drainage water and newly reclaimed lands, to determine the deficiency of elements as well as how to add the necessary shortage elements and maintain the good properties of the soil, which will be a contribution to increasing production yield (Abdel Rahman et al., 2022).

Implementing a rice breeding program to produce tolerant or resistant varieties is essential for reducing the costs of managing drainage water and minimizing environmental pollution (Rezk et al., 2025a). The Rice Research and Training Center in Egypt (RRTC) has developed short-duration rice varieties like Giza177, Sakha102, Sakha103 (Abdallah et al., 2022), and Sakha105, which grow in 120 to 125 days. Additionally, varieties such as Giza178, Giza179, and Giza183 are Indica-Japonica types that are tolerant of saline soil and drought, all achieved through conventional breeding methods. Understanding the genetic background, including the identification of genes for salinity tolerance, is crucial for creating new genotypes that can withstand various stresses (Çebi et al., 2023). Molecular markers like simple sequence repeats (SSR) assist in selecting these beneficial rice genotypes (Rezk et al., 2025b).

The current study aims to: 1) Evaluate 10 rice genotypes under irrigation by fresh water and wastewater, 2) evaluate the varieties under normal soil and fresh water to estimate the reduction in yield, and 3) investigate the genetic diversity among the genotypes based on quantitative traits.

MATERIAL AND METHODS

Rice genotypes

Ten rice varieties were used in this investigation, including five belonging to the Japonica type, three to the Indica-Japonica type, and two to the Indica type (Table 1). Two field experiments were conducted at two different locations over two growing seasons, 2022 and 2023. The first location was evaluated at the experimental farm of the Rice Research and Training Center (RRTC), Sakha, Kafr El Sheikh, Egypt, during the two rice-growing seasons. The second location is at National Investment Company (NIC) in the El-Beheria governorate, Egypt. The varieties were sown in early May during the 2022 and 2023 seasons in a Randomized Complete Block Design (RCBD) with three replicates. Transplanting was performed manually at a spacing of 20×20 cm to maintain a density of 25 hills per square meter. Three seedlings were transplanted per hill. All cultural practices, including fertilizer application and weed control, were uniformly applied at both locations and in a timely manner to ensure vigorous rice growth.

Table 1. Ten rice genotypes, parentage, types, origin, blast reaction, and duration

No.	Varieties	Parentage	Type	Origin	Blast	Duration
1	Giza177	Giza 171/Yomji No.1/PiNo.4	Japonica	Egypt	R	125
2	Giza171	Nahda (Pure line selection)/Calady40	Japonica	Egypt	S	158
3	Giza183	Giza 178/SKC 23893	Indica/Japonica	Egypt	R	123
4	Sakha108	Sakha101/HR5824/Sakha101	Japonica	Egypt	S	130
5	Sakha101	Giza 176/Milyang 79	Japonica	Egypt	S	145
6	Giza178	Giza 175/Milyang 49	Indica/Japonica	Egypt	R	135
7	Sakha104	Gz4096-8-1/Gz4100-9-1	Japonica	Egypt	S	135
8	IET1444	TN1/CO29	Indica/Japonica	India	R	133
9	Egyptian Yasmin	IR262-43–8-11/KDML105	Indica	Egypt	R	126
10	Giza182	Giza181/IR39422-163-247-2-2-3	Indica	Egypt	R	128

Not: R = resistance, S = susceptible.

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Irrigation water and soil characteristics

Agricultural wastewater from EL-Khiry drainage (El-Beheria governorate) and reclaimed soil at National Investment Company (NIC) El-Beheria governorate were analyzed for physical and chemical properties, while the fresh water and normal soil were analyzed at the Sakha location.

Stem Borer Infestation

At the maximum tillering stage, five rice hills were chopped at the soil surface from each plot, and the total count of plants was documented. The total tillers were examined, and those exhibiting the dead heart (DH) symptoms were counted. The same process was repeated three weeks preceding harvest, and the stems having white heads were counted.

DH/WH% = "No. of plants with DH/WH"/
(Total No. of plants in five hills) ×100

The data were recorded following the standard evaluation system of the Rice Research and Training Centre (RRTC), Sakha, Egypt. Resistant (R) = 0-3% WH, moderately resistant (MR) = >3-6, moderately susceptible (MS) = >6-9, susceptible (S) = >9-12, and highly susceptible (HS) = >12.

Quantitative Traits Assessment

Ten agronomic traits, namely, duration (days), plant height (cm), panicle plant^{-1}, number of panicles per (m^2), filled grains panicle^{-1}, grain yield plant^{-1} (g), hulling, milling, head, and amylose content percentage, were calculated at the experimental farm. The data for all traits were recorded based on the Standard Evaluation System (SES) for rice (IRRI, 2014). Genetic associations between the ten rice genotypes under study were constructed using the averages of these features over two years.

Statistical Analysis

An analysis of variance (ANOVA) was conducted for each season with randomly selected varieties, combining two experiments due to homogeneous error variances as per Le Clercq et al. (1962). The ANOVA identified genetic and environmental variance components, estimating their magnitudes. Phenotypic variance is defined by Dudley and Moll (1969), while genotypic (Vg), phenotypic (Vp), and error (Ve) components were estimated following Prasad et al. (1981). Broad-sense heritability (h²B) was calculated as per Allard (1999), and dissimilarity coefficients were assessed using Sneath and Sokal (1973). Similarity matrices were generated via NTSYS-PC version 2.1 (Rohlf, 2000).

RESULTS AND DISCUSSION

Establishing a rice breeding program to develop varieties tolerant or resistant to adverse conditions is essential for reducing the costs of drainage water management and minimizing environmental pollution (Rezk et al., 2025a). The Rice Research and Training Center in Egypt (RRTC) has started producing short-duration rice varieties, such as Giza177, Sakha102, and Sakha105, with growth durations of 120 to 125 days. Additionally, registered tolerant varieties like Giza178, Giza179, and Giza183 are Indica-Japonica types that can withstand saline soil and drought, developed through conventional breeding methods. These methods require an understanding of the varieties' genetic backgrounds, including identifying genes for salinity tolerance. By selecting desired gene recombinants, breeders can create new rice genotypes with increased tolerance to various stresses (Çebi et al., 2023). Molecular markers, such as simple sequence repeats (SSR), facilitate the selection of these beneficial genotypes (Rezk et al., 2025b).

Table 2. Analysis of some chemical properties for drainage agriculture (EL-Khariy drainage) and normal water components (Sakha location) and chemical properties of the soil under normal conditions at the experimental sites Sakha and reclaimed soil (NIC) farm

Chemical compositions	Agriculture drainage water	Fresh water	Reclaimed soil	Normal soil	Unit
pH	8.58	7.55	8.11	7.40	--
Electrical conductivity (EC)	2.18	0.58	1.17	0.73	ds∕m
Cations					
Na^+	8.60	4.32	3.80	1.90	meq/L
K^+	0.92	0.44	0.48	0.38	meq/L
Ca^{++}	3.00	2.88	3.60	2.70	meq/L
Mg^{++}	6.80	4.56	4.40	2.30	meq/L
Anions					
Cl	15.0	2.10	9.00	3.45	meq/L
CO_3	0.00	0.00	0.00	0.00	meq/L
HCO_3	3.8	3.12	2.40	2.01	meq/L
SO_4	0.52	0.35	0.88	0.22	meq/L

Electrical conductivity (EC) in agricultural wastewater was found to be higher than in freshwater, suggesting better water-holding capacity and nutrient availability with freshwater irrigation. Major cations such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) were present in greater concentrations in drainage water. Excessive sodium can lead to negative effects on rice growth due to hardpan formation and reduced infiltration, with optimal sodium levels in irrigation water ranging from 0 to 50 ppm. Potassium levels were also elevated in drainage water, while calcium concentrations were slightly higher than those in freshwater (Table 2). The findings indicate that sodium (Na) levels are higher in wastewater than in freshwater, which affects plant growth stages. This is consistent with Aamer et al. (2015). Potassium is essential for rice plants, enhancing their resistance to biotic and abiotic stresses. While calcium is important, it should not be used in excess. Adequate exchangeable calcium improves soil friability and drainage, aligning with the observations of Bidzakin et al. (2018). Gypsum is recommended for adding calcium, which also helps leach sodium from the root zone (Li et al., 2023). Higher levels of magnesium were found in agricultural drainage water compared to normal water, and increasing magnesium and calcium can reduce sodium risk in irrigation water (Mohamed, 2011; Hagage et al., 2025).

Evaluation of soil quality
Soil quality evaluation through direct analysis may yield unreliable results, necessitating an inference from physical and chemical properties. This study revealed that wastewater-irrigated soils had elevated pH (8.11) and electrical conductivity (EC, 1.17 dS m⁻¹) compared to freshwater-irrigated soils (pH 7.4, EC 0.73 dS m⁻¹). Major cation concentrations in wastewater-irrigated soils were significantly higher (Na: 3.80, K: 0.48, Ca: 3.60, Mg: 4.40 meq L⁻¹) than in freshwater soils (Na: 1.90, K: 0.38, Ca: 2.70, Mg: 2.30 meq L⁻¹). Additionally, anions in reclaimed wastewater-irrigated soil also showed higher concentrations, indicating progressive ion accumulation and increased salinity, which alters soil chemical properties over time.

The analysis of variance (ANOVA) showed highly significant differences ($P < 0.001$) among ten rice genotypes under both freshwater and agricultural drainage water conditions, indicating substantial inherent variability. This variability suggests potential for improving agronomic and grain quality traits through selection and hybridization of superior parental genotypes (Table 3).

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Table 3. Analysis of variance for quantitative traits under fresh water and wastewater

S.O.V.	Replications		Genotypes		Error	
Conditions	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water
d.f.	2	2	9	9	18	18
Leaf blast reaction	0.43	0.43	11.44**	11.24**	0.59	0.54
Stem borer	0.37	0.26	51.83**	39.09**	0.51	0.32
Duration (days)	1.52	0.1	330.03**	269.09**	2.71	2.25
Plant height (cm)	1.47	1.53	168.17**	283.91**	2.09	2.62
Panicle plant^{-1}	2.16	0.92	11.26**	9.56**	0.87	0.83
Panicles/square matters	3.03	4.93	4674.11**	4549.03**	5.55	6.29
Filled grains panicle^{-1}	2.74	2.54	587.68**	312.39**	2.95	2.41
Grain yield plant^{-1} (g)	2.78	2.35	44.65**	44.76**	0.74	1.35
Hulling %	1.78	0.68	16.59**	23.25**	1.1	1.11
Milling %	0.54	1.48	6.66**	8.38**	0.6	0.76
Head rice %	0.62	0.16	24.81**	28.46**	1.06	1.62
Amylose content %	0.06	0.1	2.46**	2.59**	0.15	0.12

*, ** Significant at 5% and 1% probability levels, respectively.

Mean performances

Rice stem borer infestation

The evaluation of stem borer infestation under freshwater irrigation shows rates from 2.0% to 12.9%, averaging 6.68%. Three rice varieties (Giza 183, Sakha 101, and Sakha 104) were classified as resistant, while others ranged from moderately resistant to highly susceptible. Under wastewater irrigation, infestation increased, causing a shift in resistance classifications: resistant varieties became moderately resistant, moderately resistant shifted to moderately susceptible, and moderately susceptible ones became susceptible. These results indicate that wastewater irrigation creates a more favorable environment for stem borer population buildup and infestation compared with freshwater irrigation. Similar trends have been reported by Aly et al. (2012, 2013), Ashry et al. (2018), El-Malky and Al-Daej (2018) and Rezk et al. (2025a).

Leaf blast reaction under field conditions

Leaf blast infection was assessed at the vegetative stage, and the results showed that six rice genotypes - Giza 177, Giza 183, Giza 178, IET 1444, Egyptian Yasmin, and Giza 182 - were resistant under both freshwater and wastewater irrigation (Figure 1B). In contrast, the genotypes Giza 171, Sakha 101, Sakha 108, and Sakha 104 were susceptible under both conditions. However, infection severity was higher under wastewater irrigation compared with freshwater, likely due to increased plant stress, which exacerbated the disease (Figure 1B).
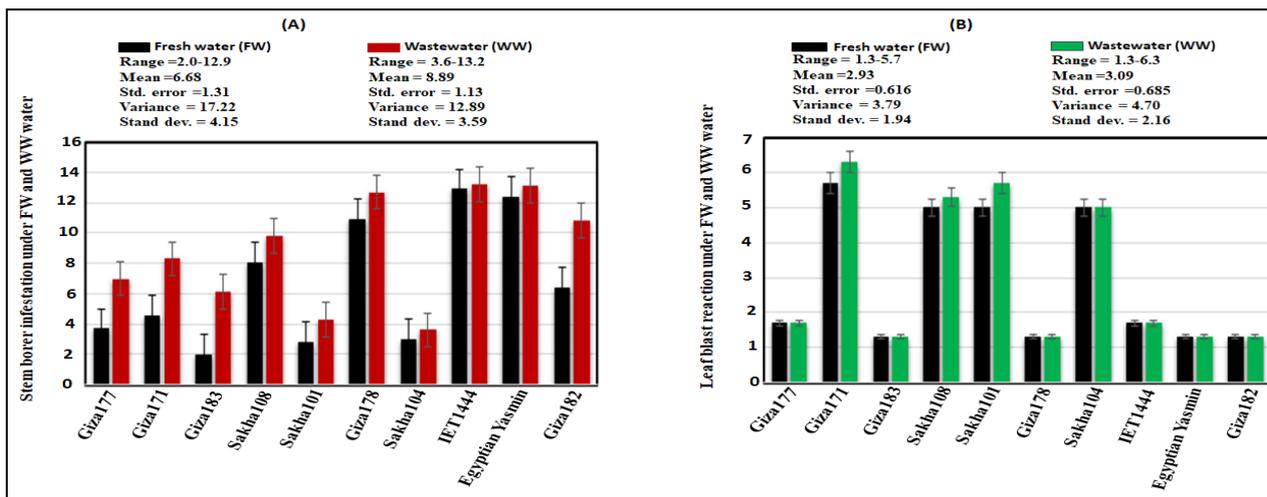
Figure 1. (A) stem borer infestation and (B) leaf blast infection in 10 rice genotypes
under freshwater and wastewater irrigation in a two-location study

Agronomic traits

The study compares the agronomic performance of ten rice varieties under freshwater (FW) and wastewater (WW) irrigation. In FW conditions, varieties such as Giza 183 and Egyptian Yasmin matured in approximately 121.8 to 128 days, while Giza 171 and Sakha 101 took longer, at 157 and 142 days, respectively. Under WW irrigation, maturity duration decreased for all varieties

due to the stress from wastewater and saline soil. In terms of height, Giza 171 and Egyptian Yasmin were the tallest at 120.0 and 106.9 cm. Conversely, Sakha 101 and Giza 177 were the shortest, measuring 94.7 and 95.7 cm. WW irrigation consistently reduced plant height across all varieties, highlighting its negative impact on rice growth.
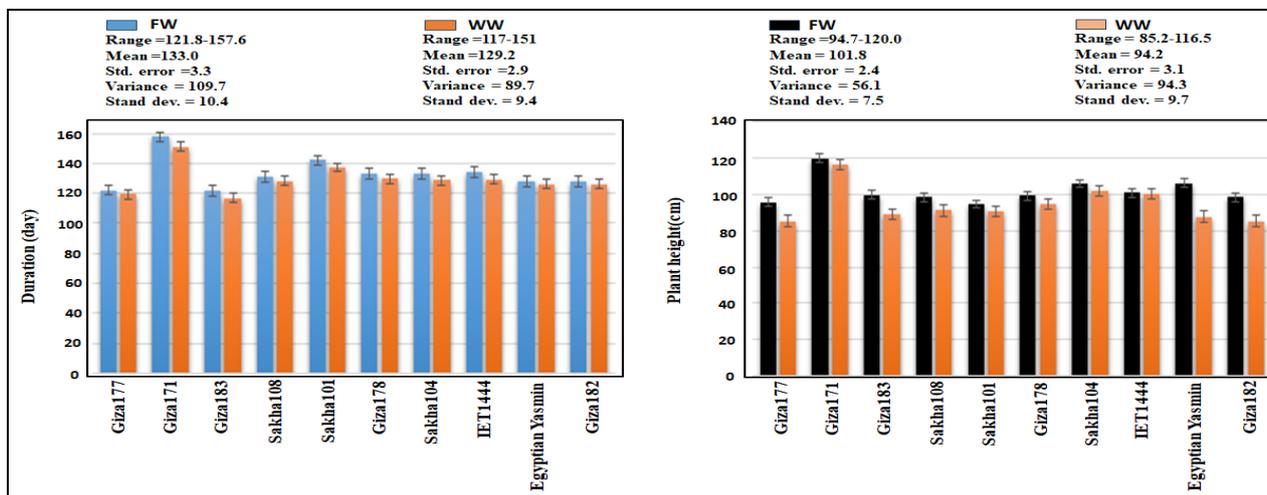

Figure 2. Duration and plant height traits for 10 rice genotypes
under freshwater and wastewater irrigations in a two-location study

The study indicates that the number of panicles per plant under freshwater irrigation ranges from 19.7 to 26.2, with Giza 182 showing the highest count. Under wastewater irrigation, values decreased to a range of 15.3 to 21.4. Freshwater irrigation resulted in higher panicle density per m², especially with

Giza 183 at 441.7, while overall densities were lower with wastewater. Filled grains per panicle were also higher in freshwater. Varieties such as Sakha 104, Giza 182, Giza 178, Giza 183, and Egyptian Yasmin performed well under both irrigation methods, indicating potential for wastewater

cultivation due to their favorable traits. Notably, top-yielding varieties under freshwater conditions included IET 1444, Giza 182, Egyptian Yasmin, Sakha 104, and Giza 183, which maintained substantial yields in wastewater settings, suggesting their adaptability.
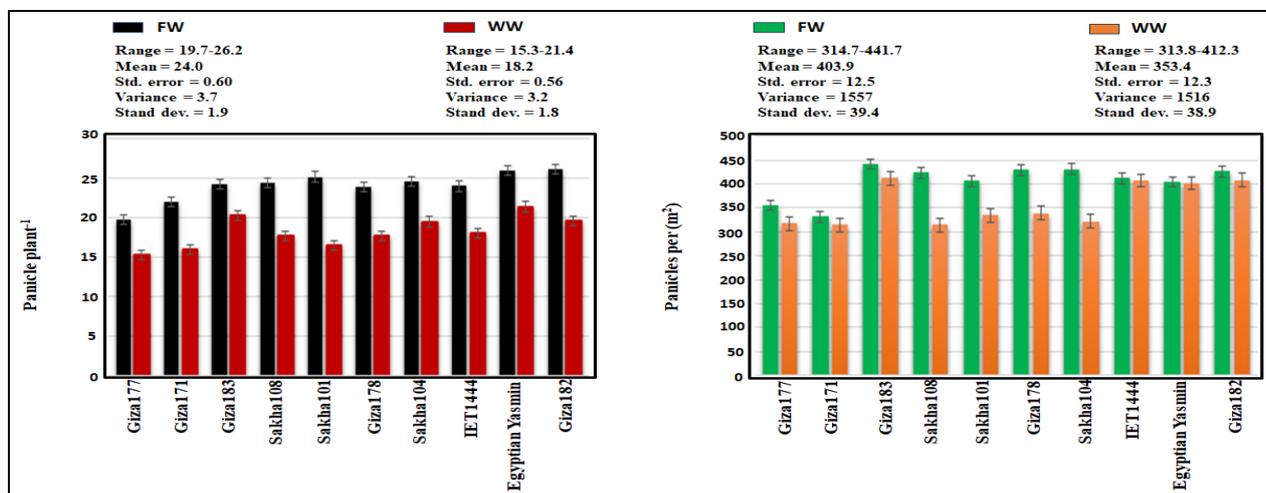

Figure 3. Panicle per and panicle per m² traits for 10 rice genotypes under freshwater and wastewater irrigation in a two-location study
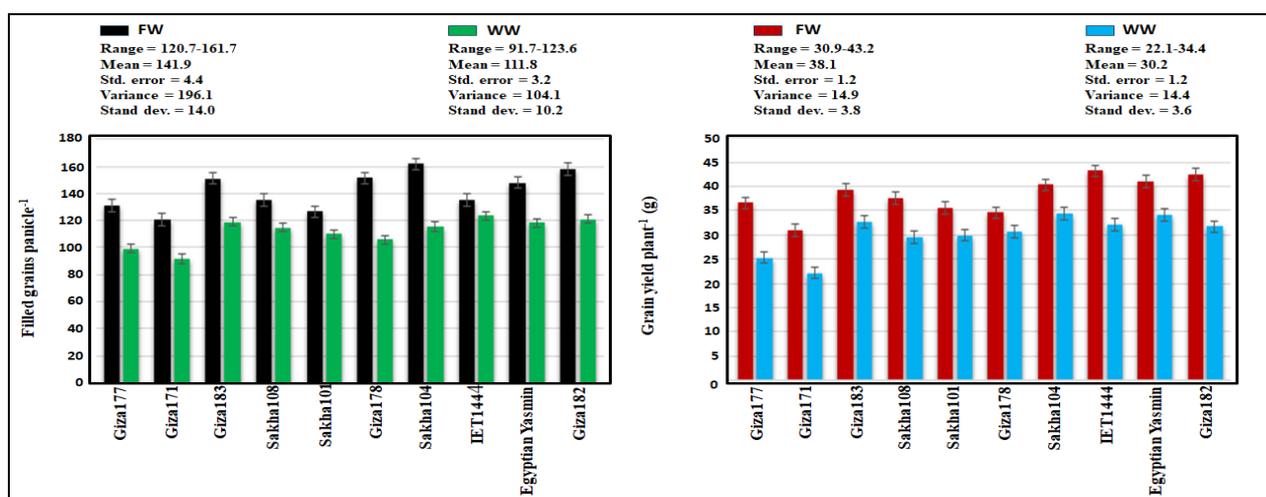

Figure 4. Filled grains panicle per panicle and grain yield per plant traits for 10 rice genotypes under freshwater and wastewater irrigation in a two-location study

Grain quality traits

Ten rice genotypes were evaluated for grain quality traits such as hulling, milling, head rice percentages, and amylose content under freshwater and wastewater irrigation. Hulling percentages under freshwater ranged from 78.4% to 85.7%, while they decreased to 72.9% to 82.4% under wastewater. Milling percentages also dropped in wastewater, from 67.3% to 64.0%-69.1%. Head rice percentages were higher under freshwater compared to wastewater. Amylose content increased slightly under wastewater conditions, indicating that the quality of irrigation water significantly impacts rice grain quality, with wastewater leading to reductions in most quality traits.
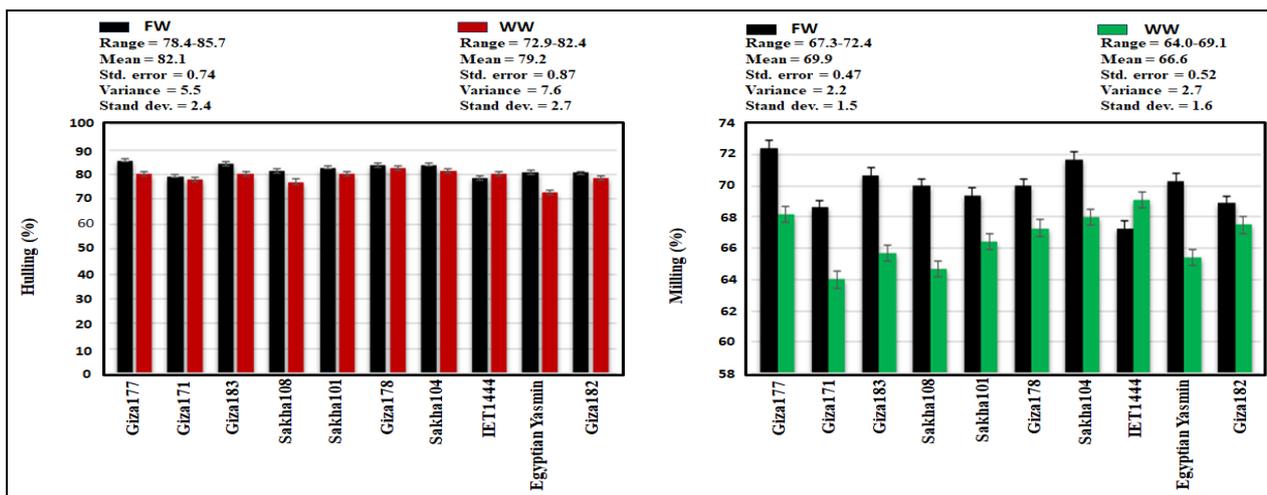
Figure 5. Hulling and milling percentage traits for 10 rice genotypes under freshwater and wastewater irrigation in a two-location study
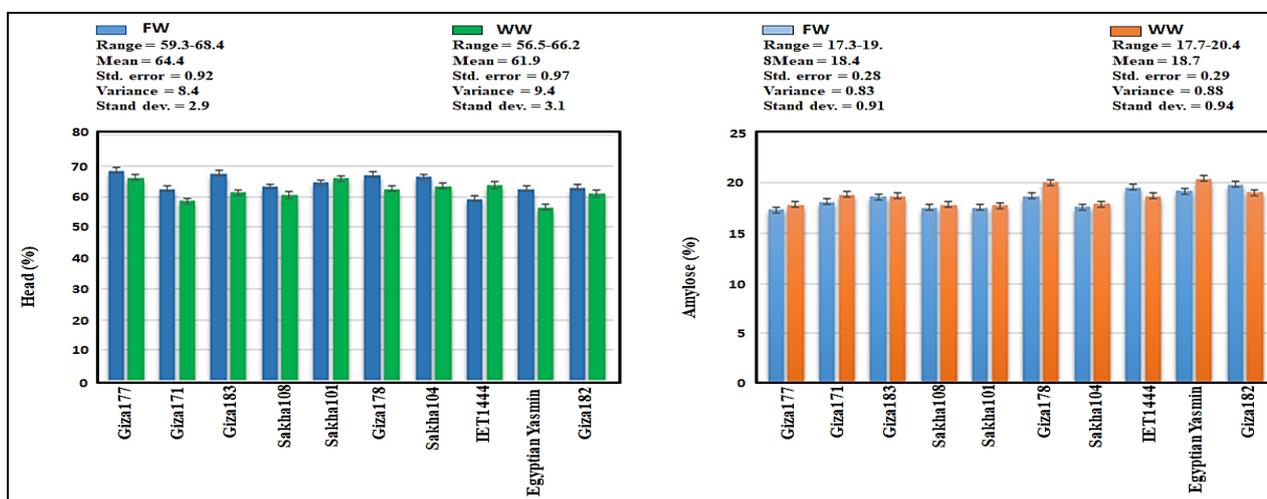

Figure 6. Head rice and amylose percentage traits for 10 rice genotypes under freshwater and wastewater irrigations in a two-location study

Yield reduction under wastewater (WW)

Stress conditions impacted rice yields, with wastewater irrigation identified as a significant factor for yield decline. Ten rice genotypes showed high yields under freshwater, but yields decreased under wastewater by 3.9 g for Giza 178 and 11.3 g for Giza 177, the most sensitive genotype. Percentage yield reductions ranged from 11.27% in Giza 178 to 30.87% in Giza 177, affecting genotypes Giza 177, Giza 171, IET 1444, Sakha 108, and Giza 182 most severely. This pattern indicates a potential correlation of loci controlling these traits for early marker-assisted selection. This result indicated that these traits were found to be the principal yield components. This positive correlation might indicate the presence of loci, controlling these traits, on the same linkage group, and consequently, it might be used for early marker-assisted selection (El-Malky and Al-Daej, 2018).

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Table 4. Reduction in grain yield of plant^{-1} (g) of ten rice genotypes and reduction percentage

No.	Varieties	Grain yield plant^{-1} (g)			Redaction %
		Fresh Water	Waste Water	Yield redaction/plant^{-1}	
1	Giza177	36.6	25.3	11.3	30.87
2	Giza171	30.9	22.1	8.8	28.47
3	Giza183	39.3	32.6	6.7	17.04
4	Sakha108	37.6	29.5	8.1	21.54
5	Sakha101	35.5	29.9	5.6	15.77
6	Giza178	34.6	30.7	3.9	11.27
7	Sakha104	40.3	34.4	5.9	14.64
8	IET1444	43.2	32.1	11.1	25.69
9	Egyptian Yasmin	41.0	34.1	6.9	16.89
10	Giza182	42.5	31.7	10.7	25.17
Range		30.9-43.2	22.1-34.7	3.9-11.3	11.27-30.87
General Mean		38.15	30.24	7.9	20.73
Std. error		1.21	1.22	0.804	2.07
Variance		14.82	14.98	6.46	43.02
Stand dev.		3.84	3.87	2.54	6.55
Coeff. var		10.09	12.80	32.19	31.63

Determination of genetic variations

Genetic parameters such as genotypic variance and environmental variance were analyzed for ten rice genotypes across twelve traits under different irrigation conditions. The findings indicate that phenotypic variance consistently exceeded genotypic variance, with phenotypic coefficients of variation (PCV) higher than genotypic coefficients of variation (GCV). Notable variability was observed particularly in leaf blast reaction, stem borer infestation, and grain yield per plant, suggesting a strong potential for genetic enhancement. Traits with high GCV and PCV values point to significant genetic variability and moderate environmental impact, alongside moderate broad-sense heritability estimates. In contrast, traits like growth duration and plant height showed high heritability, indicating additive gene action and excellent prospects for selection-based improvement. This combination indicates the predominance of additive gene action, suggesting that these traits are amenable to effective improvement through selection. These findings are consistent with previous reports by Hassan et al. (2023), who documented moderate to high heritability and substantial genetic variability for grain yield and related traits in rice.

Table 5. Genetic parameters for fresh water (FW) and wastewater (WW) conditions

Traits	Leaf blast reaction		Stem borer		Duration		Plant height	
Condition	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water
σ^2 g	3.6	3.6	17.1	12.9	109.1	88.9	55.3	93.7
σ^2 e	0.59	0.54	0.51	0.32	2.7	2.2	2.1	2.6
σ^2 Ph	4.2	4.11	17.6	13.2	111.8	91.2	57.4	96.4
Grand Mean	2.9	2.9	6.7	8.8	133.1	129.3	101.8	94.2
PCV	70.0	70.1	62.7	40.9	7.9	7.4	7.4	10.4
GCV	64.9	65.3	61.8	40.4	7.8	7.3	7.3	10.3
h^2 B	85.9	86.8	97.1	97.5	97.6	97.5	96.4	97.3
Gs	3.6	3.6	8.4	7.3	21.3	19.2	15.1	19.7
Gs%	123.9	125.4	125.5	82.3	15.9	14.8	14.8	20.8

Traits	Panicle plant^{-1}		Filled grains panicle^{-1}		Grain yield plant^{-1} (g)		Panicles per m^2	
Condition	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water
$\sigma^2 g$	3.5	2.9	194.9	103.3	14.6	14.5	1556.1	1514.2
$\sigma^2 e$	0.87	0.83	2.95	2.41	0.74	1.35	5.55	6.29
$\sigma^2 Ph$	4.3	3.7	197.8	105.7	15.3	15.8	1561.7	1520.5
Grand Mean	24.0	18.2	141.9	111.9	38.1	30.2	403.9	353.4
PCV	8.7	10.6	9.9	9.2	10.3	13.1	9.8	11.0
GCV	7.7	9.4	9.8	9.1	10.0	12.6	9.7	11.0
$h^2 b$	79.9	77.8	98.5	97.7	95.2	91.5	99.6	99.6
Gs	3.4	3.1	28.5	20.7	7.7	7.5	81.1	80.0
Gs%	14.4	17.0	20.1	18.5	20.2	24.8	20.1	22.6
Traits	Hulling %		Milling %		Head rice %		Amylose content %	
Condition	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water	Fresh Water	Waste Water
$\sigma^2 g$	5.2	7.4	2.0	2.5	7.9	8.9	0.77	0.82
$\sigma^2 e$	1.1	1.1	0.6	0.76	1.1	1.6	0.15	0.12
$\sigma^2 Ph$	6.3	8.5	2.6	3.3	8.9	10.6	0.92	0.94
Grand Mean	82.1	79.2	69.9	66.6	64.4	61.9	18.3	18.6
PCV	3.0	3.7	2.3	2.7	4.6	5.2	5.2	5.2
GCV	2.7	3.4	2.0	2.4	4.4	4.8	4.7	4.8
$h^2 b$	82.4	86.9	77.1	76.9	88.2	84.7	83.7	87.3
Gs	4.2	5.2	2.6	2.9	5.4	5.6	1.6	1.7
Gs%	5.2	6.6	3.7	4.3	8.4	9.1	9.0	9.3

Correlation coefficient

Pearson's correlation coefficients illustrate key relationships among crop performance variables. Stemborer infestation negatively correlates with leaf blast reaction (r = -0.515), hulling percentage (r = -0.567), and head rice percentage (r = -0.582), while positively correlating with amylose content (r = 0.599). Leaf blast reaction shows a negative correlation with panicles per plant (r = -0.576) and amylose content (r = -0.668), but a positive correlation with growth duration (r = 0.680). Growth duration positively correlates with plant height (r = 0.682) but negatively with filled grains per panicle (r = -0.536), grain yield per plant (r = -0.567), and panicles per m² (r = -0.628). Additionally, plant height negatively correlates with filled grains per panicle (r = -0.516). The number of panicles per plant positively correlates with filled grains per panicle (r = 0.714), grain yield per plant (r = 0.525), and panicles per m² (r = 0.514). Filled grains per panicle also positively correlate with grain yield per plant (r = 0.744), while grain yield per plant positively correlates with panicles per m² (r = 0.593), which in turn correlates positively with amylose content (r = 0.573). Analysis reveals that phenotypic coefficients of variation surpass genotypic coefficients across all traits, highlighting environmental impacts on trait expression. Traits with high heritability and genetic advance, such as growth duration and grain yield, indicate effective selection due to additive gene action. Conversely, grain quality traits, while showing high heritability, exhibit low genetic advance, suggesting non-additive gene action where direct selection may be ineffective. This aligns with previous findings by Hassan et al. (2023).
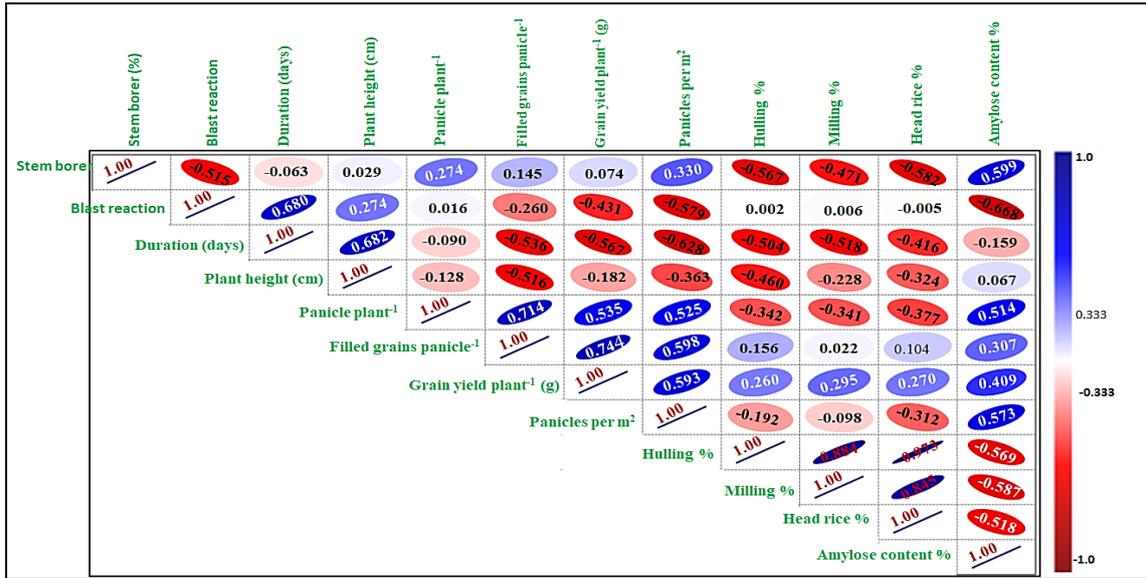
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Figure 7. Corrplot depicting Pearson's correlation among 12 traits across 10 genotypes. Red squares indicate a negative correlation, blue squares indicate a positive correlation, and white squares indicate no correlation.

Clustering analysis based on quantitative traits under freshwater

The two-year average for all traits under freshwater irrigation was assessed for normality, revealing that all traits followed a normal distribution. Cluster analysis grouped the rice varieties into two main clusters (Figure 8). The first cluster included Giza 177 and Giza 171, both showing moderate resistance to stem borer infestation and similar numbers of panicles per m², with Giza 171 being a parental variety of Giza 177. The second cluster was divided into two subgroups. The first subgroup comprised

Sakha 108, IET 1444, Egyptian Yasmin, and Sakha 101. Egyptian Yasmin and IET 1444 were closely related, sharing similar traits like stem borer infestation and grain yield. Sakha 108 and Sakha 101 also showed similarities, with Sakha 101 being a parental variety of Sakha 108. The second subgroup included Giza 183, Giza 178, Giza 182, and Sakha 104. Giza 178 and Giza 182 performed similarly in leaf blast infection and plant height. Giza 183 and Sakha 104 were resistant to stem borer infestation, showing comparable values for grain yield and panicles per m² (Figure 8).
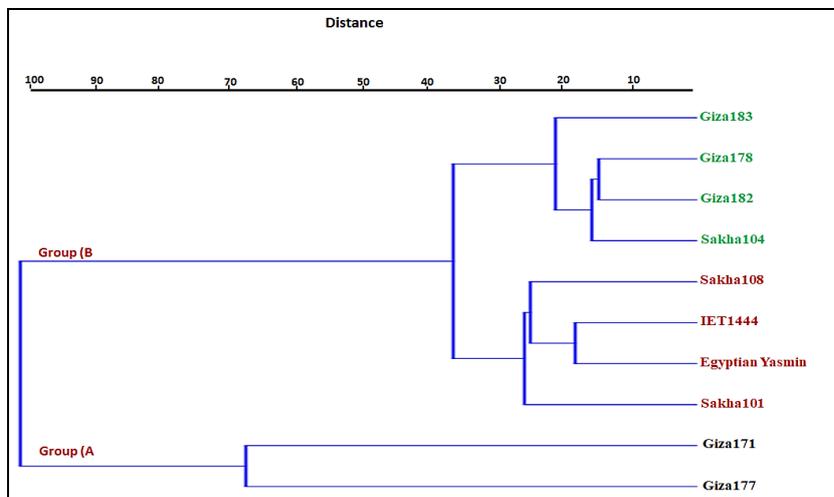

Figure 8. Dendrogram of 12 quantitative traits among 10 rice varieties, based on average taxonomic distance under fresh water

Clustering analysis based on quantitative traits under wastewater

The genetic behavior of ten rice varieties varied under wastewater irrigation, as shown in Figure 9. Cluster analysis grouped them into two main categories. The first group comprised IET 1444, Giza 182, Egyptian Yasmin, and Giza 183, all resistant to leaf blast but susceptible to stem borer. They shared similarities in growth duration, number of panicles per plant, and grain yield.

The second group featured distinct branches. Giza 171 stood out due to its long growth duration, susceptibility to blast disease, and short grain yield. Giza 177 branched off because of its short growth duration and low panicles per plant. Giza 178 and Sakha 101 were similar in growth duration and yield, while Sakha 104 and Sakha 108 were related by their shared susceptibility to blast and comparable growth traits.
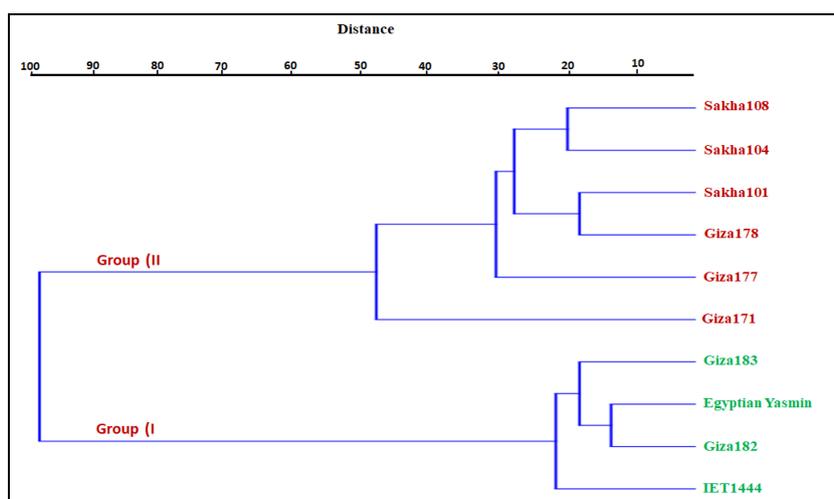

Figure 9. Dendrogram of 12 quantitative traits among 10 rice varieties, based on average taxonomic distance under fresh water

CONCLUSIONS

This study demonstrates that water irrigation, genotype selection, and soil fertility are key factors influencing rice growth, yield, and pest incidence. Wastewater irrigation increased soil salinity and nutrient levels, which negatively affected yield and pest resistance in some genotypes, particularly those of the Japonica types. However, certain varieties, including Giza 178, Sakha 104, Sakha 101, Egyptian Yasmin, and Giza 183, demonstrated good performance under both freshwater and wastewater conditions, highlighting their tolerance to stress and potential suitability for cultivation in areas prone to water quality fluctuations. High heritability and genetic variability for most traits suggest significant potential for genetic improvement. Additionally, clustering and pedigree analyses confirmed the close relationships among tolerant genotypes. Effective management of water quality and soil conditions, combined with the use of tolerant varieties, is essential for ensuring sustainable rice production under variable water conditions.

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REFERENCES

Aamer, K.K.M., Asif, N.M., Hussain, S., Aziz, T., Schoenau, J., 2015. *High sodium in irrigation water caused B toxicity at low soil solution and shoot B concentration in maize (Zea mays L.).* Journal of Plant Nutrition, 38(5): 728-741.

Abdallah, A.A., Aboyousef, M.I., Hammoud, S.A., Sedeek, S.E., EL-Namaky, R.A., El-Malky, M.M., EL-Abd, A.B., Ammar, M.H., Abdelkhalik, A.F., EL-Rafaee, I.S., Zayed, B.A., Abou-khalifa, A.B., Elkhoby, W.M., Naeem, E.S., Metwally, T.F., Gewaily, E.E., El-Refaee, Y.Z., Elmoghazy, A.M., Elgamal, W.H., Gaballah, M.M., Shehab, M.M., Bassuony, N.N., Awad-Allah, M.M., Ramadan, I.A., Anis, G.B., Ali, M.A., Hamd, H.S., Elshamy, E.A., El-Habet, H.B., Zidan, A.A., Mikhael, B.B., El-Kallawy, W.H., Hashem, I.M., Gharieb, A.S., Aboueldarag, I.H., Abd El-Naby, S.S.M., Shebl, S.M., El-Ghandor, A.M.A., Osman, M.M., Hefeina, A.G., Bassiouni, S.M.A., Bleih, E.M., Elbadawy, O.A., Sultan, S., Elsherif, A.I., Abdelkhalik, S.M., Mazal, T.M., Ghidan, W.F., Ghazy, M.I., Elnaem, S.A., Talha, I.A., Amer, S.M., Elsherbiny, H.A., Abdelrahman, M.A., Hussein, F.A., Abdelmgeed, M.F., Esaa, W.M., Elshenawy, M.A., El-Agoury, R.Y., Sakran, R.M., Okasha, A.M., Negm, M.A., Nada, A.M., Abd El-Megeed, T.M., Ghazy, H.A., Wissa, M.T., Elamawi, R.M., EL-Shafey, R.A., Elhabashy, M.M., Taha, A.S., Hendawy, A.S., Mousa, A.M., Abo-Alez, A.F., Ebeid, R.A., EL-Rewainy, I.M., El-Ekhtyar, A.M., El-Mowfi, H.F., EL-Kady, A.A., Shehata, S., Aidy, I.R., EL-Hissewy, A.A., Draz, A.E., Badawi, A.T., Mahrous, F.N., Hassan, H.M., Nofal, R.S., Sakr, S.M., Abdulmajid, D.A., Khattab, A.A., Hadifa, A.A., EL-leithy, S.A., Gomaa, M.A., Selim, M.E., ELkholy, N.K., Elsehely, A.B., Arafat, E.F.A., Reda, A.M., Abdallah, R.M., EL-Sharnobi, D.A., Freeg, H.A., Daher, E.M., El Serafy, A.M., Elekhtyar, N.M., Ghoneim, A.M., Elsaka, M.A., Elsayed, G.A., Taha, H.A., Essa, E.A.H., Abd Elhamid, M.M., Bastawesi, A.O., Sheta, I.A., Elshayb, O.M., El-Wahsh, S.M., Badr, E.A., Gabr, W.E., Kalboush, Z.A., Hassan, A.A., Saleh, M.M., Tahoon, A.M., 2022. *Sakha 107 Egyptian Rice Variety with High Yielding and Good Grain Quality under Water Shortage.* J. of Plant Production, Mansoura Univ., 13(3): 85-98. DOI: 10.21608/jpp.2022.127304.1100

Abdel Rahman, A.E., Engel, M.B., Eid, S.M.M., Aboelsoud, H.M., 2022. *A new index to assess soil sustainability based on temporal changes of soil measurements using geomatics - an example from El Sharkia, Egypt.* All Earth, 34(1): 147-166.

Allard, R.W., 1999. *Principles of plant breeding.* 2nd ed. New York, USA: John Wiley and Sons, p. 254.

Aly, A.A., Mansour, M., Mohamed, H.I., Abd-Elsalam, K.A., 2012. *Examination of correlations between several biochemical components and powdery mildew resistance of flax cultivars.* The Plant Pathology Journal, 28(2): 149-155.

Aly, A.A., Mohamed, H.I., Mansour, M.T., Omar, M.R., 2013. *Suppression of powdery mildew on flax by foliar application of essential oils.* Journal of Phytopathology, 161(6): 376-381.

Ashry, N.A., Ghonaim, M.M., Mohamed, H.I., Mogazy, A.M., 2018. *Physiological and molecular genetic studies on two elicitors for improving the tolerance of six Egyptian soybean cultivars to cotton leaf worm.* Plant Physiology and Biochemistry, 130: 224-234.

Bidzakin, J.K., Fialor, S.C., Awunyo-Vitor, D., Yahaya, I., 2018. *Impact of Irrigation Ecology on Rice Production Efficiency in Ghana.* Advances in Agriculture, 2018: 1-10.

Çebi, U., Özer, S., Öztürk, O., Aydın, B., Çakır, R., 2023. *Yield and water productivity of rice grown under different irrigation methods.* The Journal of Agricultural Science, 161: 387-397.

Dudley, J.W., and Moll, R.H., 1969. *Interpretation and use of estimates of heritability and genetic variances in plant breeding.* Crop Sci., 9: 257-262.

El-Hitya, M.A., Omara, A.E., Elsakab, M.A.M., Ibrahima, A., Metwallyb, T.F., 2024. *Assessment of Rice Quantity and Quality at Different Locations in El-Behira Governorate, Egypt.* Egypt. J. Agron., 46(2): 411-420.

El-Malky, M.M., and Al-Daej, M., 2018. *Studies of Genetic Parameters and Cluster analysis of some Quantitative Characters through Diallel analysis of rice (Oryza Sativa L.).* Vegetos, 31: 1.

Hagage, M., Hewaidy, A.G.A., Abdulaziz, A.M., 2025. *Groundwater quality assessment for drinking, irrigation, aquaculture, and industrial uses in the waterlogged northeastern Nile Delta, Egypt: a multivariate statistical approach and water quality indices.* Modeling Earth Systems and Environment, 11(1): 59.

Hassan, H.M., Hadifa, A.A., El-leithy, S.A., Batool, M., Sherif, A., Al-Ashkar, I., Ueda, A., Rahman, M.D.A., Hossain, M.A., El-Sabagh, A., 2023. *Variable level of genetic dominance controls important agronomic traits in rice populations under water deficit condition.* PeerJ, 11: e14833.

Hester, E.R., Vaksmaa, A., Valè, G., Monaco, S., Jetten, M.S.M., Lüke, G., 2022. *Effect of water management on microbial diversity and composition in an Italian rice field system.* FEMS Microbiology Ecology, 98: 1-11.

IRRI (International Rice Research Institute), 2014. *Standard Evaluation System for rice (SES).* 5th Edition, International Rice Research Institute, Los Banos.

Le Clercq, E.L., Leonard, W.H., Clark, A.G., 1962. *Field plot technique.* Minnesota, USA: Burgess Publishing Co.

ROMANIAN AGRICULTURAL RESEARCH

Li, S., Zhuang, Y., Liu, H., Wang, Z., Zhang, F., Mingquan, L., Zhai, L., Fan, X., Niu, S., Chen, J., Xu, C., Wang, N., Ruan, S., Shen, W., Mi, M., Wu, S., Du, Y., Zhang, L., 2023. *Enhancing rice production sustainability and resilience via reactivating small water bodies for irrigation and drainage*. Nature Communications, 14: 3794.

Mohamed, H.I., 2011. *Molecular and biochemical studies on the effect of gamma rays on lead toxicity in cowpea (Vigna sinensis) plants*. Biological Trace Element Research, 144(1): 1205-1218.

Mohamed, H.I., Elsherbiny, E.A., Abdelhamid, M.T., 2016. *Physiological and biochemical responses of Vicia faba plants to foliar application of zinc and iron*. Gesunde Pflanzen 68(4): 201-212.

Prasad, S.R., Prakash, R., Sharma, C.M., Haque, M.F., 1981. *Genotypic and phenotypic variability in quantitative characters in oat*. Indian J. Agric. Sci., 51(7): 480-482.

Rezk, A.A., El-Malky, M.M., Mohamed, H.I., Ismail, A.H., Al-Dossary, O., 2025a. *Impact of Climate Changes to Adaptability of Some Rice Germplasm (Oryza sativa L.) under High Temperature through Quantitative Traits and Simple Sequence Repeats (SSR) Marker*. Romanian Agricultural Research, 42: 483-498.
https://doi.org/10.59665/rar4242

Rezk, A.A., El-Malky, M.M., Mohamed, M.I., El-Beltag, H.S., 2025b. *Assessing Phenotypic Diversity, Stem Borer Infestations, and Blast Resistance of Some Hybrid and Inbred Rice Genotypes*. Romanian Agricultural Research, 42: 791-803.
https://doi.org/10.59665/rar4267

Rohlf, F.J., 2000. *NTSYS-PC Manual Exeter Software*. Setauket, New York, USA.

Sneath, P.H., and Sokal, R.R., 1973. *Numerical taxonomy: the principles and practice of numerical classification*. 1st ed. San Francisco, W.H. Freeman.

Ugalahi, U.B., Adeoye, S.O., Agbonlahor, M.U., 2016. *Irrigation Potentials and rice self-sufficiency in Nigeria: A review*. African Journal of Agricultural Research, 11(5): 298-309.