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Mitigating Salt Stress: Anti-salinity Agents for Rice Sustainability and Yield Optimizing

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ABSTRACT

Managing rice cultivation under salt stress in arid and semi-arid regions is a considerable challenge for ensuring food security and sustainability while enhancing rice production. This research was conducted during the 2022 and 2023 seasons at the Experimental Farm of El-Sirw Agriculture Research Station, located in Damietta Governorate, Egypt, aiming to identify an anti-salinity substance that could effectively assist rice plants in coping with salinity stress. The experiment employed a split-plot design arrangement in randomized complete block design (RCBD) with four replications. The main plots featured rice varieties; Giza179 and Sakha108, while the subplots included treatments such as control, Salicylic acid (SA), Gibberellic acid (GA₃), folic acid vitamin (B9), elements as NPK and micronutrients (E), Glycine betaine (GB) and their combination which were applied at three growth stages. The outcome demonstrated that all treatments improved the examined characteristics compared to the control treatment. The optimal treatment involved spraying a gibberellic acid on the foliage during mid tillering, applying elements at panicle initiation, and administering salicylic acid at the booting stage, which improved biochemical traits, the effectiveness of the antioxidant defense system, agronomic characteristics, yield attributes, rice yield and cost-effective compared to other treatments, followed by the mixture of the materials utilized in the study. In conclusion, the external application of gibberellic acid, nutrient elements, and salicylic acid at specific growth stages provides an efficient strategy to alleviate oxidative stress in salt-affected soils, thereby improving rice growth, productivity, and economic return.

Keywords: Rice, Amino acids, Antioxidants, Plant hormones, Vitamins, Saline soil

INTRODUCTION

Rice (*Oryza sativa* L.) ranks among the most significant cereal crops in Egypt (Amwal, 2023). Although crucial, rice cultivation in Egypt encounters difficulties because of salt stress and water needs in a nation with restricted water supplies (FAS, 2025). The increasing price of rice in the global market indicates a trend that could improve the cost-effectiveness of rice farming; to improve agricultural productivity, it is essential to understand the physiological and biochemical alterations in plants subjected to salt stress (Bin Rahman and Zhang, 2023). About 30% to 40% of soils in the Nile Delta are currently affected by salinity projected to increase in next days (SALAD, 2022).

Salinity significantly impacts plant growth and productivity and is a key factor contributing to reductions in crop yields across global agricultural soils (Abdul *et al.*, 2020). Salt stress has various impacts on the elements of antioxidant defense systems in plants, and there is growing proof that salt stress considerably affects the physiological and biochemical characteristics of plants (Mohammad *et al.*, 2017). The buildup of surplus Na⁺ and Cl⁻ leads to ionic imbalance, which can disrupt the selectivity of root membranes and result in reduced K⁺/Na⁺ ratio within the cytosol (Jasmes *et al.*, 2011; Hasanuzzaman *et al.*, 2014 and Ria and Jain 2022). The excessive production of ROS due to salt stress is a key factor obstructing the morpho-physiological and biochemical functions of plants, which can be significantly improved by boosting the antioxidant defense system that neutralizes ROS (Hasanuzzaman *et al.*, 2021). The plant's antioxidant defense mechanism safeguards

against oxidative damage caused by salt by neutralizing ROS and regulating the ROS generation balance during salt stress (Hasanuzzaman *et al.*, 2021). Salinity stress causes a nutrient imbalance in plants, including phosphorus, which is an essential macronutrient for growth. It acts as a structural element for nucleic acids and phospholipids, and is involved in energy transfer, signal transmission, and enzyme activation processes (Mlodzinska and Zboinska 2016). Aizaz *et al.*, (2024) reported that salinity causes a progressive decline in the level of plant hormones in the root system of plants, salinity associated with decreases in auxin, cytokinin and gibberellins. Therefore, the reduction in plant growth under stress conditions could be an outcome of altered hormonal balance

Enhancing salt resistance of crops is a productive method to boost crop production (Meng *et al.*, 2023). Salicylic acid (SA) acts as an antioxidant by scavenging free radicals, regulating various plant biological processes such as photosynthesis, proline metabolism, nitrogen metabolism, antioxidant defense mechanisms, and offers protection from abiotic stresses (Khan *et al.*, 2015 and Jini, 2017). Implementation of SA in foliar applications to mitigate the impacts of abiotic stresses has been examined, with numerous studies indicating that salicylic acid enhances resistance to these stresses (Shakirova *et al.* 2003; Majid *et al.*, 2011; Erdal *et al.*, 2011; Miura and Tada 2014; Rajeshwari and Bhuvaneshwari, 2017; El-Taher, *et al.*, 2022 and Shana *et al.*, 2024).

The exogenous application of plant hormones as GA₃ provides an attractive approach to counter stress conditions. However, plant hormones play an important role in plant physiology, such as seed germination, root formation. GA₃ foliar

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application can beneficially mitigate salinity stress by decreasing oxidative stress damage and enhancing the defense system, leading to increased activities of antioxidant enzymes additionally, GA₃ usage suppresses lipid peroxidation (Shahzad *et al.*, 2021 and Nader and Amira 2023)

Folic acid (vitamin B9) is organic chemical which is required in traces to maintain normal growth (Rady *et al.*, 2011). B9 induced an important function in plant reactions to stress (Toscano *et al.*, 2019). External applications of folic acid can mitigate the adverse impacts of salt stress by strengthening the antioxidant defense system (Semra and Hatice 2016; El-Metwally and Sadak 2019). Vitamin B9 diminishes the suppressive effects of salinity, furthermore, it enhances the antioxidant and nutrient uptake (Al-Elwany *et al.*, 2022)

The application of nutrients such as Ca, P, K, N, Cu, Zn, and Mn plays a crucial role in regulating nitrogen assimilation in plants and raises levels of nitrogen-containing compounds, primarily amino acids, when exposed to salt, which are regarded as osmo-protectants and are recognized for decreasing oxidative stress by scavenging ROS, thus improving plant salt tolerance. Nutrients play a crucial role in tolerating abiotic and biotic stresses; maintaining adequate K⁺ levels is vital for proper cellular operations as it acts as a key macronutrient for enzyme activation, osmotic regulation, creation of turgor pressure, cell expansion, preservation of membrane electric potential, and pH balance within plant cell regulates respiration (Mansour, 2000; Abdolzadeh *et al.*, 2008; Almeida *et al.*, 2017 ; Hawkesford 2017; Hasanuzzaman *et al.*, 2018 ; Amira *et al.*, 2019 and Amira *et al.*, 2024).

Glycine betaine (GB) acts as an essential compatible osmolytes, helping plants endure different abiotic stresses, such as salinity. Exogenous applications of GB have proven beneficial in alleviating stress in rice (Cha-Um, and Kirdmanee, 2010; Tania *et al.*, 2022 and Bai *et al.*, 2022). Rice is regarded as a non-accumulator of GB (Chen and Murata, 2008). The external application of GB on rice subjected to salt stress enhanced rice productivity (Rhaman *et al.*, 2024 and Lamlo *et al.*, 2025).

Different strategies are being employed to improve plant growth in saline conditions. This study aims to provide plants subjected to salt stress with what they have lost due to the stress and to determine the most effective substance for foliar application as an anti-salinity tool and appropriate growth stages for applying this substance to enhance rice yield and obtain the highest economic advantage.

MATERIALS AND METHODS

1-Experimental site

Field trials were conducted at the Experimental Farm of El-Sirw Agriculture Research Station, Agricultural Research Center, Damitta, Egypt during 2022 and 2023 growing seasons. The station is located at coordinates 31°25'3.1440" N and 31°48'51.9984" E. The research site has a dry climate without any rainfall throughout the rice growing seasons. The typical maximum and minimum temperatures fluctuated between 32.0 and 35.0 °C and 11.0 to 17.3 °C, respectively. The relative humidity levels during the morning and noon varied between 70.5 to 83.5% and 42.5 to 56.5%, respectively. The typical evaporation varied between 5.56 and 7.61 mm per day. The results of mechanical and chemical soil properties are presented in Table 1.

Table 1. Mechanical and chemical analysis of the experiment's soil

Season	2022	2023
Soil properties		
pH (1:2.5)	8.30	8.40
Ec(dS.m-1)	8.03	8.09
Organic matter%	1.06	1.0
Available P, mg/kg	10.7	11.3
Available Ammonium (ppm)	17.0	17.4
Available Nitrate (ppm)	14.2	14.7
Available Potassium (ppm)	245	263
Anions(meq/L)		
CO ₃ ²⁻	-	-
HCO ₃ ⁻	10.6	10.3
SO ₄ ²⁻	32.4	29.4
CL ⁻	40.9	39.5
Cations(meq/L)		
Ca ⁺⁺ +Mg ⁺⁺	39.4	38.4
Na ⁺	40.3	42.1
K ⁺	0.61	0.40

2- Experimental design and treatment

As shown in Figure 1, the experiment design was a split-plot design with four replications.

The main plot includes rice varieties *i.e* Giza179 and Sakha108.

The subplot utilized ten treatments:

- 1-Control (CK) without foliar spray of the tested substances
- 2- Salicylic acid (SA) foliar application at mid-tillering (MT), panicle initiation (PI) and booting (BT) stages
- 3- Gibberellic acid (GA₃) foliar application at MT, PI and BT stages,
- 4- Folic acid vitamin (B9) foliar application at MT, PI and BT stages
- 5-Elements (E) NPK and micronutrients (Zn, Fe, Mn, Cu, B, Mo) applied at MT, PI and BT stages
- 6- Glycine betaine (GB) foliar application at MT, PI and BT stages
- 7-(GB) applied at MT+(E) applied at PI+(SA) applied at BT
- 8-(B9) applied at MT +(E) applied at PI +(SA) applied at BT
- 9-(GA₃) applied at MT +(E) applied at PI +(SA) applied at BT
- 10- Salinity component (MIX) mixture of SA+E+GB+B9 applied at the three growth stages.

The concentration of different substances was shown in figure1.

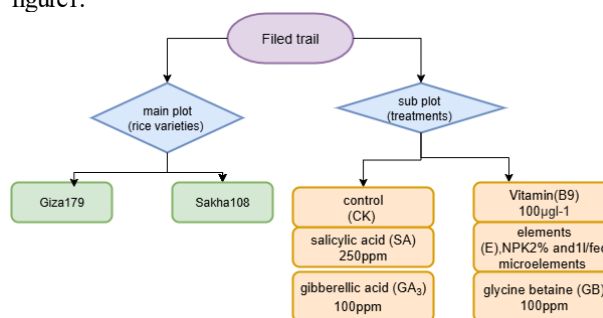


Figure 1. Implementation of different materials used in the experiment

3-Agricultural Practices:

All experiments were preceded by a clover crop. Phosphorus was applied as a basal application during land in the form of calcium super phosphate (15.5 % P₂O₅) at the rate of 55 kg P₂O₅ ha⁻¹. The rate of seeds was 165 kg ha⁻¹, soaked in water for 48 hours, and then incubated for 24 hours. Seeds after hastening early germination were uniformly broadcasted in the nursery bed in May 1st in the first season and May 5th in the second season. After the permanent field was well

prepared seedlings were transferred from the nursery after 35 days of sowing and distributed through the plots. Seedlings were manually transplanted into the plot (10 m² for each plot), 20X20 cm spacing 3-5 seedlings hill⁻¹ was applied. Seven days after transplanting the herbicide Saturn 50% [S-(4-Chlorophenol methyl) diethyl carbamothioate] at the rate of 4.5L ha⁻¹. Nitrogen fertilizer was applied at the rate of 165 Kg N ha⁻¹ in the form of ammonium sulphate (20% N) in three equal splits application at 10, 25 and 40 days after transplanting. Potassium in the form of potassium sulphate (50% K₂O) at the recommended rate (60 kg K₂O ha⁻¹) was added in two equal doses at 30 and 45 days after transplanting. The reminder agronomic practices were followed as recommended package of rice under salt-affected soil during the growing seasons developed by RRTC, FCRI, ARC, agricultural ministry.

4-Physiological Measurements

Photosynthetic pigments contents of leaves:

Chlorophyll a, chlorophyll b, and carotenoids were assessed from five disks extracted from the rice shoots. The shades were removed by grinding in 85% aqueous acetone (20 ml), and a touch of CaCO₃ was added to the acetone solution before grinding. After filtration, the total volume of the acetone solution was 20 ml. The total chlorophyll pigments were determined by examining the absorbance spectrophotometrically at 662, 644, and 470 nm, and the concentrations of photosynthetic pigments were computed according to the criteria specified by

$$\text{Chl.a} = 11.24 (0.D)_{662} - 2.04 (0.D)_{644} = \text{mg/L}$$

$$\text{Chl.b} = 20.13 (0.D)_{644} - 4.19 (0.D)_{662} = \text{mg/L}$$

$$\text{Car.} = 1000 (0.D)_{470} - 1.90 \text{ chl.a} - 63.14 \text{ chl. b} / 214 = \text{mg/L}$$

According to (Lichtenthaler and Buschmann, 2001).

CO₂ diffusion, stomatal conductance and transpiration rate:

The gas samples underwent analysis with a gas chromatograph that had a flame ionization detector (GC-8A, Shimadzu Corporation, Kyoto, Japan) (Naser *et al.* 2007).

Lipid peroxidation as measured by malondialdehyde (MDA) content

The degree of lipid peroxidation was measured in terms of malondialdehyde (MDA) employing the method of Change *et al.*, (2015).

Determination Peroxidase:

For the reaction solution preparation, 200 ml of phosphate-buffered saline (PBS) (0.2 M, pH 6.0) was combined with 0.076 ml of liquid guaiacol (2-methoxyphenol) and stirred until fully dissolved; after cooling, 0.112 ml of 30% H₂O₂ was incorporated, and the solution was thoroughly mixed before refrigeration. A 3 ml portion of this reaction solution was mixed with 30 ml of enzyme solution and PBS as a control, after which OD470 was measured (1 min). An enzyme activity unit (u) was characterized as a 0.01 rise in OD470 per minute Chance (1955).

Catalase Activity Assay: Colorimetric Assay

Citing the experimental approach of (Zhang 2004). For the reaction solution, 200 ml of PBS (0.15 M, pH 7.0) were mixed with 0.3092 ml of 30% H₂O₂ and stirred thoroughly. To analyze enzyme activity, 3 ml of the reaction solution was mixed with 0.1 ml (modified as needed) of enzyme extract, using PBS as the control. The OD240 was measured (using UV) every minute for 2 minutes. A single unit (u) of enzyme activity was defined as a decrease of 0.01 in OD240 per minute $\text{CAT} = \Delta A_{240} \times V_t / (W \times V_s \times 0.01)$ (U/gmin).

$$\Delta A_{240} = A_{240_f} - A_{240_i} / (t_f - t_i)$$

where

A_{240_f} and A_{240_i} are the final and initial A₂₄₀ values, respectively; t_f is the reaction final time; t_i is the reaction initial time; W is the sample fresh weight (g); t is the reaction time (min); V_t is the total volume of the reaction (3.1 ml); and V_s is the volume (0.1 ml) of enzyme extract in the reaction.

5-Determination of elements

The concentrations of N, P, K, and Na were analyzed in the dry material. The wet digestion of 0.2 g of plant material using sulfuric and perchloric acids was performed on leaves and dried seeds according to Piper (1947)

6-Plant growth

During the heading stage, five hills of plants were randomly selected from each plot to evaluate dry matter yield. Leaves from three hills were randomly collected to assess the leaf area of plant samples, and measurements were conducted using a Portable Area Meter (Model LI-3000A), after which the leaf area index (LAI) was calculated (Barclay *et al.*, 2000).

7-Yield and yield attributes

At harvest, plant height, panicle length and panicle numbershill⁻¹ were estimated. Ten panicles were collected randomly to estimate the panicle weight, panicle length, number of filled grains and unfilled grains per panicle⁻¹ and 1000-grain weight. The six inner rows of each plot were harvested, dried, threshed, and the grain and straw yields were calculated based on the moisture content of 14%. The yield is converted to grain yield t ha⁻¹.

8-Statistical Analysis:

As per Gomez and Gomez (1984), the collected data underwent statistical analysis by means of the analysis of variance method. Duncan's Multiple Range Test was employed to analyze the means of the treatments (Duncan 1957). All statistical analyses were performed using the "COSTAT" statistical software package. Pearson's correlation analysis was performed with R Studio 1.4.1717 software accessible at: <http://www.rstudio.org/>, retrieved on 31st October 2022.

RESULTS AND DISCUSSION

1-Physiological traits:

The data presented in Table 2 showed that the examined rice varieties exhibited significant differences in their antioxidant systems and malondialdehyde (MDA) throughout the study seasons. Giza179 exhibited a greater capacity for antioxidant production, shown by catalase and peroxides, compared to Sakha108 at the amount, the deterioration of cell membrane (MDA) in Sakha108 was more than Giza179. Giza179 appears more tolerant to stress, since higher antioxidant enzyme activities are linked with better ROS scavenging and lower oxidative damage (MDA). Salinity causes lipid peroxidation represented in (MDA) damage to cell membranes due to an excess of free oxygen radicals. The ability of Giza179 to produce antioxidant represented in catalase and peroxides was more than Sakha108, at the same time, the amount of deterioration of cell membrane (MDA) in Sakha108 was more than Giza179, this contradiction may be due to the difference in the salt tolerance aptitude of the two varieties, and the changes in antioxidant enzyme activities are depending on many factors as, the development and metabolic state of the plant, the duration and intensity of the stress (Jini and Joseph 2017 and Shahzad, *et al.*, 2021).

In comparison to the control, the materials being tested enhance the antioxidant system in rice, as shown by the increase in catalase and peroxidase, which are essential for detoxification when ROS levels rise due to salt stress. Conversely, the evaluated therapies significantly lowered MDA, especially those incorporating antioxidants. The most effective approach is the exogenous application of GA₃, E,

and SA during mid tillering, panicle initiation, and booting stage, respectively. The mixture of the tested substances occupied the second rank with respect to maintain the integrity of plant cell from oxidative and increase antioxidant system Table2. Plants possess both enzymatic and non-enzymatic antioxidants that can mitigate the negative impacts of salinity.

Table 2. Means of Catalase, peroxidase and malondialdehyde (MDA) of two rice varieties as affected by foliar spray of anti-salinity substances during 2022 and 2023 seasons.

Treatments	Catalase(U/mg protein/min)		Peroxidase(U/mg protein/min)		MDA(nmol ml ⁻¹ g ⁻¹ fw.t.)	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	6.48a	6.55a	28.5a	28.8a	572.7b	583.2b
Sakha108	4.43b	4.55b	23.3b	23.7b	681.5a	694.4a
F-test	**	**	**	**	**	**
Treatments						
CK	4.35f	4.62f	19.5d	21.2e	659.1a	662.0a
SA	5.54c	5.64c	28.1a	28.2ab	618.5e	629.0d
GA ₃	5.35cd	5.44d	25.8b	26.1cd	624.5bc	637.3c
Folic acid (B9)	4.89e	5.07e	24.0c	24.5d	628b	643.5b
Elements(E)	5.29d	5.43d	25.8b	26.3cd	630.3b	645.3b
Glycine betaine (GB)	5.43cd	5.42d	28.4a	27.7abc	628.0b	643.3b
GB+ E+SA	5.46cd	5.42d	25.8b	26.7bc	628.5b	643.5b
B9+ E+SA	5.40cd	5.48d	25.6b	26.1cd	627.3bc	642.0b
GA ₃ + E+ SA	6.59a	6.72a	28.2a	28.6a	603.6f	611.6e
Mix	6.25b	6.23b	27.7a	27.0abc	623.0d	630.6d
F-test	**	**	*	*	*	*
Interaction	**	**	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively , not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

The enzymes encompass catalase and peroxidase; therefore, an imbalance in free radical production and the antioxidant defence system would lead to oxidative stress and damage to plant cells (Libertad and Manuel 2014). In our study the materials evaluated such as SA, GA₃, GB, B9, and elements, improved the antioxidant system in rice catalase and peroxidase, essential for detoxification during elevated ROS levels. SA reduced stress levels by altering the physiological processes in the plant. Consequently, the use of SA enhanced the activities of antioxidant enzymes, SA application increasing the efficacy of the plant's antioxidant defence by elevating enzyme activities and the antioxidant system (Libertad and Manuel 2014 and Chen *et al.*, 2016). GA₃ foliar spray can beneficially reduce salinity stress by lessening oxidative stress damage, enhancing the defence system, and increasing the activities of antioxidant enzymes against free radicals, GA₃ application also inhibits lipid peroxidation (Choudhuri 1988 and Shahzad *et al.*, 2021). Elements necessary for plants to uphold the selectivity and integrity of cell membranes and minimize MDA; thus, rice plants require these elements due to the common nutritional imbalance caused by salinity, where in Na⁺ ions create disturbances in minerals and lead to excess accumulation (Rahman *et al.*, 2008). Vitamin B9 improves the antioxidant system in plants, which includes catalase, peroxidase, and it is vital for the synthesis of lipids, proteins, chlorophyll, and lignin in plants. Spraying with B9 showed a significant increase in the scavenging efficiency of H₂O₂ (Gorelova *et al.*, 2017 and Al-Elwany *et al.*, 2022). GB foliar treatment enhances antioxidant levels and lowers oxidative stress, essential responses to salt stress (Jain *et al.*, 2021).

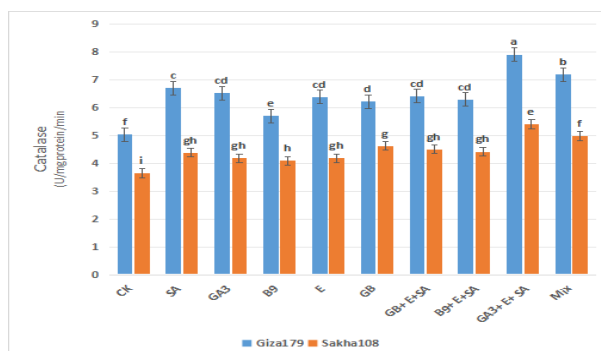
The interaction between chemical substances and rice varieties had a considerable impact on catalase during

different seasons (Figs 2 & 3). Applying GA₃, E, and SA to Giza179 rice variety at various growth stages notably resulted in the highest catalase content in both seasons. Nevertheless, Sakha108 shows the greatest catalase values with the same treatment in both seasons. The combination of the substances examined was ranked second in terms of rising catalase levels for the rice varieties tested throughout the study periods.

Stomatal openings serve as the boundary between the plant and the air, controlling the absorption of CO₂ for photosynthesis and the release of water through transpiration. Rates of photosynthesis are positively associated with stomatal conductance, and effective stomatal control achieved through morphological alterations in the number of stomata and physiological regulation of stomatal aperture size ensures an ideal balance between CO₂ absorption and water loss. As indicated in (Table3), there were no notable differences in stomatal conductivity between the Giza179 and Sakha108 rice varieties; however, differences in respiration rates and CO₂ diffusion were noted. The respiration rate was elevated in Sakha108, while Giza179 exceeded Sakha108 in CO₂ diffusion, A slight impact was noted from the chemical materials used on stomatal conductivity, respiration rate, and CO₂ diffusion (Table3). All examined materials enhanced stomatal conductivity and CO₂ diffusion, while also lowering respiration rates in comparison to the control treatment, which showed the highest respiration rates and the lowest values for stomatal conductivity and CO₂ diffusion. The initial response of plants to sodium stress is the closure of stomata. The decrease in stomatal openings and the reduction in photosynthesis rates under stress can be linked to the restricted capacity of plants to take in carbon dioxide. Additionally, increasing NaCl levels led to changes in respiration and transpiration processes, decreased root water

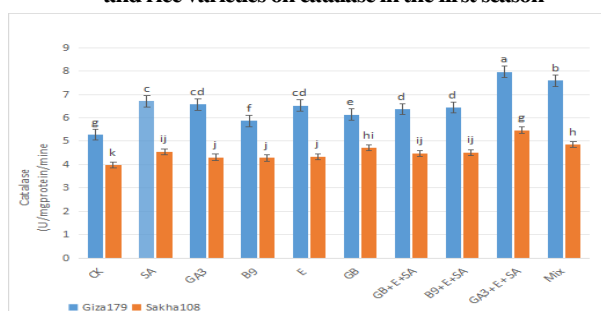
potential, and affected ABA transport from the roots to the stem, resulting in stomatal closure, which is essential for maintaining crop resilience during salt stress to avoid moisture loss in leaf tissues (Dionisio-Sese and Tobita, 2000; Qu *et al.*, 2012 ; El-Esawi *et al.*, 2018 and Zayed *et al.*, 2023). Salt stress caused a reduction in leaf water potential because of lowered osmotic potential, which may lead to stomatal closure. When CO₂ levels in chloroplasts decrease due to this closure, the electron demand for photosynthesis may be hindered, consequently lowering CO₂ availability. The diffusion of CO₂ is mainly affected by stomatal conductance. (Dubey, 2005; Wankhade *et al.*, 2013; Chen *et al.*, 2015; Flexas *et al.*, 2016 and Xiaoxiao *et al.*, 2018).

In the research, all tested materials enhanced stomatal conductivity and CO₂ diffusion while lowering respiration rate compared to the control treatment. SA treatment under salt stress increased stomatal density, alleviated the adverse effects of salinity stress on photosynthesis by regulating CO₂, non-stomatal limitations, the membrane structure of the photosynthetic apparatus, energy supply at the photosynthetic reaction centre, and the associated enzymatic activities (Li *et al.*, 2014; Ma *et al.*, 2017). Exogenous folic acid (B9) reduces salt-induced toxicity (Semara and Tugba., 2016). According to Hamani *et al.*, (2021), enhanced salt tolerance due to exogenous GB application may arise from its substantial improvement in gas exchange parameters.



CK, SA, GA₃, GB, E and mix indicate control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Figure 2. Effect of the interaction between anti-salinity materials and rice varieties on catalase in the first season



CK, SA, GA₃, GB, E and mix indicated control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Fig3. Effect of the interaction between anti-salinity materials and rice varieties in the second season

Table 3. Means of Stomata conductivity, respiration rate and CO₂ diffusion of two rice varieties as affected by foliar spray of anti-salinity substances in2022 and 2023 seasons.

Treatments	Stomata conductivity (mol m ⁻² s ⁻¹)		Respiration rate μmol m ⁻² s ⁻¹		CO ₂ diffusion μmol /mol	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	0.087	0.085	23.1b	23.2b	99.7a	99.4a
Sakha108	0.085	0.085	29.7a	30.04a	90.03b	91.0b
F-test	NS	NS	**	**	**	**
Treatments						
CK	0.080c	0.074d	28.8a	29.2a	86.1c	87.0e
SA	0.085bc	0.082bc	26.0bc	25.8cde	96.7ab	98.2ab
GA ₃	0.086b	0.081c	26.2bc	26.05b-e	94.2b	94.8cd
Folic acid (B9)	0.086ab	0.086abc	27.8a	27.6ab	94.9ab	94.2d
Elements(E)	0.085bc	0.085abc	26.4bc	27.2bc	94.9ab	95.1cd
Glycine betaine (GB)	0.088ab	0.087ab	26.6b	27.3bc	99.3a	96.7abc
GB+ E+SA	0.089ab	0.090a	26.4bc	26.9bc	95.4ab	95.7cd
B9+ E+SA	0.087ab	0.090a	25.4cd	24.4e	94.7b	95.9bcd
GA ₃ + E+ SA	0.091a	0.090a	24.7d	25.1de	97.7ab	99.0a
Mix	0.086b	0.088a	25.9bc	26.7bcd	94.6b	95.4cd
F-test	*	*	**	**	*	**
Interaction	NS	NS	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Photosynthesis is an essential metabolic process in plants, with chlorophyll being the primary pigment involved in photosynthesis and significantly contributing to various physiological functions in plants. Salinity stress markedly lowered leaf chlorophyll levels, and salt stress can diminish the activity of photosynthetic pigments. Marked contrasts in the content of photosynthetic pigments between Giza179 and Sakha108 were evident (Table 4). Giza179 was better than Sakha108 in manufacturing chlorophyll a, chlorophyll b and carotenoid in both seasons.

Applied chemical materials increased photosynthesis pigments compared with control treatment, the implementation of GA₃, E and SA at different growth stages produced the highest amount of chlorophyll a and chlorophyll b. In the intervening time, carotenoid was amplified by applying all the tested materials with insignificant difference among them during alternate years (Table 4).

The toxicity levels of mature leaves in rice plants increase when exposed to high salt concentrations, leading to premature aging of the leaves and a subsequent reduction in the photosynthetically active leaf area. This decrease results

in lowered production of photosynthetic pigments by altering the specific functions of the enzymes involved in this process, and by impacting the chlorophyll precursors, it hinders chlorophyll production. Under salt stress, the absorption of CO₂ is directly impacted, stomatal closure, decreased rubisco efficiency, displacement of crucial cations in the various membrane structures of the leaf; all of this results in changes in permeability, expansion and ineffectiveness of the grana this stress mainly impacts the growth process, consequently reducing the ability of the leaves to expand and consequently restricts the capability to capture photosynthetically active radiation (Blakeslee *et al.*, 2019, Nutan *et al.*, 2020 and Gonzalez-Villagra *et al.*, 2021). Employed chemical compounds improved photosynthetic pigments compared to

the control treatment; the use of plant hormones, elements, and antioxidants during different growth stages led to the highest concentrations of chlorophyll a and b. At the same time, carotenoid levels rose as a result of all the substances tested, with no notable differences among them. The use of GA₃ resulted in a notable increase in total chlorophyll levels in saline conditions (Tuna *et al.*, 2008). SA elevates chlorophyll and carotenoid pigment levels and can effectively mitigate photosynthetic damage, as indicated by the changes in the photosynthetic rate (Tohma and Esitken., 2011; Per *et al.*, 2017). The application of the element via foliar method raises the concentrations of chlorophyll and carotenoid pigments, as noted by (Rani *et al.* 2014; Jagathjothi *et al.*, 2012 and Hashim 2019).

Table 4. Means of chlorophyll a, chlorophyll b and carotenoid of two rice varieties as affected by foliar spray of anti-salinity substances in 2022 and 2023 seasons.

Treatments	Chlorophyll a (mg/L)		Chlorophyll b (mg/L)		Carotenoid(mg/L)	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	3.93a	3.75a	2.15a	2.23a	2.23a	1.21a
Sakha108	3.32b	3.47b	1.23b	1.34b	1.34b	1.10b
F-test	**	**	**	**	**	**
Treatments						
CK	2.98f	2.98e	1.32f	1.38g	0.86c	1.00b
SA	3.35e	3.23d	1.53e	1.66f	1.19ab	1.15a
GA ₃	3.69cd	3.79bc	1.77bc	1.88bcd	1.08ab	1.17a
Folic acid (B9)	3.45e	3.38d	1.62de	1.74def	1.02bc	1.15a
Elements(E)	3.78bc	3.66bc	1.83ab	1.91abc	1.11ab	1.18a
Glycine betaine (GB)	3.74bcd	3.61c	1.66cd	1.77c-f	1.04abc	1.15a
GB+ E+SA	3.61d	3.69bc	1.64de	1.73ef	1.07ab	1.19a
B9+ E+SA	3.76bc	3.82b	1.86ab	1.92ab	1.22a	1.20a
GA ₃ + E+ SA	4.01a	4.08a	1.90a	2.04a	1.22a	1.18a
Mix	3.87b	3.86b	1.77bc	1.85b-e	1.18ab	1.16a
F-test	**	**	*	**	*	*
Interaction	NS	NS	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

2- Elements content in rice leaf:

Salinity led to elevated levels of Na and Cl in plant cells, which adversely affected the cell membrane, restricted water and nutrient uptake by roots, and negatively influenced K influx in the cells; K is a vital element necessary for plant growth. The composition of rice leaves in terms of potassium, calcium, sodium, and chlorine differed between Giza179 and

Sakha108 (Table 5). Potassium and calcium were higher in Giza179 compared with Sakha108 meanwhile, amount of sodium and chlorine was higher in Sakha108 compared with Giza179. The salt tolerant varieties were able to maintain equilibrium among the nutrients in the tissues whereas, other varieties hurt nutritional imbalance (Robin and Saha 2015 and Zayed *et al.*, 2023).

Table 5. Means of potassium (K⁺), calcium (Ca⁺⁺), sodium (Na⁺) and chlorine (Cl⁻) content of rice leaf as affected by foliar spray of anti-salinity substances in 2022 and 2023 seasons.

Treatments	K ⁺ (mg g ⁻¹ DW)		Ca ⁺⁺ (mg g ⁻¹ DW)		Na ⁺ (mg g ⁻¹ DW)		Cl ⁻ (mg g ⁻¹ DW)	
	2022	2023	2022	2023	2022	2023	2022	2023
Rice varieties								
Giza179	30.5a	30.9a	1.88a	1.87a	10.4b	10.7b	10.7b	11.3b
Sakha108	25.2b	26.0b	1.43b	1.50b	12.1a	12.5a	12.5a	14.6a
F-test	**	**	**	**	**	**	**	**
Treatments								
CK	22.1e	22.8g	0.711e	0.741d	15.8a	15.5a	15.5a	14.9a
SA	26.1d	26.4f	1.69d	1.70c	10.6e	11.3c	11.3c	13.7b
GA ₃	28.0c	28.1de	1.75c	1.79abc	10.8de	11.5bc	11.5bc	12.9c
Folic acid (B9)	26.8d	27.5e	1.70d	1.79abc	10.9de	11.3c	11.3c	12.9c
Elements(E)	30.2ab	30.8ab	1.67d	1.74bc	11.5b	11.7b	11.7b	12.8cd
Glycine betaine (GB)	28.2c	29.1c	1.75c	1.81ab	11.1cd	11.4bc	11.4bc	12.6cde
GB+ E+SA	28.1c	28.8cd	1.79bc	1.88a	11.2bc	11.4bc	11.4bc	12.5cde
B9+ E+SA	27.9c	28.6cd	1.76c	1.79abc	11.5b	11.6bc	11.6bc	12.6cde
GA ₃ + E+ SA	31.0a	31.8a	1.88a	1.82ab	9.45g	10.2d	10.2d	12.2e
Mix	30.1b	30.7b	1.84ab	1.80ab	10.0f	10.5d	10.5d	12.5de
F-test	**	**	**	**	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

NS, CK, SA, GA₃, GB, E and mix indicated not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

All of the tested materials reduced Na and Cl and increased K and Ca in plant leaves compared with control treatment which induced the highest amount of Na and Cl in

plant leaves. Exogenous application of GA₃, E and SA at mid tillering, panicle initiation and booting stage, respectively, significantly produced the highest amount of potassium and

calcium in rice leaves and surpassed in excluding and reducing Na and Cl from rice leaves (Table 5). Supplying the rice plant with elements alone is not enough to increase Ca, K and decrease Na and Cl but an integrated supplement of elements, plant hormone and antioxidant may save ion homeostasis in rice plant. Applying GA₃, nutrients, and SA from as a foliar spray during the mid tillering, panicle initiation, and booting stages led to a notable rise in potassium and calcium levels in rice leaves, while successfully limiting and decreasing Na⁺ and Cl⁻ concentrations in those leaves. All tested materials reduced Na and Cl while increasing K and Ca in plant leaves. GA₃ treatments might obstruct the transfer of Na⁺ from roots to shoots (Shahzad, *et al.*, 2021). SA influences several vital physiological functions in plants, notably improving nutrient absorption and significantly lowering Na⁺ concentrations during salt stress, resulting in enhanced nutrient accumulation and reduced Na⁺ and Cl⁻ levels (Jini *et al* 2017 and El-Taher *et al.* 2022). Foliar application of vitamin B9 enhances the absorption of nutrients NPK while raising the leaf K/Na ratio and decreasing the levels of Na⁺ and Cl⁻ in leaves (Al-Elwany *et al.*, 2022). Providing the rice plant with elements alone is insufficient to raise Ca and K levels and lowering Na and Cl (Schachtman, 2000). However, a combined supplement of elements, plant hormones, and antioxidants could help maintain ion balance in the rice plant.

3-Agronomic traits:

Plant growth

Data in Table 6 clarified that the growth characteristics of the two rice varieties tested were influenced by foliar

application of anti-salinity at various growth stages. The salt-tolerant variety Giza179 outperformed Sakha108 in plant height (cm), leaf area index, and dry matter (g hill⁻¹). Plant height is mostly governed by the genetic makeup of the genotypes, but the environmental factors also influence it. All of tested materials increased the tested growth traits than the control treatment, The maximum value of leaf area index and dry matter was noticed by foliar spray of plant hormone (GA₃) at different growth stages. Moreover, the tallest plant was given by foliar spray of the three materials GB, E, and SA without significant difference with foliar spray of GA₃, E and SA. In the meantime, the anti-salinity component, which included mixture of the tested substances ranked second in enhancing the tested growth traits (Table 6). All tested materials enhanced the growth traits compared to the control treatment. Simultaneously. The positive effects of salicylic acid may stem from its function as an endogenous growth regulator of a phenolic type, impacting numerous physiological processes such as ion permeability, photosynthesis, and the growth rate of plants. Additionally, salicylic acid protects against the harmful effects of diverse stressors in various plant species (Rafique *et al.*, 2011). The influence of GA₃ on growth traits may result from enhanced leaf nutrient content, biochemical compounds, and energy compounds like ATP, leading to an increase in biochemical processes associated with growth, which promotes cell division and elongation, thereby raising mineral nutrients that are essential for plant stress resistance (Gavino *et al.*, 2008).

Table 6. Means of leaf area index, dry matter and plant height of two rice varieties as affected by foliar spray of anti-salinity substances in 2022 and 2023 seasons.

Treatments	LAI		Dry matter (g hill ⁻¹)		Plant height (cm)	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	3.99a	4.26a	75.3a	75.4a	102.2a	101.3a
Sakha108	3.57b	3.71b	45.3b	46.2b	95.4b	95.4b
F-test	**	**	**	**	**	**
Treatments						
CK	2.05f	2.40f	49.3f	49.7f	92.3f	91.0f
SA	3.33e	3.73e	57.3de	52.9ef	96.4e	95.9e
GA ₃	4.44a	4.48ab	71.8a	70.6a	99.6cd	98.7bcd
Folic acid (B9)	3.97b	4.10cd	60.8c	64.1bc	98.1de	97.2cde
Elements(E)	3.59d	3.75e	60.8c	61.5bcd	97.3e	96.8de
Glycine betaine (GB)	3.66cd	4.03de	57.1e	59.9cd	100.1bc	99.1bc
GB+ E+SA	4.26a	4.20bcd	55.0e	56.7de	101.7ab	102.6a
B9+ E+SA	3.85bc	4.02de	65.9b	65.1b	99.2cd	99.6b
GA ₃ + E+ SA	4.35a	4.76a	60.1cd	62.0bc	103.0a	102.4a
Mix	4.32a	4.40bc	64.6b	65.6b	100.6bc	100.4b
F-test	**	**	**	**	*	**
Interaction	NS	NS	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

As stated earlier, the substances utilized in this research play a crucial role within the plant; all of this material functions harmoniously with potassium, which is absorbed by plant leaves in saline conditions. The enhancement of analysed growth traits may result from the involvement of factors that encompass both macro and micro elements; potassium has a crucial role in the regulation of stomatal movement, photosynthesis, and osmoregulatory adjustments of plants under water stress in saline soils (Su *et al.*, 2018). Nitrogen is a key nutrient for plants and is essential for photosynthesis and biomass generation, as it affects cell division and elongation (Laroo and Shivay., 2011). Foliar spray with elements enhanced plant growth under salt stress

(Amira *et al.*, 2019). Vitamins are made of natural materials and safe in order to improve the growth of plants (Shadia, 2017).

Yield and yield attributes:

Data presented in Tables 7, 8, and 9 indicated that various chemical substances influenced the yield and yield component traits of certain rice varieties. Giza179 surpassed Sakha108 in yield and yield attribute characteristics except thousand grain weight. The quantity of unfilled grains was greater in Sakha108 than in Giza179 throughout the study season. Giza179 surpassed Sakha108 regarding plant growth, yield, and yield trait characteristics, likely because of the differing salt tolerance levels of the two varieties. Changes in antioxidant enzyme activities depend on several factors

including the plant's growth stage and metabolic status, the duration and severity of stress, genetic background, and others (Ashrafuzzaman *et al* 2009; Rahman *et al.*, 2008; Hakim *et*

al., 2014; Haworth *et al.*, 2015 ; Haworth *et al.*, 2016; Jini, and Joseph 2017; Shahzad, *et al.*, 2021).

Table 7. Means of panicles number hill⁻¹, panicle length and panicle weight of two rice varieties as affected by foliar spray of anti-salinity materials in 2022 and 2023 seasons.

Treatments	Panicles number hill ⁻¹		Panicle length (cm)		Panicle weight (g)	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	14.35a	13.7a	21.7a	21.0a	2.87a	2.69a
Sakha108	12.1b	11.5b	21.0b	19.6b	2.43b	2.25b
F-test	**	**	**	**	**	**
Treatments						
CK	10.2d	9.15e	18.5d	18.2d	2.19f	2.02e
SA	12.7c	11.8d	21.4c	20.1c	2.61de	2.43cd
GA ₃	13.3bc	12.6c	21.6bc	20.6abc	2.70bcd	2.51bc
Folic acid (B9)	12.8c	12.7c	22.2ab	21.2a	2.81b	2.63b
Elements(E)	13.4bc	12.6c	22.8a	20.8ab	2.77bc	2.50cd
Glycine betaine (GB)	13.8ab	13.5ab	21.6c	20.6abc	2.53e	2.38d
GB+ E+SA	13.9ab	13.6a	21.4c	20.4bc	2.62de	2.38d
B9+ E+SA	13.5abc	12.9bc	21.7bc	20.8abc	2.67cd	2.50bcd
GA ₃ + E+ SA	14.4a	13.6a	21.2c	20.8abc	2.98a	2.85a
Mix	14.1ab	14.0a	21.3c	20.4bc	2.63de	2.52bc
F-test	**	**	**	*	**	**
Interaction	NS	NS	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Table 8. Means of number of filled grains panicle⁻¹, number of unfilled grains panicle⁻¹ and 1000-grain weight (g) of two rice varieties as affected by foliar spray of anti-salinity substances in 2022 and 2023 seasons.

Treatments	Number of filled grains panicle ⁻¹		Number of unfilled grains panicle ⁻¹		1000-grain weight (g)	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	112.7a	108.6a	10.7b	11.4b	24.3b	23.7b
Sakha108	94.13b	94.06b	14.9a	16.1a	25.2a	24.4a
F-test	**	**	**	**	**	**
Treatments						
CK	87.7f	86.4d	20.8a	22.9a	23.4d	23.1c
SA	100.9e	102.6b	15.08b	15.9c	24.5c	24.0abc
GA ₃	101.6de	98.15c	15.8b	17.3b	24.9ab	24.3ab
Folic acid (B9)	100.9e	97.7c	10.8de	12.5def	24.8bc	24.1ab
Elements(E)	102.3de	100.5bc	11.5d	11.1fg	24.4c	24.2ab
Glycine betaine (GB)	104.7cde	102.3b	13.1c	13.8d	25.0ab	24.4ab
GB+ E+SA	105.3cd	103.1b	11.8cd	12.7de	25.3a	24.4a
B9+ E+SA	107.3bc	103.1b	10.9de	11.5efg	24.8bc	23.5bc
GA ₃ + E+ SA	113.6a	110.6a	9.18f	9.68h	25.01ab	24.1ab
Mix	110.0ab	108.9a	9.50ef	10.2gh	25.3a	24.4a
F-test	**	**	**	**	**	**
Interaction	**	NS	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Table 9. Means of grain yield t ha⁻¹, straw yield t ha⁻¹ and harvest index of two rice varieties as influenced by foliar spray of different substances in 2022 and 2023 seasons

Treatments	Grain yield t ha ⁻¹		Straw yield t ha ⁻¹		Harvest index	
	2022	2023	2022	2023	2022	2023
Rice varieties						
Giza179	6.24a	5.81a	7.56a	7.59a	0.452a	0.437
Sakha108	4.74b	4.49b	5.87b	5.81b	0.445b	0.433
F-test	**	**	**	**	**	NS
Treatments						
CK	4.63f	4.41e	5.91c	5.59f	0.436d	0.443b
SA	5.21e	5.03cd	6.65b	6.37de	0.439cd	0.443b
GA ₃	5.55c	5.16c	6.49b	6.13e	0.459ab	0.457a
Folic acid (B9)	5.32de	5.10cd	6.63b	6.67cd	0.445bcd	0.435bc
Elements(E)	5.26e	4.87d	6.58b	6.57cd	0.444cd	0.427cd
Glycine betaine (GB)	5.46cd	5.23bc	6.6b	6.87bc	0.453bc	0.432c
GB+ E+SA	5.80b	5.46ab	7.09a	7.20ab	0.450bcd	0.431c
B9+ E+SA	5.23e	5.03cd	6.65b	6.91bc	0.440cd	0.420d
GA ₃ + E+ SA	6.44a	5.83a	7.28a	7.43a	0.470a	0.427cd
Mix	5.96b	5.35b	7.29a	7.30a	0.449bcd	0.434c
F-test	**	**	**	**	**	*
Interaction	**	**	NS	NS	NS	NS

**, *, NS, CK, SA, GA₃, GB, E and mix indicated significant at 0.01 and 0.05 levels respectively, not significant, control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

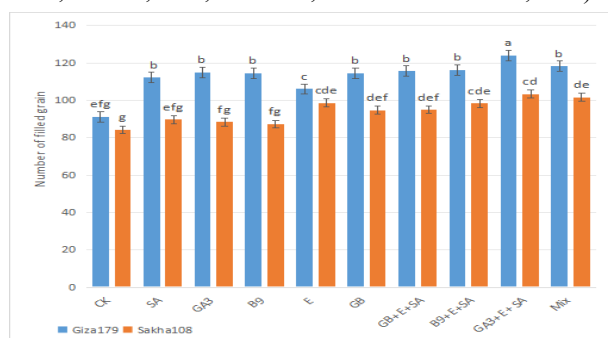
Salinity stress led to a decrease in yield, negatively impacting photosynthesis, physiological functions, growth traits, water absorption, and pigments, which ultimately caused lower yield. Salt stress leads to a reduction in tiller

numbers and spikelet sterility, which ultimately diminishes yield. Utilization of various chemical materials greatly enhanced yield and yield attribute traits in both seasons. Utilization of various chemical substances that surpass the

current ones throughout multiple growth phases. The top performance resulted from foliar spraying three substances, including gibberellic acid, elements, and salicylic acid, during various growth stages.

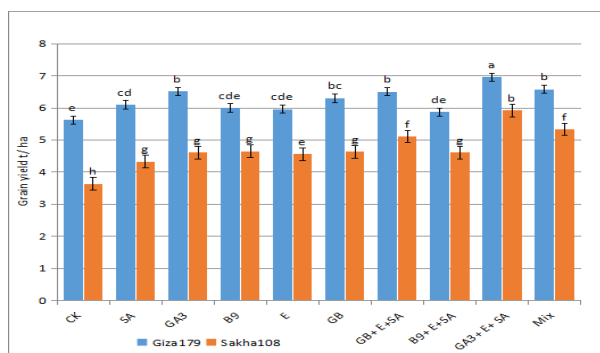
Salt stress negatively affects the morphological characteristics of rice plants, including grain weight per plant, total spikelet counts per plant, spikelet viability, average weight of 1000 grains, plant height, panicle length, tiller number, and the quantity of panicles per plant, along with the rate of sterile flowers. As a result, the transfer of soluble sugar concentrations to the upper and lower spikelets and the inhibition of starch synthesis during grain development. For each unit rise (dS.m^{-1}) in the soil's electrical conductivity within the root zone above 3 dS.m^{-1} , grain yield decreases by more than 10%. (James *et al.*, 2011 and Gupta *et al.* 2020). Salt stress results in fewer tillers and spikelet sterility, which in turn leads to decreased yields (Razzaq *et al.*, 2020). The decrease in yield caused by salinity might result from the opposing effects of salt stress on physiological functions and growth traits, including water absorption, photosynthetic pigments, and others, resulting in lower yields (Abdelaal *et al.*, 2020).

The use of various chemical materials greatly enhanced yield and yield attribute features in both growing seasons. Utilization of two or more varied chemical substances is superior to the previously used one at various growth phases. The optimal performance was observed with foliar applications of the three substances: SA, GA_3 , and E at various growth stages. Nevertheless, in this study, the application of SA improved salinity tolerance in rice and boosted the yields. The role of SA in yields is likely attributed to reduced oxidative harm and enhanced plant growth and yields under salinity stress, while also improving nutrient absorption, raising chlorophyll and carotenoid pigment levels, regulating the activities of various enzymes, and preserving the integrity of cell membranes. It also contributes to the regulation of plant hormones enhancing yield and its characteristics through element application, likely due to a significant boost in early growth, which reflects in improved grain yield traits (number of panicles per hill, panicle weight, number of filled grains per panicle, and 1000-grain weight), subsequently leading to increased grain output. Foliar spraying of the three substances: SA, GA_3 , and elements reduces the negative impacts of salt stress and enhances 1000-grain weight, grain yield, biological yield, and harvest index (Tohma and Esitken., 2011; Ibrahim *et al.*, 2015; Zayed *et al.*, 2016; Per *et al.*, 2017; Raeisi *et al.*, 2017; Shadia 2017; Hawkesford, 2017; Husen *et al.*, 2018; Su *et al.*, 2018; Pessarakli, 2019 and Amira *et al.*, 2024).



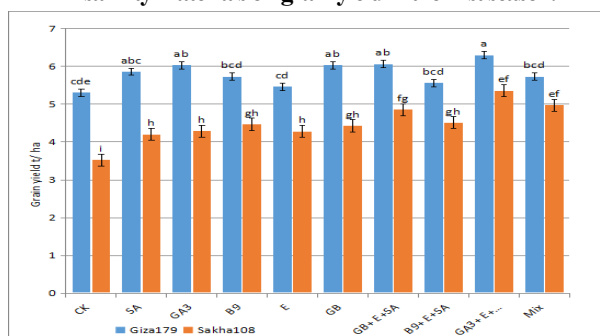
CK, SA, GA_3 , GB, E and mix indicated control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Fig 4. Effect of the interaction between anti-salinity materials and rice varieties on number of filled grains panicle⁻¹



CK, SA, GA_3 , GB, E and mix indicated control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Fig 5. Effect of the interaction between rice cultivars and anti-salinity materials on grain yield in the first season.



CK, SA, GA_3 , GB, E and mix indicated control, salicylic acid, gibberellic acid, glycine betaine, element and mixture of them respectively.

Fig 6. Effect of the interaction between rice cultivars and anti-salinity materials on grain yield in the second season.

The effect of interaction between chemical subjects and rice varieties was significant on was significant on number of filled grains panicle⁻¹ during the first season only figure (4) and grin yield in both seasons (Figures5&6). The maximum number of filled grains panicle⁻¹ and grain yield was noticed by Giza179 implemented by the three materials lonely including GA_3 , E and SA during different growth stages. The same treatment gave the best grain yield for Sakha108 rice variety in both seasons. Anti-salinity component occupied the second order regarding increase grain yield for Giza179 and Sakha108 rice varieties the lowest values was obtained by Sakha108 under control treatment. Giza179 consistently outperformed Sakha108 across all treatments. This indicates that Giza179 has higher tolerance and yield potential under the tested conditions

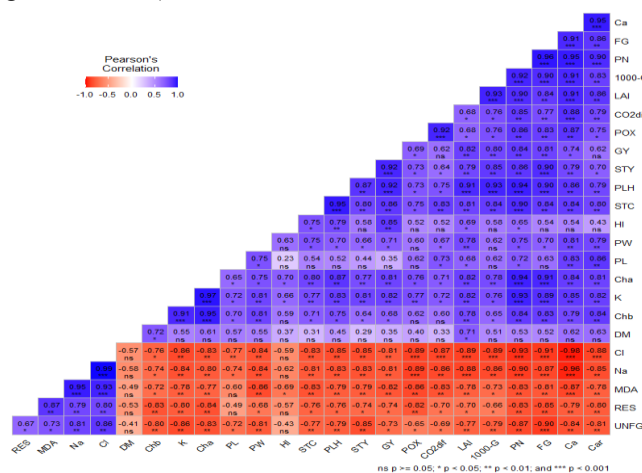
The interaction shows that while both varieties benefit from treatments, the magnitude of response is higher in Giza179.

4-The correlation between the studied characteristics:

The results in Figure7 illustrate that the heatmap clearly separates into two clusters blue zone (positive correlations): Growth, yield, and physiological traits (GY, STY, PN, FG, 1000-G, HI, LAI, PLH, STC, photosynthetic pigments, Ca, K, etc.). Red zone (negative correlations) stress indicators (MDA, Na^+ , Cl^- , DM, RES, UNFG), this indicates a trade-off between oxidative and ionic stress on growth and yield performance. Stress indicators MDA, Na^+ , Cl^- , RES, UNFG all show strong negative correlations with yield-related traits (GY, STY, PN, FG, HI), this confirms that higher oxidative and ionic stress reduces grain yield and biomass production. Antioxidant enzymes POX shows positive correlations with yield traits (GY $r = 0.85^{***}$, STY $r =$

0.79***, HI $r = 0.70^{**}$) this suggests antioxidant activity is directly associated with stress tolerance and higher productivity. Nutrient balance Ca and K strongly and positively correlate with yield traits they also negatively correlate with Na and Cl. This indicates that maintaining higher Ca^{2+} and K^{+} helps reduce ionic toxicity and supports yield stability. Photosynthetic traits Chlorophyll a, b, and total pigments (Ch-a, Ch-b, DM) are positively correlated with yield (GY, PN, FG) and negatively correlated with stress markers (Na, Cl, MDA), this shows that maintaining photosynthetic pigment integrity is essential for sustaining productivity under stress. Negative cluster (MDA, Na, Cl,

RES): Indicators of oxidative and ionic stress, strongly reducing yield. Positive cluster (POX, K, Ca, chlorophylls, yield traits): Indicators of tolerance mechanisms and better growth. The strongest beneficial traits linked with yield are K, Ca, POX, chlorophyll content, and LAI, suggesting they are reliable biomarkers of salinity tolerance in rice. The correlation matrix highlights a clear antagonism between stress parameters (MDA, Na^{+} , Cl^{-}) and yield, while antioxidant defence (POX), nutrient balance (K, Ca), and photosynthetic pigments are key contributors to stress resilience and productivity in rice.



POX=peroxidase, RES=Respiration rate, MDA= lipid peroxidation, Na= sodium, Cl=chloride, K=potassium, Ca =Calcium, RES=respiration rate, DM=dry matter, Ch- a = chlorophyll a, Ch- b = chlorophyll b, Car = carotenoid, STC = Stomatal conductance, PLH = plant height; PN = panicle number per plant, PL= panicle length, PW= panicle weight; FG= number of filled grains per panicle; UNFG = number of unfilled grains per panicle; 1000-G = thousand-grain weight; GY = grain yield ha^{-1} ; STY = straw yield ha^{-1} and HI = harvest index.

Fig 7. Pearson's correlation matrix between different parameters across two seasons in different treatments

5-Economic evaluation

The economic assessment indicates that the use of anti-salinity agents typically enhanced net returns and benefit-

cost ratio (BCR) compared to the untreated treatment (CK) in both 2022 and 2023 (Table 10)..

Table 10. Economic Evaluations for using anti-salinity substance during different growth stages

Treatments	Fixed cost LE/ha	Cost of treatment foliar spray thrice (LE)	Total cost (LE/ha)	Total income (LE/ha)	Net return (LE/ha)	Benefit cost ratio (BCR)
2022						
CK	46410	-	46410.0	78710	32300.0	1.696
SA	46410	443.7	46853.7	88570	41716.3	1.890
GA3	46410	210.0	46620	94350	47730.0	2.024
B9	46410	630.0	47040	90440	43400.0	1.923
E	46410	1500	47910	89420	41510.0	1.866
GB	46410	934.5	47344.5	92820	45475.5	1.961
GB+ E+SA	46410	959.4	47369.4	98600	51230.6	2.082
B9+ E+SA	46410	857.9	47267.9	88910	41642.1	1.881
GA3+ E+ SA	46410	717.9	47127.9	109480	62352.1	2.323
Mix	46410	3718.2	50128.2	101320	51191.8	2.021
2023						
CK	49980	-	49980	74970	24990.0	1.500
SA	49980	443.7	50423.7	85510	35086.3	1.696
GA3	49980	210	50190	87720	37530.0	1.748
B9	49980	630	50610	86700	36090.0	1.713
E	49980	1500	51480	82790	31310.0	1.608
GB	49980	934.5	50914.5	88910	37995.5	1.746
GB+ E+SA	49980	959.4	50939.4	92820	41880.6	1.822
B9+ E+SA	49980	857.9	50837.9	85510	34672.1	1.682
GA3+ E+ SA	49980	717.9	50697.9	99110	48412.1	1.955
Mix	49980	3718.2	53698.2	90950	37251.8	1.696

1 g SA cost 1.7LE, 1g GA₃ cost 2 LE, 1g folic acid cost 6 LE, 1Kg NPK+1L micronutrients cost 150 LE and 1 kg rice cost 17 LE, fixed cost included land preparation, planting, transpiration, fertilizing, weed and pest management, workforce and harvest, etc and US\$ 1 = 48 and 49.3 Egyptian pounds (LE).

In both years, GA₃ + E + SA achieved the greatest profitability, with the highest net returns (62,352.1 LE in 2022 and 48,412.1 LE in 2023) and the top BCR (2.323 in 2022 and 1.955 in 2023). Individual applications such as GA₃ and GB proved to be economically beneficial, consistently yielding higher returns and BCR compared to the control. SA

by itself enhanced income but was not as profitable as GA₃ or GB. E and Mix treatments exhibited comparatively lower effectiveness, with Mix being lucrative in 2022 (BCR 2.021) but not in 2023 (BCR 1.396), indicating that increased expenses diminished returns. the treatments of GA₃ + E + SA

foliar spray during different growth stages offered the greatest economic benefit under salinity stress.

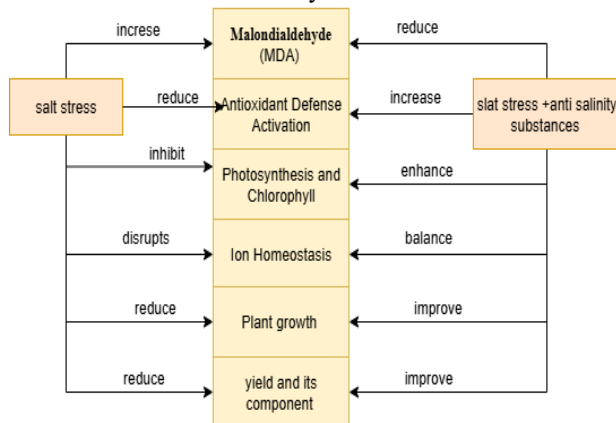


Fig 8. Effect of salinity stress and anti- salinity substances on rice plant

CONCLUSION

In conclusion, salinity produced negative effects on rice plants such as osmotic, ionic and oxidative stress. To improve the growth, physiology, and yield of rice plants in these soils, specific integrated farming techniques must be implemented to counteract the negative effects of salinity stress. Applied plant hormone GA₃ at mid tillering, elements at panicle initiation and antioxidant (SA) at booting stage might remain constant to ease the negative impact of salt stress on rice, increase rice grain yield and offer the greatest economic benefit.

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التخفيف من الإجهاد الملحي: مواد مقاومة للملوحة من أجل استدامة الأرز وتحسين إنتاجيته

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الملخص

تُعد الملوحة من أبرز التحديات التي تواجه زراعة الأرز في البيئات الجافة وشبه الجافة، حيث تؤثر سلباً على النمو والإنتاجية. هدفت هذه الدراسة، التي أجريت بمحطة بحوث السرو الزراعية بمحافظة دمياط خلال موسمي ٢٠٢٢ و٢٠٢٣، إلى تقييم بعض المواد المقاومة للملوحة في تحسين قدرة نبات الأرز على مواجهة الإجهاد الملحي. استخدمت تجربة القطع المنشقة في تصميم القطاعات كاملة العشوائية في أربع مكررات، حيث اشتملت القطع الرئيسية على الصنفين جيزة ١٧٩ وسخا ١٠٨، بينما تضمنت القطع الشقية المعاملات وهي الكنترول، حمض السيليك، حمض الجبريليك، حمض الفوليك والعناصر الكبرى والصغرى وأيضاً الجلابيسين بتباين والتوليفات المختلفة، والتي طبقت في أثناء مراحل النمو المختلفة. أوضحت النتائج أن جميع المعاملات حسنت الصفات الفسيولوجية والنمو والمحصول ومكوناته مقارنة بالكنترول. وكانت المعاملة الأكثر فعالية هي الرش بـ حمض الجبريليك في مرحلة التفرع، مع إضافة العناصر الكبرى والصغرى عند بداية تكوين السنابل، ورش حمض السيليك في مرحلة الطرد. حيث أدت هذه المعاملة إلى تعزيز نشاط الأنظمة المضادة للأكسدة، وتحسين النمو، ومكونات المحصول، والإنتاجية النهائية، إضافة إلى فعاليتها الاقتصادية تشير النتائج إلى أن رش حمض الجبريليك والعناصر وحمض السيليك في المراحل الحرجة من حياة نمو الأرز يمثل إستراتيجية فعالة وواعدة للتخفيف من تأثيرات الملوحة، وبالتالي دعم استدامة إنتاج الأرز في الأراضي المتأثرة بالملوحة.