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EXOGENOUS APPLICATION OF SALICYLIC ACID IMPROVES PHYSIOCHEMICAL AND QUALITY TRAITS OF TOMATO (*SOLANUM LYCOPERSICUM* L.) UNDER ELEVATED TEMPERATURE STRESS

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Abstract

Globally temperature is increasing continuously due to climate change and anthropogenic activities. This rampant increase in temperature disturbs certain plant metabolic functions and retards plant growth. Tomato (*Solanum lycopersicum* L.) is highly economical but heat prune crops that hamper growth at high temperatures. Salicylic acid (SA) is a plant hormone used to mitigate environmental stresses but its role against high temperatures is largely unknown. Therefore, this study was aimed to investigate the impact of SA (0.0 mM, 0.25 mM, 0.75 mM, and 1.25 mM) exogenous foliar applications on tomato crops under elevated temperatures at 30 days (35 ± 2°C), 60 days (40 ± 2°C), and 90 days interval (45 ± 2°C). The results revealed that SA application was quite effective in enhancing tomato morphological traits including number of leaves, flowers, plant height, and stem diameter, and SA 0.25 mM concentration was highly efficient among other treatments. Likewise, in plant physiological traits, the highest leaf relative water contents (0.04%), photosynthesis rate (4.80 μmol $m^{-2}s^{-1}$), vapor pressure deficient (14.44 kPa), and lowest stomatal conductance (326.86 gs, mol $m^{-2}s^{-1}$) and transpiration rate (326.86 mol $m^{-2}s^{-1}$) were also observed at a similar concentration. The application of SA on tomato crops under high elevated temperatures ameliorated its quality attributes like total soluble solids, titratable acidity, and ascorbic acid contents.

Key words: Climate change; Elevated temperature; Physiological traits; Salicylic acid.

Introduction

Tomato (*Solanum lycopersicum* L.) is an important economic vegetable that is grown worldwide, having a global production of 182 million tons (El-Hady *et al*., 2021). It is highly nutritious having several health promoting bioactive compounds including vitamins, antioxidants, phenolic, and carotenoids, playing a major role in food safety, food security, and human health (Chaudhary *et al*., 2018; Slavin & Lloyd, 2012). Lycopene, is potent antioxidant predominantly found in tomatoes, has attention significant attention for its potential anticancer properties, particularly about prostate cancer. It helps in neutralizing free radicals, by reducing oxidative stress and the risk of chronic diseases. It is observed that people with diets rich in tomatoes exhibit lower incidences of prostate cancer (Giovannucci, 2002; Chen *et al*., 2015). The role of tomato in food security is apparent from its usage as either it is consumed fresh as salads, or in processed form as jams, ketchup, sauces, and fish or meat dishes (Khokhar, 2013). Being tropical in nature, it is widely adapted to certain climatic conditions. However, the ideal temperature for its growth is between 22-32ºC (Shinwari *et al*., 2018).

Nowadays, climate change is of global concern and the elevated temperature is threatening agricultural crops, causing certain morphological and physiological changes to plants (Deligios *et al*., 2019). These changes may suffer crop yield and global food production. The tomato crop is heat sensitive and plants grown in arid regions of the world have low yields due to high temperatures (Driedonks *et al*., 2018). In tomatoes, high temperature in early summer reduces crop growth and fruit set that ultimately declining tomato yield (Hussain *et al*., 2006). High temperatures above normal may lead to plant cell injuries, cell disorders, and deform fruit shape and structure. Similarly, the elevated temperature during vegetative and reproductive phases is a threat to tomato growing regions that reduces tomato production (Singh *et al*., 2007).

Generally, it is observed that an increase in 1ºC temperature may lead to a decrease in yield by up to 17% (Lobell & Asner, 2003). High temperature with prolonged heatwaves has a negative impact on the ecosystem. For example, in 2003, heatwaves in Europe reduced 30% production of gross primary products (Ciais *et al*., 2005). Similarly, in 2010, Russia faced drastic heatwaves that caused 50% reduction in gross primary products (Bastos, 2013). In upcoming years, an increase in temperature will be a major constraint for food production and food security, as extreme climatic conditions like high temperature will disturb plant endogenous functions. Therefore, there is utmost need to adapt new agronomic strategies to enhance stress tolerance and improve tomato yield during changing climatic conditions (Shinwari *et al*., 2018; Francini & Sebastiani, 2019).

Plant growth hormones play an essential part in overcoming biotic and abiotic stress. Salicylic acid (SA) as an endogenous hormone stimulates plant growth and tolerance during abiotic stresses (El-Hady *et al*., 2021: Ding & Ding, 2020). It is known as a key signaling molecule that responds under stress conditions, improves source link relationship, develops stress against resistance, stimulates photo-assimilates translocation, protein synthesis, reprogramming of genes expression, and better flower and fruit retention (Saeed *et al*., 2007; Huang *et al*., 2020; Janda *et al*., 2020). It is also helpful in stimulating certain metabolic and physiological processes like ion uptakes, transpiration, and photosynthesis (Abreu *et al*., 2009), foliar application of SA improves vegetable yield by reducing plant stresses (Khan *et al*., 2015). Further, it is helpful in osmoregulation, enzymes activation, and stomatal conductance (Stevens *et al*., 2006). Therefore, the aim of this study was to analyze the impact of SA on tomatoes grown under elevated temperature stress and to evaluate the influence of SA foliar applications on morphological, physiological, and fruit quality attributes of tomatoes.

Material and Methods

Planting material: This study was conducted in 2016 at Horticulture Research Area, located at PMAS-Arid Agriculture University, Rawalpindi, Pakistan. The tomato (*Solanum lycopersicum* L.) seedling of cv. “T-1359” were collected from a government-registered nursery, “Awan Seed Garden” situated in Islamabad. This cultivar was a hybrid that is normally used for fresh consumption. For this experiment, peat and vermiculite were used as a growing substrate that was collected from a similar source. However, before seedling transplantation, these substrates were placed in an open space and were solar sterilized by covering them with a transparent sheet to avoid harmful pathogens and all debris was carefully sorted and removed from the media (Qadri *et al*., 2018).

Chemical properties of substrate: After sterilization, substrates chemical analysis of major nutrients nitrogen (N), phosphorous (P), potassium (K), pH, electrical conductivity (EC), and organic matter contents (%) were determined in the soil chemistry laboratory, PMAS-Arid Agriculture University, Rawalpindi, Pakistan. The analyses showed that the growing media has the following properties as shown in (Table 1). After substrates analysis, the growing media was filled in 12 inches of clay pots, by placing a pebble at the pot bottom to remove excess water and for gaseous exchange, and 25 days old seedlings were shifted in pots.

Application of salicylic acid (SA): The various concentrations of SA (0.0 mM, 0.25 mM, 0.75 mM and 1.25 mM) were prepared in distilled water. After the solutions preparations, pH was checked with the help of a pH meter (HI 98107, HANNA instruments, US). The values of pH ranged between 6.8-7 which was near neutral. The seedlings used for the experiments were healthy, disease free, and with 2-4 true leaves. The foliar applications of prepared SA solutions were applied to tomato plants with the help of an atomizer. The prepared solution of each treatment was applied to the individual plant separately till the whole plant was wet and the droplets started to fall from the leaves. The plants were grown in semi-controlled greenhouse and treatments were applied at the intervals of 30, 60, and 90, days of intervals, and the following temperature conditions were maintained at 35 ± 2°C during the first interval (30 days), 40 ± 2°C second interval (60 days), and 45 ± 2°C third (90 days) respectively, by using solar radiations, heaters and cooling fans.

Evaluation of morphological attributes: To evaluate the effect of SA foliar applications, the data of plant morphological attributes viz. number of leaves, number of flowers, plant height (cm) and stem diameter (cm) were taken at the interval of 30 days, 60 days, and 90 days respectively.

Determination of physiological parameters: The physiological parameters of the plant were taken at crop maturity and data was collected at 90 days of seedling transplanting.

Leaf relative water contents (LRWC): To determine water status present in plants during stress conditions, leaf relative water contents (LWRC) were ascertained by the procedure as mentioned by Costes *et al*., (2006). In this procedure, leaves were collected, weighed (F.W), and dipped in distilled water for 5 hours in dark. After leaves were fully turgid due to water saturation (T.W) they were again weighed. In the next step, leaves were dried in an oven at 75°C for 48 hours and dry weight was measured (D.W). After LRWC was measured by using the following formula:

$$LRWC\ \% = (F.W-D.W)/(T.W-D.W)\times 100$$

Stomatal conductance, transpiration rate, photosynthetic rate and vapor pressure deficit: The parameter stomatal conductance (gs, mol $m^{-2}s^{-1}$), transpiration rate (E, mol m^{-2} s^{-1}), photosynthetic rate (A, μmol m^{-2} s^{-1}) and vapor pressure deficit (kPa), were calculated with the help of LI-6400XT Portable Photosynthesis System (LI-COR GmbH, Germany) as performed by Kaya *et al*., (2015).

Evaluation of fruit quality traits

Fruit firmness and total soluble solids (TSS): To measure fruit firmness three fruit samples from each treatment were taken and their average was calculated and measured with the help of a penetrometer (Fruit pressure tester, FT 327, Italy). The values of fruit firmness were measured in newton (N). For the determination of total soluble solid, fruit juice was extracted with the help of muslin cloth and was measured by hand refractometer (model RS 5000 Atago, Japan), and its unit was taken in °Brix (Akram *et al*., 2020).

Titratable acidity (TA) and ascorbic acid contents (Vit C): To calculate TA, 10 mL of juice extracted tomato juice was inserted in a 100 mL conical flask and was diluted with distilled water to make its final volume up to 50 mL. After that it was titrated with 0.1 N sodium hydroxide solution and 2-3 drops of phenolphthalein were used as an indicator. The titration was performed untill light pink color appeared and its value was expressed in percentage (%). While ascorbic acid contents were determined by titrating it against 2, 6- dichloro-indophenol dye Tillmans reagent (Zahid *et al*., 2020).

Table. 1. Chemical properties of the growing substrate (peat and vermiculite, 1:1).

Nutrients	Values	Biochemical properties	Values
Nitrogen (N)	300 mg/L	pH	5.5
Phosphorous (P)	300 mg/L	Electrical conductivity (EC)	250 mhos/cm
Potassium (K)	400 mg/L	Organic matter	2%

Statistical analysis

The experiment was laid out under randomized complete block design (RCBD) with 3 replications and in each replication 8 plants were analyzed. The data were analyzed by using the ANOVA technique and the difference between means was compared by using Tukey's HSD at a 5% probability level.

Results

Effect of salicylic acid (SA) foliar applications on morphological attributes:

Number of leaves: The results exhibited that the applications of salicylic acid (SA) had significantly influenced the number of leaves (Fig. 1). The results revealed that there was a gradual increase in leaves number and the maximum number of leaves (86.47) were observed in plants treated with 0.25mM concentration of SA after 90 days, followed by 60 days (65.29) and 30 days (61.53) as shown in Fig. 1. While the minimum number of leaves (17) were observed at 1.25mM concentration of SA after 30 days followed by 60 days at a similar concentration (18.67).

Number of flowers: The number of flowers significantly varied with SA concentrations as shown in (Fig. 2). The maximum number of flowers (23.53) was noticed at 90 days in 0.25mM concentration followed by 1.25mM concentration of SA (17.93). While the lowest number of flowers (5.20) was also observed at 30 days in 1.25mM SA concentration, followed by 0.75mM SA (7.0) and control (7.20), respectively.

Plant height (cm): Different foliar applications of SA had a significant effect on plant height (Fig. 3). The result indicated a positive relationship between time and plant height, and plant height was constantly increased with an increase in day numbers. The highest plant height (65.06 cm) was obtained in plants treated with 0.25mM salicylic acid for 90 days followed by plants treated with 0.75mM concentration (54.13 cm). While the minimum plant height (23.26 cm) was observed at 30 days with 1.25mM SA concentration followed by control (26.03 cm).

Stem diameter (cm): Salicylic acid also showed a significant impact on plant stem diameter (Fig. 4). The maximum stem diameter (1.43 cm) was noted in plants treated with 0.25mM concentration of SA followed by control (1.03 cm) at 90 days. While the minimum plant height (0.51 cm) was observed in the control at 30 days.

Impact of salicylic acid (SA) foliar applications on plant physiological parameters

Leaf relative water contents (%): The results related to leaf relative water contents (%) were depicted in (Fig. 5A). The results exhibited that SA foliar spray had a significant influence on leaf relative water contents, and it was maximum in SA 0.25mM (0.04%) followed by untreated plants (0.03%). While the lowest amount of leaf relative water contents (0.01%) was observed at 0.75mM SA concentration.

Stomatal conductance (gs, mol $m^{-2}s^{-1}$): The results regarding stomatal conductance have been exhibited in (Fig. 5B). The results manifested that the application of SA has a significant impact on stomatal conductance and is helpful in regulating stomatal conductance in elevated water stress. The results showed that the minimum stomatal conductance (326.86 gs, mol $m^{-2}s^{-1}$) was observed in SA 0.25mM concentration. While the maximum stomatal conductance (344.46 gs, mol $m^{-2}s^{-1}$) was noticed in control followed by 1.25mM (340.13 gs, mol $m^{-2}s^{-1}$) and 0.75 SA (335.16 gs, mol $m^{-2}s^{-1}$) concentrations respectively.

Transpiration rate (E, mol $m^{-2}s^{-1}$): Concerning transpiration rate, the application of SA has a significant impact on tomato transpiration rate (Fig. 5C). The results revealed that the highest transpiration (344.46 mol $m^{-2}s^{-1}$) was noticed in untreated plants tomato followed by 1.25 mM (340.13 mol $m^{-2}s^{-1}$) and 0.75 mM concentrations of SA (335.60 mol $m^{-2}s^{-1}$) respectively. While the lowest transpiration rate (326.86 mol $m^{-2}s^{-1}$) was observed in tomato plants treated with SA 0.25 mM concentration.

Vapor pressure deficit (kPa): The results in (Fig. 5D) showed that the foliar application of salicylic acid had a significant effect on vapor pressure deficit (VPD). The result showed that the highest VPD (14.44 KPa) was obtained in tomato plants in SA 0.25 Mm concentration followed by 1.25 mM (12.04 kPa) and 0.75 mM SA (11.80 kPa) concentrations respectively. However, the minimum VPD value (9.64 KPa) was obtained in the control.

Photosynthetic rate (A, µmol m^{-2} s^{-1}): The rate of photosynthesis was significantly affected by the application of SA as shown in (Fig. 6A). The highest photosynthesis rate (4.80 µmol m^{-2} s^{-1}) was observed in SA 0.25 mM concentration followed by control (3.18 µmol m^{-2} s^{-1}). While the minimum photosynthetic rate (2.73 µmol m^{-2} s^{-1}) was observed in 0.75 mM SA concentration at par with 1.25 mM (2.66 µmol m^{-2} s^{-1}) SA concentration.

Total soluble solids (°brix): The application of SA significantly influenced fruit quality traits like TSS (Fig. 6B). The results exhibited that the maximum TSS (5.98 °brix) was obtained in 0.25 mM SA followed by 0.75 mM SA (5.06 °brix). While the minimum TSS (3.67 °brix) was observed in controlled treatment.

Titratable acidity (%): Likewise, TSS, the titratable acidity was also highly influenced by SA (Fig. 6C). The results exhibited that maximum titratable acidity (0.27%), obtained in 0.25 mM concentration of salicylic acid followed by 1.25 mM SA concentration (0.19%). While the lowest amount of titratable acidity (0.14%) was noticed in the control.

Ascorbic acid (mg/100g): The results regarding ascorbic acid has been shown in (Fig. 6D). The results indicated that SA exogenous application has a significant impact on tomato ascorbic acid contents and the highest amount of ascorbic acid (5.98 mg/100g) was also observed in plants treated with 0.25 mM SA followed by 1.25 mM SA (5.06 mg/100g) and 0.25 mM SA concentration (4.38 mg/100g).

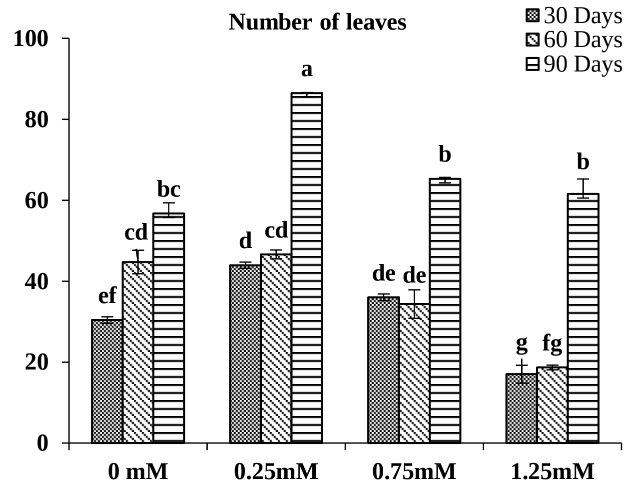

Fig. 1. Impact of Salicylic acid foliar applications on tomato leaves under elevated temperature stress.

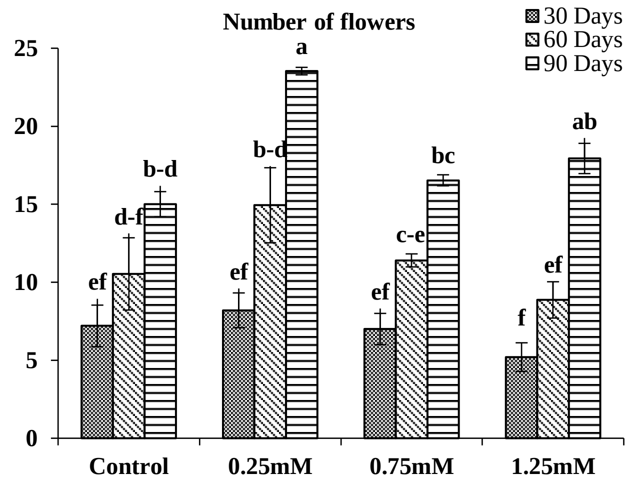

Fig. 2. Impact of salicylic acid foliar applications on tomato plant flowering under elevated temperature stress.

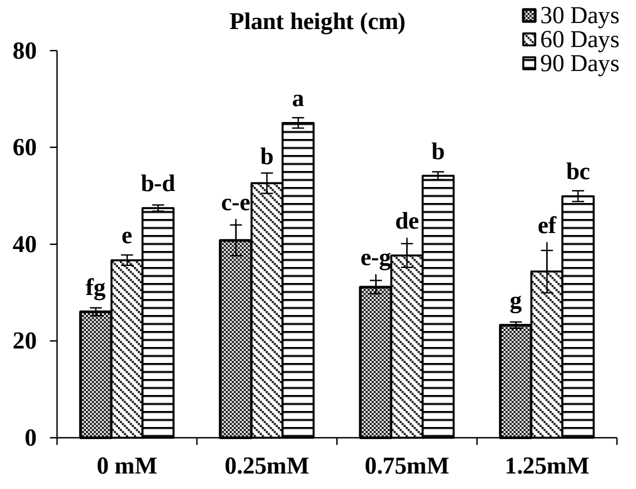

Fig. 3. Impact of salicylic acid foliar applications on tomato plant height (cm) under elevated temperature stress.

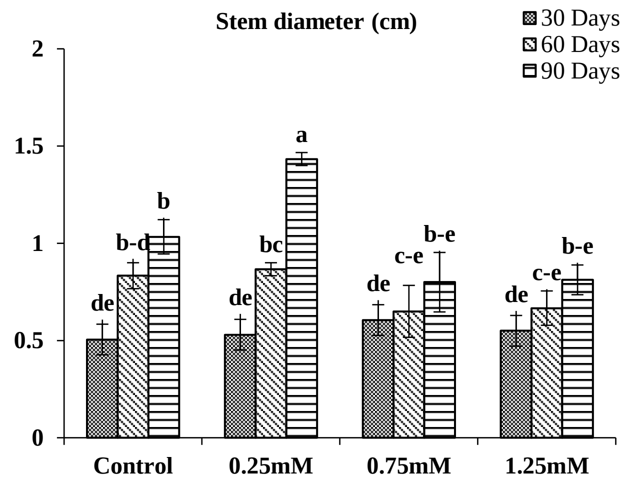

Fig. 4. Impact of salicylic acid foliar applications on tomato stem diameter (cm) under elevated temperature stress.

Discussion

Influence of SA on plant morphological traits: Under the current climate changing scenario both high and low (chilling or cold) temperature stresses have a deleterious impact on plant growth, and it affects plant physiological functions (Abd-Elkader *et al*., 2016; Khan *et al*., 2015). Plant hormones play a key role in the regulation of plant developmental processes and are involved in a variety of biotic and abiotic responses during stress and generate signals for certain mechanisms and induce tolerance in plants by producing glycine betaine, regulating proline and nitrogen plant metabolism, photosynthesis, and maintains plant water relations, especially in stress conditions (El-Taher *et al*., 2022; Miura & Tada, 2014).

The exogenous application of SA is reported to induce stress tolerance in plants either by seed soaking or spraying plants (Palma *et al*., 2015). However, its low or high dose may inhabit plant functions; therefore, optimum salicylic acid dose is required for proper plant function (Khan *et al*., 2015). In our findings, the maximum number of leaves (86.47) were observed at SA 0.25mM concentration as its application to plants improves plant growth by regulating plant physiological processes and ethylene biosynthesis (Yusuf *et al*., 2013). Further, it prevents leaves abscission by reverting abscisic acid formation (Khan *et al*., 2015). Therefore, during stress, the formation of secondary metabolites can be controlled by using SA as it is helpful in the regulation of nutrient production, ion uptake, and plant metabolism at high temperatures. Similar observations were noted by Shinwari *et al*., (2018) who found an increase in leaves number by applying the exogenous application of SA in tomato crops during high-temperature stress. Likewise, a similar finding was assessed by other workers (Abd-Elkader *et al*., 2016; Munné-Bosch *et al*., 2009).

SA is a precursor for the auxin synthesis that is produced in the plant's meristematic tissues and promotes plant growth. Salicylic acid is also believed to be responsible for changing plant hormonal status that is involved in plant height (Gharib, 2006). The application of salicylic acid also improves other phytohormones like gibberellin and cytokinin that are responsible for cell division and enlargement (Kumar & Kaur, 2019). This study's findings were in harmony with Shinwari *et al*. (2018) who revealed that the application of SA boosted plant height. Similarly, the plant stem diameter has a direct relation with plant height and normally it enhances with the increase in plant height. The increase in stem wall may be due to an increase in the epidermis, parenchymatous area, xylem, and phloem tissues of plants (El-Taher *et al*., 2022; Hasan *et al*., 2018). Similar observations were reported by other scientists who observed an increase in stem diameter by SA applications (Kang *et al*., 2012; Abd-Elkader *et al*., 2006). It is also observed that the exogenous of SA under heat stress increases photosynthesis in plants that enhance plant height (Jahan *et al*., 2019).

SA has a significant impact on the vegetative and reproductive phases of the plant as it aids in the accumulation of carbohydrates to induce flowers and promotes reproductive organs developments such as stigma elongation, pollen dehiscence, their viability, and production as well (Vazirimehr *et al*., 2014). In our study, it was observed that SA exogenous application enhanced the number of flowers that had a direct relation to plant yields. More number of flowers results in more fruits that will ultimately increase crop productivity (Abd-Elkader *et al*., 2016). The flower induction by SA is also confirmed by other researchers (Janda *et al*., 2020; Kaushal *et al*., 2016). SA acting as an endogenous chelating agent, stimulates flowering and enhances the plant's ability to produce florigen that enhances flower production, their shelf life (Hafeznia *et al*., 2014).

Effect on plant physiological functions: Plant growth is being badly affected by climate change, and both low and high temperatures are posing a threat to vegetables. High temperature has an adverse impact on plant physiological functions such as photosynthesis, leaf relative water contents, stomatal conductance, transpiration rate and induces molecular mechanisms (Siboza *et al*., 2014; Kazemi-Shahandashti *et al*., 2014). SA promotes plant growth and development being useful in the mitigation of plant stresses (Jahan *et al*., 2019). Saneoka *et al*., (2004) and Gracia *et al*., 2007 have reported that stress has negative impact on plant growth, as it reduces the water contents of many crops. However, it depends upon the plant species and stress type (Khan *et al*., 2022). In our findings, salicylic acid was effective in retaining leaf relative water contents (LRWC)and the highest LRWC (0.04%) was observed at 0.25 mM concentration of SA under high-temperature stress compared to untreated plants. The application of SA influence plant physiology processes and during stress it regulates stomata opening and minimizes transpiration loss, increasing ion uptake by roots and water transportation, therefore it leads to increase leaf water content (Jahan *et al*., 2019). Similar findings were observed by other researchers who found the exogenous application of SA in tomatoes reduced water stress (Shaheen *et al*., 2017; Szepesi *et al*., 2005). The results were in harmony with other researchers who noticed less leaf water contents in tomatoes during stress conditions (Calcagno *et al*., 2011; Noreen *et al*., 2010).

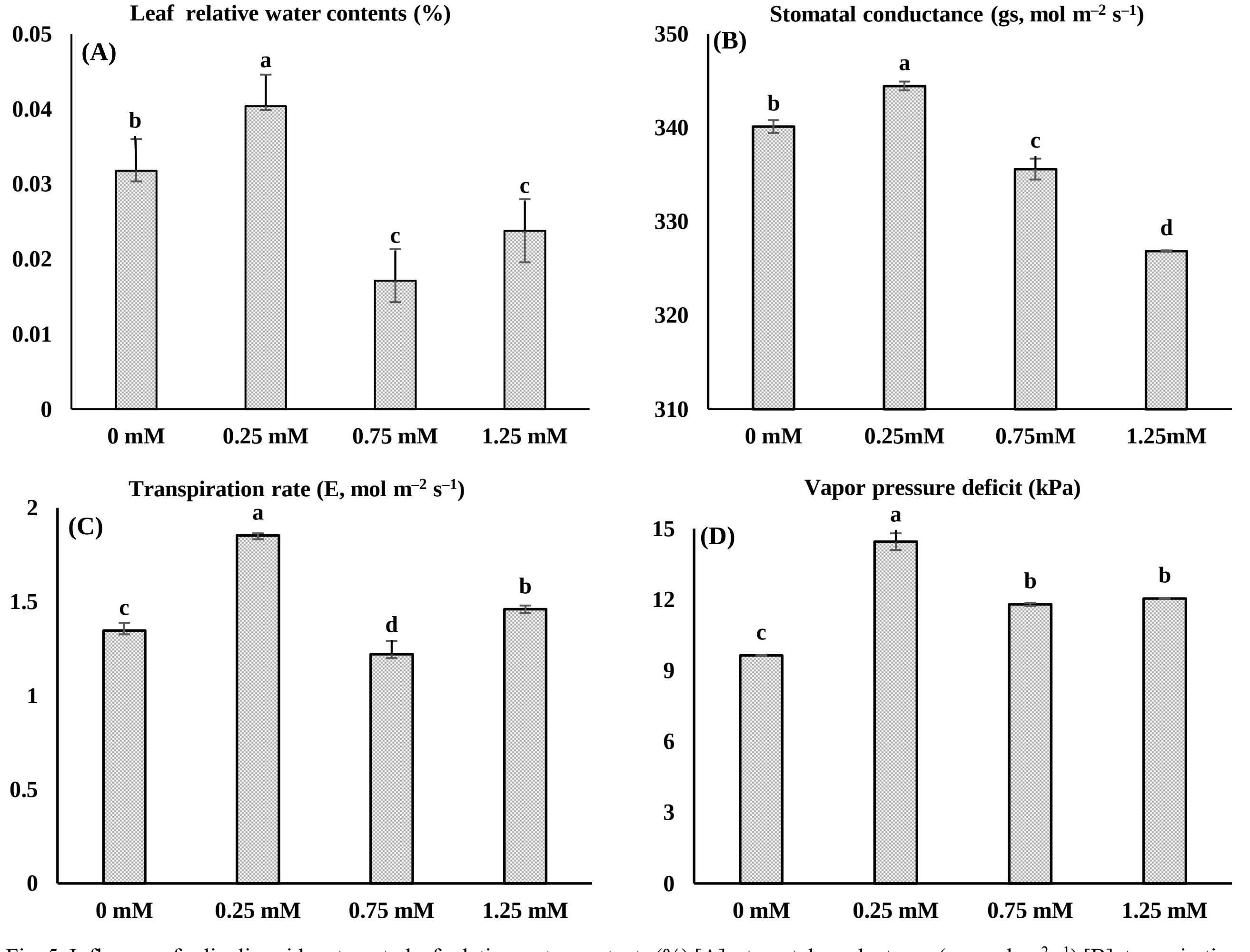

Fig. 5. Influence of salicylic acid on tomato leaf relative water contents (%) [A], stomatal conductance (gs, mol $m^{-2}s^{-1}$) [B], transpiration rate (E mol $m^{-2}s^{-1}$) [C] and vapor pressure deficit (kPa) [D] under elevated temperature stress.

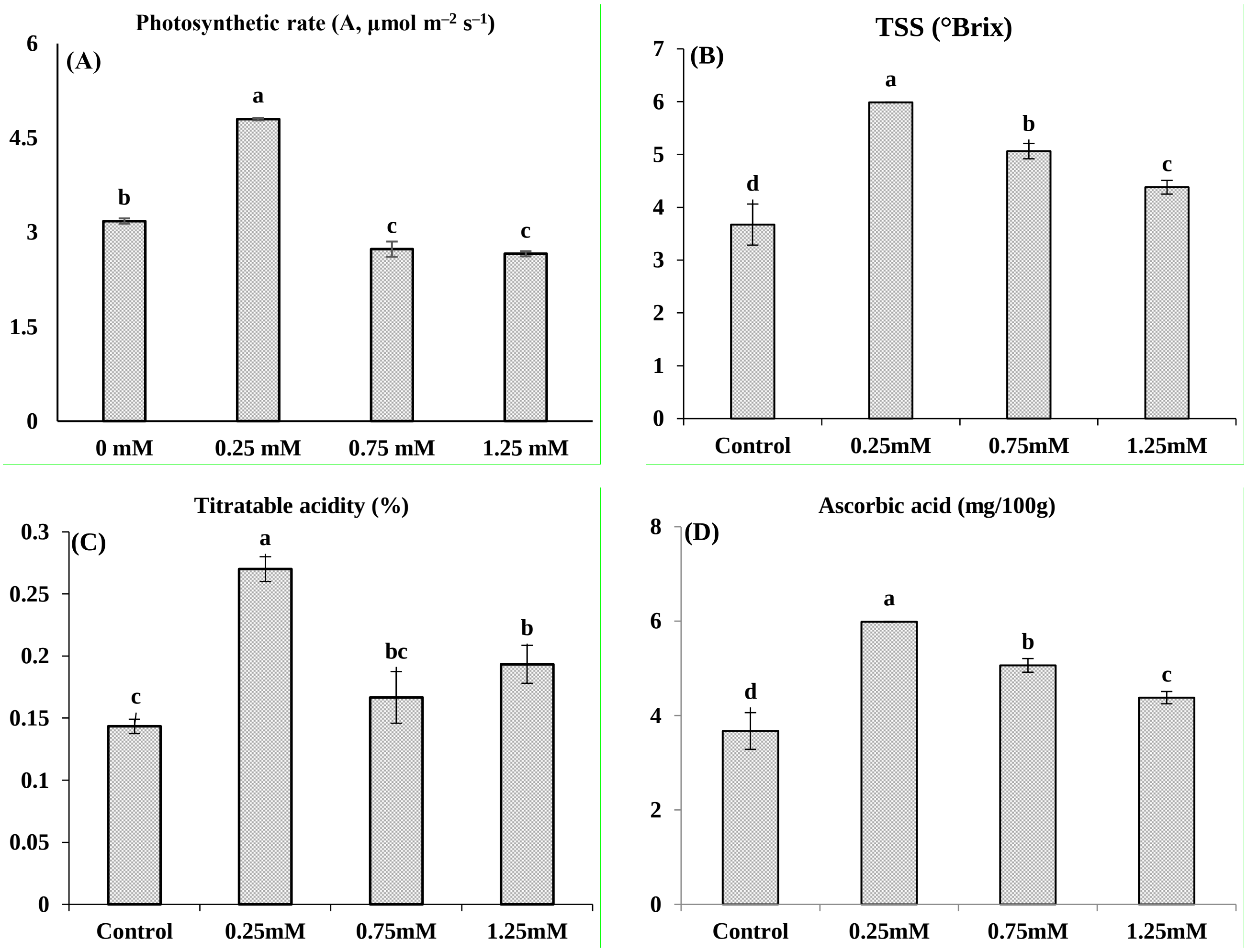

Fig. 6. Effect of salicylic acid on tomato photosynthetic rate (µmol $m^{-2}s^{-1}$) [A], total soluble solids contents (°brix) [B], titratable acidity (%) [C] and ascorbic acid contents (mg/100g) [D] under elevated temperature stress.

During high-temperature stress, plants open their stomata, and different internal activities enhance evapo-transpiration and other metabolic functions (Farooq *et al.*, 2009; Mazorra *et al.*, 2002). Salicylic acid has a significant impact on plant stomatal opening and plays role in guard cell functioning. The application of SA during high-temperature stress regulates stomatal conductance and decreased transpiration. In our study, SA 0.25mM concentration was effective to modulate stomatal conductance and minimize transpiration rate. The reduction in transpiration rate improves the water status of horticultural crops and extends shelf life. A similar finding was reported by Krantev *et al.*, (2008) who found reduction in transpiration rate in wheat plants when SA was applied at high-temperature stress.

Photosynthesis is the elementary process in which plants convert light energy to chemical energy and this physiological system provides energy to plants for their growth and development. During stress conditions, the rate of photosynthesis is highly affected, and it reduces plant efficiency (Ashraf & Harris, 2013). It is revealed that elevated temperature or heat stress declines plant photosynthetic rate, however, the application of SA improves plant photosynthetic activities (Jahan *et al.*, 2019; Kaushal *et al.*, 2016; Song *et al.*, 2014). SA encouraged the production of chloroplast "Rubisco activase", a protein that accelerates photosynthesis, in plants exposed to heat stress (Locharoen & Chulaka, 2021). The application of SA increases the effectiveness of PS II (photosystem II), increases Pn (net photosynthetic rate) in leaves, and increases the electron transfer rate, it improves the photosynthetic efficiency of plants (Jahan *et al.*, 2019). Further, salicylic acid enhances the amount of chlorophyll "a" and "b" in plant leaves as well as the effective conversion of absorbed light to photochemistry, which in turn increases the rate of photosynthesis (Moustakas *et al.*, 2022). Similar results were observed in our study in which SA improved plant photosynthetic rate and vapor pressure deficit compared to untreated plants.

Impact on fruit quality traits: Total soluble solids (TSS) are one of the main maturity attributes for horticulture crops including fruits and vegetables. In our findings, the application of SA improved the TSS concentration of tomato fruits and showed higher contents of TSS in all SA treated plants compared to untreated. The soluble solids play a great role in osmotic regulation due to the presence of sugars and it also contribute to protein and polysaccharide synthesis that ultimately affects the growth of the whole plant (Loutfy *et al.*, 2012). Similar findings were observed by Gharezi *et al.*, (2012) who found an increase in TSS content when SA was applied to plants. Besides TSS, titratable acidity is another parameter that determines fruit quality. Titratable acidity has a positive relation with ascorbic acid contents. In this study, high acidity and ascorbic acid contents were observed in SA treated plants while the least contents of high acidity and ascorbic acid contents were noticed in control that was applied no treatment. Due to its protective effect against abiotic stresses, the application of salicylic acid raises the concentration of ascorbic acid under stress conditions (Karlidag *et al*., 2009). In abiotic stresses, SA stimulates the production of phenylalanine ammoniumylase that is responsible for the synthesis of phenolic compounds which ultimately results in the increased amount of TSS and ascorbic acid production thus enhance the plant defense mechanism (El-Hadi *et al*., 2021). Likewise, Pila *et al*., (2010) observed a delay in ascorbic acid degradation when treated with SA. Similar results were reported by some other researchers (Chavan & Sakhale, 2020; Mandal *et al*., 2016).

Conclusion

The findings of this endeavor manifested that the exogenous application of salicylic acid was helpful in alleviating high temperature stress in tomato crops, especially in hot summers. The results revealed that at elevated temperatures (45 ± 2°C), 0.25 mM concentration of SA improved tomato vegetative characteristics and regulated plant physiological processes. Moreover, the application of SA was valuable in enhancing tomato fruit quality attributes. Therefore, it is recommended to use SA low concentration during high-temperature extremes, and it is further suggested to evaluate SA's impact on other solanaceous vegetables.

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