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ALLEVIATING THE ADVERSE EFFECTS OF SALINITY STRESS ON THE GROWTH AND YIELD OF TOMATO PLANTS BY USING FOLIAR SPRAYING WITH JASMONIC ACID AND GLYCINE BETAINE

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Salinity reduces agricultural production's yield and quality, which results in major global economic losses. Jasmonic acid and glycine betaine are well known for their significant roles in facilitating physiological and metabolic processes in plants and for boosting their resistance to different abiotic stressors. The objective of the study was to lessen the negative impacts of saline stress on tomato plants. The field experiments were conducted in the Experimental Station of Desert Research Center in Ras Sudr, South Sinai Governorate, Egypt, during the summer 2020 and 2021 seasons to investigate the effect of jasmonic acid (0, 5, and 10 mM) and glycine betaine (0, 50, and 100 mM) on tomato plant growth, photosynthetic pigments, and content of sucrose, malondialdehyde, and proline, as well as yield and fruit quality. Based on the results, plant growth characteristics, photosynthetic pigments, yield, and its various characteristics, including fruit diameter, fruit number and fruit weight per plant were stimulated by applying either 5 mM of jasmonic acid or 50 mM of glycine betaine, and both together. In addition, treatment with jasmonic acid and/or glycine betaine increased the fruit firmness, total soluble solids, total titratable acidity, and ascorbic acid contents. Sucrose, malondialdehyde, and proline contents were markedly decreased with the application of jasmonic acid and/or glycine betaine treatment. Consequently, given that jasmonic acid and glycine betaine help tomato plants which are stressed by salinity, these treatments may be used as an alternate strategy for growing plants under salinity conditions.

Keywords: Plant exogenous hormones, salinity, photosynthesis, proline, fruit quality

INTRODUCTION

Tomato (*Solanum lycopersicon* L.) plants are regarded as the second most significant vegetable crop after potatoes in terms of agricultural implications for human consumption (Chandrasekaran et al., 2019). Tomato includes the most essential antioxidants, including lycopene, carotenoids, vitamin C, and minerals. They are also a substantial source of vitamins A and C (Shalaby et al., 2017 and Shehata et al., 2021). A total of 155.738 hectares are used for tomato cultivation in Egypt, with an output of almost 6.49 million tons in 2020 (Attia and El Sayed, 2023). The tomato is regarded as having a moderate tolerance to salinity because it can maintain ionic and water balance in the root zone at moderate salinity levels (Martinez-Rodriguez et al., 2008). On the other hand, it is well-recognized that high salinity stress inhibits plant growth and yield (Cuartero et al., 2006).

A major environmental constraint that adversely impacts plant growth and development, causing physiological abnormalities and ultimately jeopardizing global food security is salinity, a severe abiotic stressor (Machado and Serralheiro, 2017; Safdar et al., 2019; Ramadan et al., 2022 and Balasubramaniam et al., 2023). Climate change, excessive groundwater consumption (especially near the sea), the use of low-quality water for irrigation, and the widespread implementation of irrigation linked to intensive farming can all exacerbate this process (Machado and Serralheiro, 2017). Major plant functions including photosynthesis and metabolism slow down or stop altogether when plants experience salinity stress due to ionic toxicity and water deficiency (Safdar et al., 2019; Etesami and Glick, 2020 and Hussain et al., 2022). Reactive oxygen species (ROS) are produced in excess when salt stress upsets the ionic balance of cells (Hasanuzzaman et al., 2021), as a result, plant growth effectively stops at different degrees of stress-induced deterioration by destroying genetic material and significantly oxidizing essential biomolecules like membrane lipids, proteins, and carbohydrates (Foyer and Noctor, 2009 and Choudhury et al., 2013).

Synthetic compounds that mimic natural plant hormones are known as plant growth regulators or plant exogenous hormones. They regulate plant growth, function as signaling molecules in defense, developmental, and abiotic stress responses, and are significant tools for increasing agricultural productivity (Tayyab et al., 2020 and Quamruzzaman et al., 2021). Plant hormone called jasmonic acid (JA) is produced from lipids and modulates a variety of biological processes. It belongs to a class of plant growth regulators called jasmonates, which are significant cellular regulators involved in several developmental processes, including germination of seeds, root growth, fruit ripening, senescence, fertility, and cellular regulation (Avalbaeva et al., 2016 and Quamruzzaman et al., 2021). Jasmonic acid (JA) significantly alters fluorescence and gas exchange

activities, reduces the detrimental effects of salinity stress, enhances plant agronomical parameters, and helps protect antioxidants from harmful salinity stress-induced conditions (Quamruzzaman et al., 2021 and Hussain et al., 2022). By encouraging the accumulation of nontoxic metabolites (sugars, free proline, and proteins) as well as N, P, and K as a protective adaptation, the researchers found that JA improved plants' ability to withstand salinity (Sheteawi, 2007 and Ali et al., 2022). Additionally, promoted an increase in plant growth characteristics, chlorophyll content, and yield (Alikhani and Abbaspour, 2019; Nascimento et al., 2019 and Keshtkar et al., 2021).

Many plant species contain varying amounts of glycine betaine (GB), a quaternary ammonium compound that is non-toxic, environmentally friendly, and water-soluble (Kumar et al., 2017). It stabilizes or increases photosynthetic efficiency (Chen and Murata, 2011 and Dustgeer et al., 2021). In a similar vein, when GB builds up in plants, the nitrogen it contains encourages seed germination and root growth, which furthers plant growth and yield (He et al., 2011 and Shemi et al., 2021). Numerous studies have shown that exogenous GB helps plants fight abiotic stress by regulating the activity of many antioxidants, both enzymatic and non-enzymatic, protecting cellular macromolecules, and detoxifying reactive oxygen species (Dustgeer et al., 2021; Maqsood et al., 2021; Shemi et al., 2021; Jimenez-Arias et al., 2022 and Shahzad et al., 2023), and mitigate salinity stress damages (Osman and Salim, 2016; Yao et al., 2016 and Oddo et al., 2019). A recent publication shows how a GB foliar application can increase growth, yield, yield components, fiber, chlorophyll, proline, and total soluble sugar content of plants (Maqsood et al., 2021; Alhoshan and Zahedf, 2022; Devi et al., 2023 and Drwish et al., 2023). The current study examined the role of JA and GB in tomato plant growth, with an emphasis on the latter's capacity to increase salinity stress tolerance. This work aimed to study the effect of JA and GB on vegetative growth, photosynthetic pigments, yield, and fruit quality of tomato hybrid Super strain B grown under the saline conditions of the Ras Sudr region.

MATERIALS AND METHODS

1. Site Description

The field experiments were conducted in the Experimental Station of Desert Research Center in Ras Sudr, South Sinai Governorate, Egypt, during the summer 2020 and 2021 seasons. In the experimental field, the soil has a sandy loam texture that is very calcareous and saline. Its pH is 7.7, its EC is 8.65 $mS \cdot cm^{-1}$, and its $CaCO_3$ concentration is 54.84%, with 1.47 $g \cdot kg^{-1}$ of organic carbon in the 0-30 cm soil layer.

2. Plant Materials, Experimental Design and Treatments

The seeds of tomato hybrid (Super strain B) were obtained from the Agricultural Research Center, Egypt. The seeds were sown on the 1st of February in both summer seasons (2020 and 2021), and After 45 days of seed sowing, the healthy seedlings with uniform size growth and five true leaves were transplanted into rows, with a 50 cm spacing between each plant. All plants were irrigated with saline irrigation water (5500 ppm) for 30 minutes per day at 3-day intervals. According to commonly recommended in commercial tomato production, fertilization, and other cultural practices were used (Maynard and Hochmuth, 2007), to investigate the effects of JA and GB on plant growth parameters, photosynthetic pigments, yield attributes, and fruit yield. The experiment was laid out under a split-plot design with three replicates, randomizing the levels of JA, namely 0 (control), 5, and 10 mM, in the main plots, and GB concentrations, namely 0 (control), 50, and 100 mM in subplots. The area of each main plot was 30 m^2; consisted of three rows each row was 10 m in length and 1 m in width. Starting 30 days after transplanting, three foliar sprays were used for all treatment applications. There was a 15-day interval between each of the three spray applications.

3. Plant Measurements

3.1. Plant growth parameters

Several vegetative features were measured for treated tomato plants at the early budding stage (60 days after transplanting), including plant height, number of branches, number of leaves, and leaf area.

3.2. Determination of photosynthetic pigments

The content of chlorophyll in fresh leaves of tomato plant was measured at 60 days after transplanting using the methods outlined by Vernon and Seely (1966). This method involved extracting pigments from fresh leaves (1 g) using 100 mL of 80% acetone. After filtering the extract, a spectrophotometer was used to measure the green color at 470, 649, and 665 nm. The following formulae are used to calculate photosynthetic pigments according to Lichtenthaler (1987):

Chl a ($mg \cdot g^{-1}$ FW) $= \mathbf{11.63(A665 - 2.39(A649)}$

Chl b ($mg \cdot g^{-1}$ FW)$= \mathbf{20.11(A649) - 5.18(A665)}$

Chl a + b ($mg \cdot g^{-1}$ FW) = $\mathbf{6.45\ (A665) + 17.72\ (A649)}$

Carotenoids (mg.g-1 FW) $= \frac{\mathbf{(1000 \times A470) - (1.82 \times Chl\ a) - (85.02 \times Chl\ b)}}{\mathbf{198}}$

3.3. Sucrose, malondialdehyde (MDA), and proline content

The spectrophotometer was used to measure the content of sucrose content at 620 nm in wavelength (Wu et al., 2011). According to a method of Liu et al. (2014), the MDA content of leaf tissues was determined using spectrophotometry at 532 and 600 nm absorbance using the extinction

coefficient of 155 $mM^{-1}cm^{-1}$ according to Cakmak and Horst (1991) with the formula:

$$\text{MDA (mmol·kg}^{-1}\text{ FW)} = \frac{\textbf{Abs532 nm} - \textbf{Abs600 nm}}{\textbf{1.55} \times \textbf{1.05}}$$

The proline content was calculated using a spectrophotometer to test the samples at 520 nm, and the proline concentration was calculated as $mmol \cdot kg^{-1}FW$ according to Bates et al. (1973).

3.4. Yield and its attributes

Five plants were chosen at random from each treatment at each harvest, and the fruit diameter and number of fruits per plant was recorded. The fruit weight per plant was calculated by weighing the fruits at each harvest from selected plants in each treatment. The total yield per hectare was determined by adding the cumulative yield of all five pickings, which were taken at a six-day interval between the pickings, to calculate the yield per hectare.

3.5. Fruit quality attributes

3.5.1. Fruit firmness

The firmness of the fruit was measured using a penetrometer (Effigi 11-mm probe). To assess the penetration force, five fruits from each treatment were selected, and the probe was gently inserted into the equatorial region of fruit. The corresponding treatments were represented by averaging the readings for all five fruits according to Rab and Haq (2012).

3.5.2. Total soluble solids (TSS)

The total soluble solids (TSS) in freshly filtered fruit juice using Whatman filter paper No. 1, was measured using a digital refractometer (DR-101-60, Krüss, Germany). One drop was pounded to the prism, and TSS was measured in Brix % (Rab and Haq, 2012).

3.5.3. Total titratable acidity (TTA)

The method according to A.O.A.C. (2000) was used to measure the TTA in tomato fruit. To calculate the TTA of juice using this method, a random sample of 100 g of fully ripe fruit was selected from each experimental plot and titrated with 0.1 N NaOH solution using phenolphthalin indicators.

3.5.4. Ascorbic acid (AsA)

The content of AsA was measured using the standard method described by Almajidi and Alqubury (2016). This approach involved homogenizing a blended sample of fruits in a solution containing 85% sulphuric acid and 10% acetic acid, and then adding bromine water to use the acetic acid to oxidize AsA to dehydroascorbic acid. Then, adding three to four drops of 10% thiourea, the excess percentage of bromine was eliminated. After two hours of coupling with 2,4-dinitrophenyl hydrazine at 37°C, the solution was cooled in an ice bath. The solution was treated with diluted sulfuric acid after cooling to create a red color complex. Then, the absorbance was read using the UV-spectrophotometric at 280 nm.

4. Statistical Analysis

Statistical analysis was performed using analysis of variance (ANOVA) using CoStat (CoHort software, Monterey, CA, USA) to determine significant differences between treatments. Since the homogeneity test of the two years for all characters was non-significant, the combined analysis of the two seasons was also done for all characters. A significant difference between treatments was indicated by the least significant difference (LSD) at $p \leq 0.05$.

RESULTS

1. Tomato Plant Growth Parameters

The findings indicated that all the assessed growth parameters were significantly ($p \leq 0.05$) impacted by the JA and GB treatments (Table 1). Tomato plants under 5 mM JA or 50 mM GB treatment gave the highest values for plant height, branch number, leaf number, and leaf area. Whereas the control treatment showed the lowest values for each of these indicators. Nevertheless, plant height and leaf number per plant were not statistically different between JA at 0 and 10 mM treatments. Moreover, all the growth indexes were not statistically different between GB at 0 and 100 mM treatments. Notably, the growth parameters of tomato plants were significantly affected by the combined application of JA and GB, compared to the individual applications. The maximum values for plant height, branch number, leaf number, and leaf area of tomato plants were indicated by treatment of the JA at 5 mM × GB at 50 mM.

2. Photosynthetic Pigments

Fig. (1) shows that chlorophyll a, b, a+b, and carotenoids contents were all affected ($p \leq 0.05$) by JA and GB treatments. Plants treated by JA at 5 mM or GB at 50 mM generally had significantly higher values of chlorophyll a by 10.28 or 1.91%, chlorophyll b by 34.41 or 26.95%, chlorophyll a+b by 18.68 or 10.79%, and carotenoids by 16.03 or 12.48%, respectively, compared to control treatment. Meanwhile, the lowest values of photosynthetic indexes were observed in the control, except for the plants under GB at 100 mM treatment had the lowest chlorophyll a values. Under JA at 5 mM treatment, the application of GB (50 mM) showed the highest values of chlorophyll a, b, a+b, and carotenoids in plants compared with other treatments.

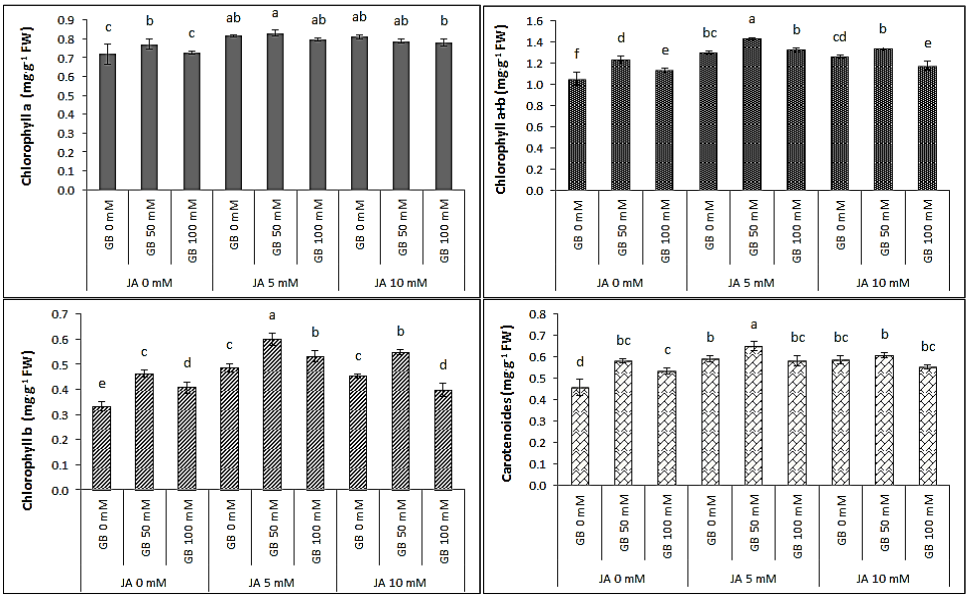
3. Sucrose, MDA, and Proline Contents

Fig. (2) obviously indicates that there were statistically significant effects of JA, GB, and their interaction treatments on sucrose, MDA, and proline contents of tomato plants.

Table (1). Effect of jasmonic acid and glycine betaine on tomato plant growth parameters under saline conditions, 60 days after transplanting (combined analysis of the 2020 and 2021 seasons).

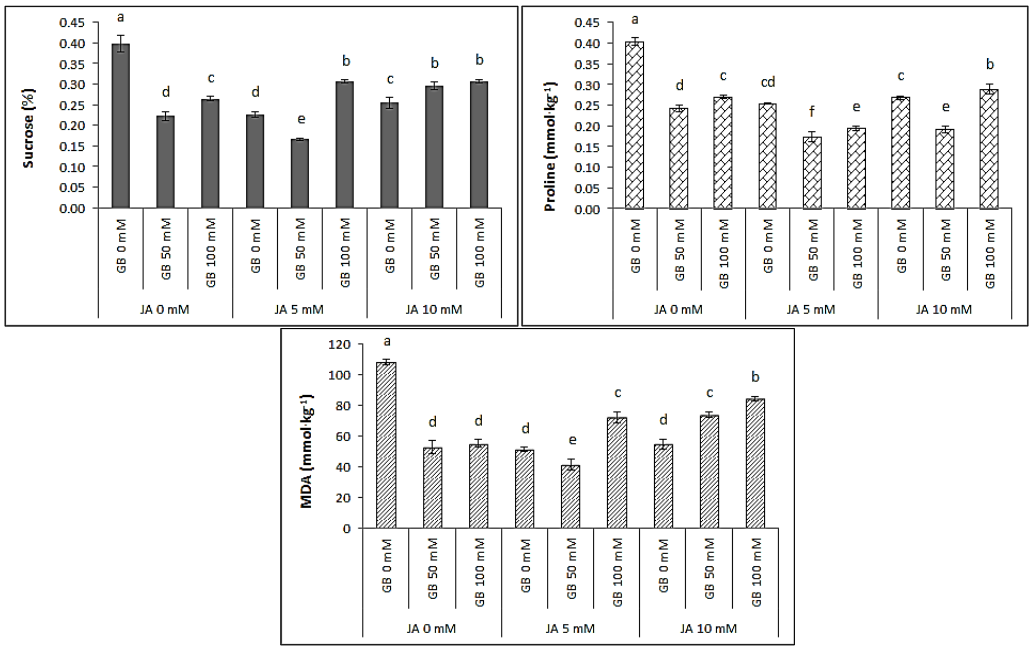
Jasmonic acid (mM)	Glycine betaine (mM)	Plant height (cm)	Branch no. /plant	Leaf no. /plant	Leaf area (cm^2)
0		43.34^{B}	6.04^{C}	22.51^{B}	437.87^{C}
5		46.37^{A}	7.36^{A}	25.52^{A}	510.54^{A}
10		43.48^{B}	6.85^{B}	22.67^{B}	482.50^{B}
	0	42.97^{B}	6.48^{B}	22.93^{B}	457.67^{B}
	50	47.08^{A}	7.18^{A}	24.51^{A}	506.76^{A}
	100	43.14^{B}	6.59^{B}	23.26^{B}	466.49^{B}
JA × GB					
	0	41.97^{d}	5.66^{d}	21.78^{e}	415.58^{c}
0	50	45.06^{b}	6.44^{bc}	23.65^{cd}	486.98^{b}
	100	43.00^{cd}	6.00^{cd}	22.11^{e}	411.06^{c}
	0	43.85^{bcd}	7.22^{b}	24.11^{c}	481.34^{b}
5	50	51.00^{a}	7.99^{a}	27.22^{a}	549.79^{a}
	100	44.27^{bc}	6.89^{b}	25.22^{b}	500.48^{b}
	0	43.10^{cd}	6.55^{bc}	22.89^{cde}	476.07^{b}
10	50	45.18^{b}	7.11^{b}	22.67^{de}	483.52^{b}
	100	42.17^{d}	6.88^{b}	22.44^{de}	487.92^{b}

JA: Jasmonic acid; GB: Glycine betaine.



JA: Jasmonic acid; GB: Glycine betaine

Fig. (1). Effect of jasmonic acid and glycine betaine on chlorophyll a, b, a+b, and carotenoids content of tomato plants under saline conditions, 60 days after transplanting (combined analysis of the 2020 and 2021 seasons).



JA: Jasmonic acid; GB: Glycine betaine; MDA: Malondialdehyde

Fig. (2). Effect of jasmonic acid and glycine betaine on sucrose, MDA, and proline content of tomato plants under saline conditions at 60 days after transplanting (combined analysis of the 2020 and 2021 seasons).

The JA (5 mM) or GB (50 mM) treatment led to a significant decrease in sucrose content by 21.02 or 22.18%, MDA content by 23.88 or 21.62%, and proline content by 32.35 or 34.09%, respectively, compared to the control condition. The applications of 10 mM JA or 100 mM GB were found to be ineffective in decreasing sucrose and MDA contents of tomato plants, but they significantly decreased proline content compared to control. The results showed that there was a significant interaction effect between JA and GB on sucrose, MDA, and proline content. On the other hand, 5 mM JA x 50 mM GB treatment significantly decreased sucrose, MDA, and proline content by 58.29, 61.92, and 56.93%, respectively, compared to plants under control treatment.

4. Yield and Its Attributes

The application of JA enhanced the tomato yield and its different attributes, including fruit diameter, fruit number per plant, and fruit weight per plant (Table 2). Significant increases recorded by the individual treatment with JA at 5 mM were observed in fruit diameter by 21%, fruit number per plant by 28.31%, fruit weight per plant by 40.21%, and fruit yield per hectare by 17.58% as compared to the control plants. Furthermore, the individual treatment with GB at 50 mM recorded significant increases in

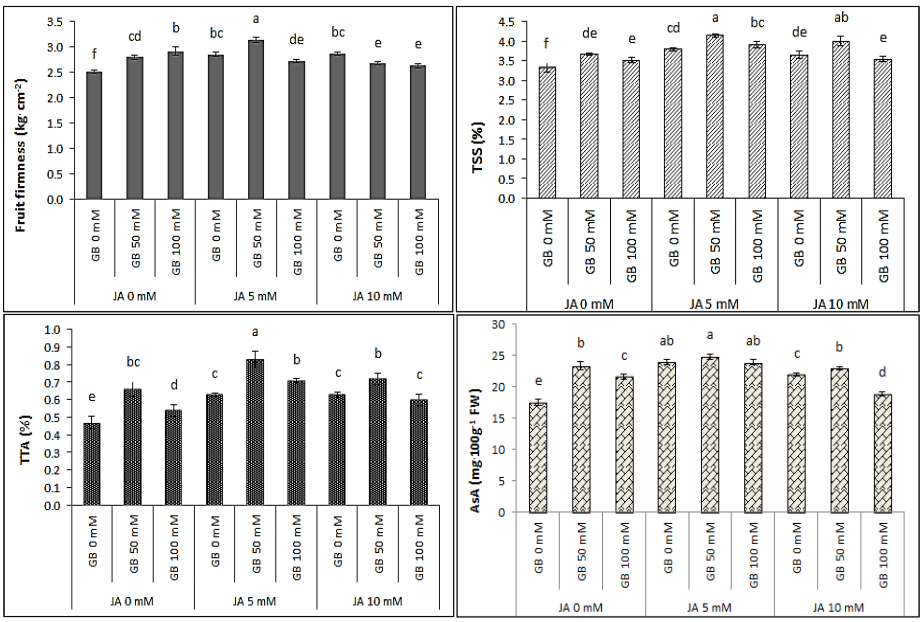
fruit diameter by 20.28%, fruit number per plant by 32.63%, fruit weight per plant by 43.92%, and fruit yield per hectare by 21.02% as compared to un-treatment tomato plants (control). The interaction between JA and GB indicated that significant increases reached 45.12%, fruit number per plant by 92.59%, fruit weight per plant by 155%, and fruit yield per hectare by 26.25% with the application of JA at 5 mM with GB at 50 mM as compared to control plants.

Table (2). Effect of jasmonic acid and glycine betaine on tomato yield and its attributes under saline conditions (combined analysis of the 2020 and 2021 seasons).
JA: Jasmonic acid; GB: Glycine betaine

Jasmonic acid (mM)	Glycine betaine (mM)	Fruit diameter (cm)	Fruit no. /plant	Fruit weight/plant (kg)	Yield (t/ha)
0		4.19^{C}	26.67^{C}	1.89^{C}	32.09^{B}
5		5.07^{A}	34.22^{A}	2.65^{A}	37.73^{A}
10		4.56^{B}	28.04^{B}	2.04^{B}	31.59^{B}
	0	4.24^{C}	26.67^{B}	1.89^{C}	31.78^{B}
	50	5.10^{A}	35.37^{A}	2.72^{A}	38.46^{A}
	100	4.47^{B}	26.89^{B}	1.96^{B}	31.18^{C}
JA × GB					
0	0	3.79^{f}	19.56^{f}	1.20^{g}	26.74^{g}
	50	4.64^{c}	35.11^{b}	2.61^{b}	38.42^{b}
	100	4.13^{e}	25.33^{e}	1.85^{e}	31.12^{e}
5	0	4.57^{cd}	34.67^{b}	2.60^{b}	37.89^{b}
	50	5.50^{a}	37.67^{a}	3.06^{a}	41.78^{a}
	100	5.13^{b}	30.33^{d}	2.28^{d}	33.53^{d}
10	0	4.36^{de}	25.78^{e}	1.88^{e}	30.71^{e}
	50	5.17^{b}	33.33^{c}	2.49^{c}	35.17^{c}
	100	4.15^{e}	25.00^{e}	1.76^{f}	28.89^{f}

5. Fruit Quality Attributes at Harvesting

Fruit firmness, TSS, TTA, and AsA contents of fruits were significantly enhanced in response to application with JA or GB and its combination (Fig. 3). Application of JA at 5 mM, GB at 50 mM and their interaction, respectively recorded significant increases by 5.82, 5.11, and 24.60% of fruit firmness, 12.82, 9.72, and 24.25% of TSS, 28.57, 27.59, and 76.60% of TTA and 16.27, 12.14 and 41.42% of AsA content in comparison with control plants.



JA: Jasmonic acid; GB: Glycine betaine; TSS: Total soluble solids; TTA: Total titratable acidity; AsA: Ascorbic acid

Fig. (3). Effect of jasmonic acid and glycine betaine on fruit firmness, TSS, TTA, and AsA content of tomato plants under saline conditions (combined analysis of the 2020 and 2021 seasons).

DISCUSSION

The salinity problem challenges plant crops and causes losses in yield and quality through the stresses it causes, such as sodium ion toxicity and physiological dehydration (Hazman et al., 2022 and Yildirim et al., 2023). Plants under salinity stress suffer oxidative stress due to the accumulation of ROS, such as H_2O_2, which harm nucleic acids and proteins and result in lipid peroxidation. Lipid peroxidation is the most detrimental process known in all living organisms. When ROS levels exceed the threshold, lipid peroxidation occurs (Yan et al., 2018 and Ekinci et al., 2022). Consequently, this study examined the effects of JA and GB treatments on tomato plants in salinity conditions; the findings are presented in Tables (1 and 2), and Figs. (1, 2 and 3).

Treatments with JA reduced the inhibitory effect of salinity stress on tomato plant growth, including plant height, branch number per plant, leaf number per plant, and leaf area, as well as yield and its attributes, including fruit diameter, fruit number per plant, and fruit weight per plant. Particularly for these characteristics, treatment with 5 mM JA proved to be more effective (Tables 1 and 2). Previous studies have indicated the beneficial

effects of JA treatment on plant damage caused by salinity stress (Chavoushi et al., 2019; Ali et al., 2022 and Hussain et al., 2022). By managing the antioxidant system and protein synthesis, JA can protect plants from harmful ions throughout the growth stage, which can improve the growth and yield characteristics of plants under salinity stress (Sirhindi et al., 2015). These results are consistent with the findings of Kumari et al. (2006), who suggested that the rapid accumulation of a specific set of proteins dubbed jasmonate-induced stem proteins may be the cause of the enhanced protein accumulation. The findings of the study show that GB application positively influenced the tomato plant growth and yield under saline conditions (Tables 1 and 2). The positive effect of GB on growth may be due to being a known osmoprotectant, and its ability to maintain a better water status, which promotes gas exchange and photosynthesis, as well as improved turgor, which promotes cell expansion and shoot growth under salinity stress (Oddo et al., 2019 and Maqsood et al, 2021). Zhang et al. (2014) also noted that the application of GB has been enhancing the nitrogen content of leaves, which has enhanced plant growth and yield. According to other research, foliar application of GB increased fresh biomass levels because the higher tissue water content of shoots lessened the harmful effects of high salinity (Marcum and Murdoch, 1990). Previous studies on the stimulatory effects of GB on plant growth and yield in salinity conditions have been provided by (Sakr et al., 2012; Oddo et al., 2019; Dustgeer et al., 2021 and Maqsood et al., 2021).

The findings of the present study pointed out that applications of JA and GB and their interaction under saline conditions resulted in significant increases in chlorophyll a, chlorophyll b, chlorophyll a+b, and carotenoids (Fig. 1). The findings are concurred with those of Ali et al. (2022), who reported that under conditions of salt stress, the application of JA enhanced the accumulation of photosynthetic pigments. This may be due to the protective role of JA, through its ability to decrease Na^+ accumulation and adjust K^+ distribution between roots and shoots of plants, exogenous application of JA could maintain ion homeostasis in plants under salt stress, allowing the plants to maintain essential functions like photosynthesis, metabolism, and osmotic pressure while also reducing ion toxicity (Zhu, 2003). Exogenous application of JA could increase the expression of photosynthesis-related genes encoding leading to increased chlorophyll content (Janoudi and Flore, 2003 and Chavoushi et al., 2019). In the present study, the application of GB increased the photosynthetic pigments under salinity conditions (Fig. 1). One possible explanation for the increase in photosynthetic pigments caused by GB treatment is the preservation of endogenous water availability. Furthermore, GB can stabilize the activity of the protein during salinity stress, protecting the photosynthetic apparatus. The increased chlorophyll and carotenoid levels are consistent with the findings of several authors who found that applying GB to plants under

salinity stress significantly enhanced photosynthetic pigments content (Sakr et al., 2012; Dustgeer et al., 2021 and Maqsood et al., 2021).

The results of the present experiment indicated that treating plants with JA and GB was significant in reducing the contents of sucrose, MDA, and proline of tomato plants under salinity conditions (Fig. 2). The negative effect of JA on sucrose, MDA, and proline contents in tomato plants was more effective with JA at 5 mM treatment. Plants treated with JA may have lower MDA and proline concentrations as a result of lessening the negative effects of salinity stress by enhancing the activities of antioxidant enzymes and limiting Na^+ entrance into leaf cells (Farhangi and Ghassemi, 2018). Application of JA can cause oxidative stress and acid invertase hydrolytic enzymes, which can affect the bioavailability of sucrose and cause a reduction in sucrose (Moreira et al., 2019). Similar results were announced earlier with exogenously applied JA (Farhangi and Ghassemi, 2018 and Hussain et al., 2022). The reduction in the accumulation of MDA by the application of GB may be due to the stimulating effect of GB on roots increasing and Ca^{2+} accumulation maintained the membrane integrity and enzymatic activities under saline stress (Munns and Tester, 2008) which reduced the MDA content of tomato plants (Dustgeer et al., 2021; Maqsood et al., 2021; Shemi et al., 2021 and Khedr et al., 2022). The findings of the present study showed that applying GB reduced the proline level of plants under salinity conditions. The reason for this could be because GB might have some influence at the membrane level since it was found that triethylammonium chloride mimicked the GB inhibitory impact on the osmoinduced proline response (Larther et al., 1996). These findings agree with those of Salama et al. (2015) and Khedr et al., 2022), they discovered that application of GB reduced proline and MDA in plants.

The increase in fruit firmness, TSS, TTA, and AsA contents was quite evident under JA and GB applications (Fig. 3). Similarly, plants treated with JA showed increases in fruit firmness, TSS, TTA, and AsA levels (Huang et al., 2015; Baek et al., 2021 and Deshi et al., 2022). The application of JA to plants may have improved the activity of the enzymes phenylalanine ammonia-lyase and peroxidase, which might be responsible for the increase in fruit firmness (Yao and Tian, 2005) that are involved in the biosynthesis of lignin (Garcia-Ulloa et al., 2020), which might therefore improve fruit firmness. In addition, the application of JA could decrease the polygalacturonase genes expression and the activity of the enzymes associated with them, as well as delay cell wall softening (Yao and Tian, 2005). The delay in physiological processes caused by JA treatment, which downregulates the ripening process by decreasing the gene expression for ACC synthase, ACC oxidase, and ethylene receptors, may be the cause of the rise in TSS, TTA, and AsA contents of plant fruits (Ruiz et al., 2013). Furthermore, the exogenous application of JA slows down respiration,

allowing fruit to retain its energy sources, thus higher content of TSS, TTA, and AsA in JA-treated plant fruits. It might also be due to an increase in anthocyanins, which contribute to soluble solids (Huang et al., 2015). According to the findings, GB treatments effectively raised the fruit firmness, TSS, TTA, and AsA contents (Fig. 3). Similar results were announced earlier in plants with exogenously applied GB (Awad et al., 2017; Adak, 2019 and Zheng et al., 2023). One important factor influencing tomato fruit's market appeal is fruit firmness. GB consistently preserves the structure of biological macromolecules by functioning as an osmotic regulator (Acharyya et al., 2020), thereby protecting cell membrane stability (Annunziata et al., 2019). The increasing content of TSS by GB treatment may be due to regulating cytoplasmic dehydration while increasing the capability of plants to allocate more assimilates which may have improved the content of sugar in the fruit (Cefola et al., 2014). Plant fruits treated with GB likely have a higher TTA content is probably due to an effect on respiration rate by reducing glycolytic enzyme activities, thus maintaining organic acids in the fruits (Valero et al., 2011). In tomato fruits, the GB treatment significantly increased AsA. The increase could be attributed to the beneficial influence of GB on maintaining comparatively high-water content in the fruits, which lessened physiological problems, caused by oxidative stress and increased ascorbic acid levels (Zheng et al., 2023).

CONCLUSIONS

In the present study, the effects of JA and GB with different doses under salinity stress on tomato plants were investigated and the results were examined regarding different morphological, physiological, and biochemical aspects, yield, and fruit quality. The exogenous application of JA or GB and their interactions on tomato improved the tolerance of plants to salinity conditions. The effect of 5 mM JA or 50 mM GB treatment and interaction between of them on plant growth parameters, photosynthetic pigments, yield attributes and fruit quality were more pronounced in tomato. In contrast, the content of sucrose, MDA, and proline were decreased in treated tomato plants under salinity conditions. In tomato plants under salinity conditions, JA and GB play a protective role by enhancing photosynthetic activity and adjusting the contents of sucrose, MDA, and proline to suit the needs of the plants against stress.

As a result, based on the effects of JA and GB on tomato plants grown under salinity conditions, it can therefore be regarded as an alternate treatment for cultivation in problematic salinity stress conditions. In addition, it will be helpful to study the effects at the molecular level at a later stage for more detailed results.

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التخفيف من الآثار السلبية لإجهاد الملوحة على نمو ومحصول نباتات الطماطم باستخدام الرش الورقي بحامض الجاسمونيك والجليسين بيتان

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الملوحة من أهم المشاكل التي تواجه المحاصيل الزراعية فهي تؤدي إلى تقييد إنتاجيتها وتقلل من نوعيتها، مما يؤدي إلى خسائر اقتصادية كبيرة. من المعروف أن حامض الجاسمونيك والجليسين بيتان يلعبان دورًا كبيرًا في تحفيز العمليات الفسيولوجية والتمثيل الغذائي في النباتات، كما يزيدان من قدرة النبات على تحمل العديد من الإجهادات البيئية المختلفة. أجريت هذه الدراسة خلال موسمي صيف ٢٠٢٠ و٢٠٢١ بالمحطة البحثية التابعة لمركز بحوث الصحراء، رأس سدر، محافظة جنوب سيناء، بهدف دراسة تأثير مستويات حامض الجاسمونيك (٠، ٥ و١٠ ملليمول) والجليسين بيتان (٠، ٥٠ و١٠٠ ملليمول) لتخفيف الآثار السلبية للملوحة وتحفيز نمو وإنتاجية نباتات الطماطم. أظهرت النتائج أن تطبيق حامض الجاسمونيك (٥ ملليمول) و/أو الجليسين بيتان (٥٠ ملليمول) أدت إلى زيادة صفات النمو وصبغات التمثيل الضوئي للنباتات المجهدة. علاوة على ذلك، زيادة محصول الطماطم وخصائصه المختلفة مثل قطر الثمرة، عدد الثمار لكل نبات، ووزن الثمار لكل نبات نتيجة للمعاملات المذكورة أعلاه. في الوقت نفسه، زادت صلابة الثمرة، والمواد الصلبة الذائبة الكلية، والحموضة الكلية القابلة للمعايرة، ومحتوى حمض الأسكوربيك، بينما انخفضت محتويات السكروز والمالونديالدهيد (MDA) والبرولين بشكل كبير مع تطبيق حمض الجاسمونيك و/أو الجليسين بيتان. نتيجة لذلك واستنادًا إلى التأثيرات المفيدة لحامض الجاسمونيك والجليسين بيتان في نباتات الطماطم تحت ظروف إجهاد الملوحة، يمكن اعتبار حامض الجاسمونيك والجليسين بيتان أحد البدائل المطروحة للتغلب على مشاكل الزراعة تحت ظروف إجهاد الملوحة.