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EFFECT OF SALICYLIC ACID ON TOMATO PLANT GROWTH AND PRODUCTIVITY UNDER THE CHANGING CLIMATIC CONDITIONS

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Abstract

Tomato is an important vegetable crop all over the world due to its nutritional and medicinal value. Its demand is increasing while its production is adversely affected by the changing climate. There is a need to adopt such strategies to cope with the changing climate and improve fruit production under changing climatic conditions. This study was designed to evaluate the effect of salicylic acid on tomato plants and its production. During this study the salicylic acid's effect was evaluated on tomato plants grown under the Chinese solar greenhouse during the two growing seasons 2021 and 2022. Different concentrations of salicylic acid (0 mM, 0.5 mM, 0.75 mM and 1 mM) were sprayed on tomato plants at an interval of 14 days from transplanting to the first harvest stage. Its effect was studied on both morphological and biochemical properties of tomato plants. The results revealed that the 0.75 mM concentration of SA has a positive effect on both the traits i.e., morphological such as plant height (154.33 cm and 141.33 cm) number of clusters (17 and 15.667) and biochemical characters such as total soluble solids (4.733 ºBrix and 4.8 ºBrix) titratable acidity (0.7827% and 0.8107%) of tomato. 0.75 mM concentration of SA has significant effect on the tomato plant and improved the morphological and biochemical characteristics of plants. Thus, the 0.75 mM concentration of SA is found optimal for improving the quality and quantity of tomato fruits.

Key words: Climate change, Tomato, Chinese solar greenhouse, Morphological traits, Biochemical characteristics, Fruit quality, Heat stress.

Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the family "*Solanaceae*", which is known as the nightshade family and have several other commercially important species like eggplant, pepper and potato. Tomato is the second most cultivated crop in the world, after potatoes (Heuvelink, 2005). The region between the Andes Mountain ranges and western South America's Pacific coast has been identified as the natural geographic location of origin for *Solanum lycopersicum L*. In South Asia, the tomato crop was introduced by Europeans, then people of Indo-Pak slowly became consumers of tomatoes (Bergougnoux, 2014). It is extensively cultivated for its edible fruit. Botanically, it is a fruit (berry) but labeled as a vegetable for its horticultural use. Its fruit is commonly used as raw salads, cooked vegetable, pickles and is an important constituent of various cooked dishes.

The changing climate is adversely affecting the global agriculture production (Moat *et al*., 2019). On average there is an increase of about 1℃ in global average surface temperature of earth, which drives multiple adverse effects on ecology and production of crops (Kohli *et al*., 2018). It affected the pattern of rainfall, especially the fluctuating trend in peak rainfall during the summer season. In some areas farmers have come up climatic shocks such as droughts, pest and disease manifestation, hailstorms and flooding. Especially the arid areas are extremely sensitive and highly vulnerable to climate change. The global agricultural production has been predicted to be decreased by 3 to 16% by 2080 due to climate change (Bhandari *et al*., 2021).

Increasing temperature has also an adverse effect on the productivity of tomato crops. Mainly, high temperature during flowering resulted in pollen sterility, flower abortion or poor color development of fruit (Johkan *et al*., 2011). In tomatoes increasing temperature has reduced the number of fruit set and pollen viability, ultimately affecting the yield of tomato (Ayankojo & Morgan, 2020). The temperature above 35℃ causes dryness of the stigma and pollens which results in poor or no fruit set. The temperature of 40℃ or above damages the ovule and pollen production (Nicola *et al*., 2009).

The environment within tunnel or protected structure is helpful to cope with different biotic and abiotic problems. Those diseases, favored by high humidity may increase in severity due to a small flow of air in tunnel (Kaiser & Ernst, 2012). Full sunlight can increase temperature within tunnel above optimal temperature during day. Increased temperature may cause flower abortion, pollen sterility and ripening disorder (Jett, 2000). On the other hand low temperature (below 10℃) during night may cause chilling stress affecting the photosynthesis rate of plant and in severe conditions plants can die (Hunter *et al*., 2010). If temperature falls below 12℃ (55 °F) during night, it causes blossom drop also known as floral abortion (Gatahi, 2020). However, at low temperature fruit set reduces due to poor pollen quality and the gap between anthesis and ripening may prolong (Ploeg & Heuvelink, 2005).

Salicylic acid is a natural compound synthesized by plant itself and is effective in mitigating the different biotic and abiotic stresses (Ruano *et al*., 2016). It has been verified that salicylic acid regulates numerous cold-induced changes (Ansari & Sharif-Zadeh, 2012; Kaur & Gupta, 2017). Many signaling pathways of plants, including the calcium ion signaling pathway, ABA-dependent or independent pathway, reactive oxygen species (ROS), reactive nitrogen species (RNS) pathway and mitogen-activated protein kinase pathway are activated or triggered by salicylic acid in response to cold-induced effects. By enhancing the production of cold responsive proteins, antioxidants, osmolytes and heat shock proteins within the plant body, these pathways help to mitigate cold-induced alterations (Saleem *et al*., 2021).

It is reported that the exogenous application of SA has developed the local and systemic acquired resistance against various biotic and abiotic stresses. The application of salicylic acid is effective in control of the bio-trophic and hemi-bio-trophic organisms such as viruses, bacteria and fungi. It enhances the plant's tolerance to abiotic stress by accumulating the osmolytes that help in maintaining osmotic homeostasis, regulate the mineral uptake, enhance the scavenging activity by reactive oxygen species (ROS) and secondary metabolites (Klessig *et al*., 2018). It also regulates the plant growth and development under normal and different abiotic stress conditions such as salinity, drought, heat stress and physical injury and plays many roles in plant physiology such as enhancement of seed germination, budding, flowering, fruit setting and ripening of fruit (Le *et al*., 2017). It is also reported that SA is also involved in the gene's expressions such as pathogenic related gene (Koo *et al*., 2020).

Salicylic acid exploits the development and growth of plants by improving physiological roles against stresses (biotic, abiotic) by improving the resistance of plant (Ruano *et al*., 2016). Plant growth under stress is regulated by salicylic acid affecting nutrient uptake, water relations, stomatal regulation and photosynthesis (Zahid *et al*., 2021; War *et al*., 2012). It is involved in many important roles within plant body during adverse conditions and helps in general growth, flower induction, cell respiration, stomatal movements and enzymes biosynthesis (Souri & Tohidloo, 2019). It has a critical role in thermogenesis and disease resistance and protects the plant by mitigating the colonization and spread of pathogens on plant tissues by signaling the defense system of plant and activation of pattern-triggered immunity (PTI), plant's effector-triggered immunity system (ETI) and systematic acquired resistance (SAR), that (Dempsey & Klessig, 2017). Further, it helps increase the "system acquired resistance" of plants.

With the changing climatic conditions such as prevailing hot and humid conditions and irregular rainfall during tomato growing season the production and quality of tomatoes is adversely affected. There is a need to adopt such strategies that can cope with the changing climatic conditions and suppress the environmental stresses to improve the production and quality of tomato fruits.

Material and Methods

The research was carried out at University Research Farm, Koont, PMAS-AAUR. Hybrid tomato cv. "Chittan" seeds were purchased from 'Chaudhry Kher din and sons company (CKD)' and were sown in the glasshouse in plug trays at the end of October and later one month after, when the seedlings reached a height of 4-5 inches, were transplanted at a distance of 18 inches in "Chinese solar greenhouse". The performance of tomato hybrid was evaluated for two years (2021 and 2022) respectively by applying the different engrossment of salicylic acid.

Preparation of salicylic acid solution: For the dissolution of salicylic acid, 1 liter of water was taken in glass jar (1.5 liters) and required amount of salicylic acid (grams) already dissolved in 5 ml of ethanol was added to it. The jar containing water and salicylic acid was constantly shaken until a homogenous solution was prepared.

The required amount of salicylic acid was calculated in grams by following formula and SA concentrations were prepared.

138 × milimoles of salicylic acid in each treatment
(138 g = molar mass of salicylic acid).

In each treatment there were three replications and each replication included four plants.

Treatments of salicylic acid concentrations: Four different concentrations of salicylic acid (0 mM, 0.5 mM, 0.75 mM and 1.0 mM) were used in this experiment to evaluate its effect on the pre-harvest parameters and the post-harvest quality of fruits.

Application of salicylic acid: Salicylic acid solution was applied soon after the transplanting of seedlings in the solar greenhouse and thereafter at an interval of fifteen days till first picking.

The following parameters were studied during this experiment:

Morphological attributes

Plant height (cm): Heights of fully matured plants were considered, by using measuring tape, in centimeters (cm) at fully matured stage.

Floral clusters/plant: Three randomly chosen plants were carefully counted for number of flower clusters in each plant. The average was measured by using the following formula:

$$\text{Floral clusters per plant} = \frac{\text{Total numbers of clusters}}{\text{Number of plants}}$$

Flowers/cluster: Flowers number per cluster of tomato plants was counted manually from three randomly selected plants and the mean was calculated by using following formula:

$$\text{Flowers per cluster} = \frac{\text{Total numbers of flowers}}{\text{Floral clusters per plant}}$$

Total number of flowers: To calculate the flowers number, flowers were counted from three randomly selected plants and average was calculated by using following equation:

$$\text{Number of flowers} = \frac{\text{Total flowers}}{\text{Number of plants}}$$

Number of fruits/plant: To observe the fruit numbers of plant, three random plants were selected and their fruits were counted and their mean value was calculated to measure fruit number per plant.

Fruit set percentage (%): The percent fruit set was computed using the algorithm below:

$$\text{Fruit set \%} = \frac{\text{No. of fruits per plant X 100}}{\text{No. of flowers per plant}}$$

Fruit size (mm): Three fruits of different sizes were selected and their sizes were determined with a digital vernier caliper. The mean value of three fruits was calculated.

Number of diseased fruits: The number of diseased fruits was counted manually from three randomly selected plants and their mean value was calculated.

Biochemical attributes: To evaluate the biochemical parameters of tomato fruits, randomly ten fruits from each treatment, were selected and their juice was extracted by using a juice extraction machine.

Total soluble solids (°Brix): Total soluble solids in fruit were measured by using hand refractometer (RHB-32ATC). A drop of juice was poured onto the lens of refractometer. Total soluble solids were measured in degree Brix (°Brix).

Leaf relative water content (%): To determine the water content, leaves from three randomly selected plants were collected and were weighted to measure the fresh weight (FW). Furthermore, leaves were dipped in distilled water to measure the turgor weight (TW) of leaves. Leaves were periodically weighed until a steady state was achieved. After achieving a steady state of weight, leaves were transferred to pre-heated oven at 80℃ and were left for 48 hours in the oven to estimate the leaves dry weight (DW). To estimate the water content of leaves following equation was used:

$$\text{LRWC \%} = \text{FW- DW/TW-DW} \times 100$$

Titratable acidity of juice (%): The AOAC standard method (2002) was used to measure the titratable acidity of tomato juice. Before taking the fruit juice samples, the tomato juice was well shaken. 10 mL juice was diluted by using distilled water up to the desired concentration (50 ml). Then this solution was titrated with NaOH (0.1 N) till the solution turned into a steady light pink color. It was repeated three times for each sample and the acidity percentage of a solution (as citric acid) was calculated using the formula:

$$\text{TA (\%)} = (\text{N x T x 0.0064}) \text{ x } 100/ \text{ S x D}$$

Results and Discussion

Plant height (cm): The statistically analyzed data showed that the maximum plant height (154.33 cm and 141.33 cm) was achieved in plants that were treated with 0.75 mM of salicylic acid and the lowest plant height was achieved in control plants (116 cm and 113 cm) during the two growing seasons 2021 and 2022 respectively (Table 1). The 0.75 mM concentration of SA has significantly enhanced the vegetative growth of plants as compared to other treatments. The other concentrations of salicylic acid 0.5 mM and 1 mM also showed an increase in the plant height (115 and 117 cm, 103 and 125.50 cm) respectively, as compared to control plants during both growing seasons 2021 and 2022.

The cell division in the apical meristem and leaf growth of plants is enhanced with the salicylic acid application. Our results are in agreement with Khodary, 2004, who described that the salicylic acid has a positive impact on plant growth and improves the plant height in tomatoes. Shakirova *et al.,* (2003) also described that the improvement in vegetative growth of tomato plants due to salicylic acid application is because of hormonal changes within the plant. The increase in vegetative growth is due to the increase in photosynthesis, chlorophyll content and regulation of stomata opening and closing. Similar findings were observed by other researchers who stated that the salicylic acid concentrations >1 mM showed negative impact on plant growth and the concentrations <1 mM have a positive impact on the plant growth and development of plant (Yildirim *et al*., 2008).

Number of clusters per plant: The data related to the number of clusters per plant for two years 2021 and 2022 growing seasons is shown in (Table 2). The results showed that the maximum floral cluster per plant (17 and 15.667) were observed in plants that were treated with 0.75 mM of salicylic acid and the minimum number of clusters per plant (13.367 and 13.50) were observed in the untreated plants during both growing seasons. Similarly, the plants treated with 0.5 mM and 1 mM of salicylic acid also showed an increase in the number of clusters per plant (14.667 and 14.500) and (15.467 and 15.500) respectively.

A significant enhancement in number of clusters was observed in salicylic acid treated plants. The foliar spray of salicylic acid has proved to be beneficial for enhancing the number of clusters and ultimately increasing the total yield of a plant. The findings have a resemblance with Afsana *et al*., (2017), who described that salicylic acid has a role in increasing the number of clusters. The foliar application of salicylic acid may influence the hormones of plants such as auxin and cytokinin, which increased the number of cluster. SA has enhanced the number of clusters by affecting the endogenous growth regulators of plant that are responsible for the production of flowers and the florigenic effect of plant. It is also observed that SA enhances the floral clusters by acting as a chelating agent (Hafeznia *et al*., 2014).

Maddy (2014) stated that the floral clusters increase in tomato plants might be due to the increased level of cytokinin and translocation of photo assimilates due to SA application. Further, SA has enhanced the assimilation of carbohydrates within the plant by increasing the nitrites translocation in plant tissues and enhances the chlorophyll content to increase photosynthesis which ultimately results in an increase number of floral clusters (Ullah *et al*., 2019). SA has an important role in the uptake of ions, vegetative growth of plants and floral initiation (Hayat & Ahmad, 2007).

Number of flowers per cluster: Data related to the number of flowers per cluster attained during the two growing season (2021 and 2022) is depicted in (Table 3). The plants treated with 0.75 mM of salicylic acid showed the highest number of flowers per cluster (7.833 and 7.50) during 2021 and 2022 respectively and the lowest numbers were calculated in control plants (6.25 and 6.33). While the 0.5 mM (6.81 and 6.91) and 1 mM (7.0 and 7.0) of SA also showed an increase in number of flowers as compared to the control plants.

In our findings the number of flowers were increased with increasing salicylic concentration up to 0.75 mM however, decreased at 1 mM of salicylic acid. Similar findings were observed by Yildirim *et al*., (2008) who stated that the salicylic acid concentrations more than or equal to 1 mM harms plant growth and the flowering of plant. Foliar application of SA plays an important role in increasing the number of flowers. The findings of the present research are following the research of Mohamed *et al*., (2018).

Total number of flowers: The data regarding the effect of salicylic acid on total number of flowers per plant is shown in (Table 4). All the plants treated with salicylic acid have significantly increased the total number of flowers. The results from two growing seasons 2021 and 2022 depicted that the plants treated with 0.75 mM of salicylic acid produced the maximum number of flowers (120.88 and 121.65) while, the lowest number of flowers were calculated in untreated plants (85.167 and 93.625).

The results agree with Pacheco *et al*., (2013), who studied the effect of salicylic acid on the flowering of marigolds. They reported that the increase in the number of flowers is due to an increase in the accumulation of gibberellic acid within the plant after foliar application of SA. SA changes the internal level of hormones within the plant body which causes the increased number of flower production. Martínez *et al*., (2004) reported that SA enhances flowering by interacting with the photoperiod or autonomous pathways of a plant.

SA has influenced three different physiological pathways of plants which enhance the flowering of a plant (Martínez *et al*., 2004). The first pathway is CO-independent pathway which is a photo-period dependent pathway and affects the plant physiological activity. The second is photo-period independent pathway, known as FLC-dependent pathway which is also involved in controlling and enhancing the physiological activity within the plant body (War *et al*., 2011). The third pathway is FCA-independent pathway that is mediated through FVE-autonomous pathway. All these pathways affect the flowering of plant and the application of salicylic acid alters these pathways and results in improved flowering of the plants (Klessig *et al*., 2018).

Number of fruits per plant: The data regarding the number of fruits per plant is presented in (Table 5). The data was calculated for consecutive two growing seasons, 2021 and 2022. The results showed that the plants treated with 0.75 mM of SA beard the maximum number of fruits (42.33 and 44.08) and the lowest fruits were calculated in untreated plants (control) (28.33 and 29.83) during 2021 and 2022 respectively. The other concentrations of SA 0.5 mM and 1 mM also increased the number of fruits (33.66 and 32, 30 and 35 respectively) during the 2021 and 2022 growing season as compared to the control plants.

Chakma *et al*., (2021) evaluated the impact of salicylic acid on tomato plants and found that SA increases the fruits per plant. It has also been reported that exogenous application of SA influences the number of flowers per plant and ultimately affects fruiting of plant (Martínez *et al*., 2004). The results are in line with Hafeznia *et al*., (2014) which reported that foliar application of SA improved the plant yield. SA improves the plant yield by increasing flowers, regulating ion uptake by roots, controlling stomatal closure and decreasing senescence of flowers (Zhang *et al*., 2010). The results are also in agreement with Mohamed *et al*., (2018), who studied the effect of SA on strawberry cultivars, have reported a significant increase in fruit number.

Fruit set percentage: The data representing the fruit set percentage of tomato plants grown in Chinese solar greenhouse during 2021 and 2022 growing season (Table 6). The highest fruit set percentage (37.09 and 44.85) was observed in plants that were treated with 0.75 mM of salicylic acid. The other concentrations of SA (0.5 mM and 1 mM) also showed an increase in fruit set (33.41 and 33.19, 31.32 and 36.14) respectively during both years (2021 and 2022). The lowest percentage of fruit set (30.83 and 30.05) was observed in control plants.

The results of the present research agree with the Kumar & Kaur (2019), who reported that salicylic acid has a significant role in increasing the fruit set percentage. Mady (2009) also reported an increase in the fruit set of tomatoes by foliar application of SA as its application has increased the flower bunches flowers per bunch and increased the fruit set percentage of a plant.

Fruit size: The results showed maximum fruit size (54.58 and 54.20) was achieved in plants that were treated with 0.75 mM of SA during 2021 and 2022 respectively (Table 7), while the minimum fruit size (32.97 and 33.08) was observed in untreated plants during these years.

Mohammad *et al*., (2020) studied the effect of foliar application of SA on tomato plants and reported an increase in the fruit size. Foliar application of SA increases the ion uptake by roots, regulates stomatal closure and enhances the chlorophyll content in the leaves of plants resulting in a high photosynthetic rate and ultimately increasing the fruit size (Naeem *et al*., 2020). The results of the present research are also in agreement with Preciado-Rangel *et al*., (2019), who studied the effect of SA on the cucumber plant. They reported that SA has increased the fruit size by enhancing the cell division while higher doses of SA, more than 1 mM, have adverse effects on fruit size of a plant.

Number of diseased fruit: The maximum number of diseased fruits (4.00 and 3.83) were observed in the untreated plants (Table 8) while the plants that were treated with 0.75 mM of SA showed resistance to diseases and minimum number of diseased fruits (0.66 and 2.16) were observed in these plants. The plants treated with 0.5 mM and 1 mM concentrations of SA have also reduced the disease incidence (2.33 and 3.50, 3.00 and 3.80) respectively, as compared to untreated plants.

Table 1. Impact of salicylic acid on plant height (cm).

Salicylic acid treatments	2021	2022
0 mM	116.00 ± 7.21 b	113.17 ± 7.58 c
0.5mM	115.00 ± 2.33 b	117.50 ± 2.78 c
0.75mM	154.33 ± 1.06 a	141.33 ± 1.04 a
1mM	103.67 ± 2.72 a	125.50 ± 2.00 b
Mean	122.25 ± 22.10 A	124.37 ± 12.40 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 2. Impact of salicylic acid on number of clusters.

Salicylic acid treatments	2021	2022
0 mM	13.36 ± 1.32 c	13.50 ± 0.66 c
0.5mM	14.66 ± 1.75 b	14.50 ± 0.66 b
0.75mM	17.00 ± 1.12 a	15.66 ± 0.62 a
1mM	15.46 ± 0.90 b	15.50 ± 0.52 a
Mean	15.124 ± 1.60 A	14.791 ± 0.78 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 3. Impact of salicylic acid on of flowers per clusters.

Salicylic acid treatments	2021	2022
0 mM	6.25 ± 1.25 c	6.33 ± 0.38 c
0.5mM	6.81 ± 0.16 bc	6.91 ± 0.28 b
0.75mM	7.83 ± 0.86 a	7.50 ± 0.25 a
1mM	7.00 ± 0.90 b	7.00 ± 0.25 b
Mean	6.97 ± 0.48 A	6.93 ± 0.47 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 4. Impact of salicylic acid on total number of flowers.

Salicylic acid treatments	2021	2022
0 mM	85.16 ± 14.46 c	93.62 ± 12.95 c
0.5mM	96.26 ± 13.23 b	98.93 ± 6.83 bc
0.75mM	120.88 ± 23.23 a	121.65 ± 25.18 a
1mM	100.08 ± 6.18 b	100.48 ± 15.75 b
Mean	100.59 ± 12.79 A	103.67 ± 7.31 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 5. Impact of salicylic acid on number of fruits per plant.

Salicylic acid treatments	2021	2022
0 mM	28.33 ± 1.52 c	29.83 ± 0.87 c
0.5mM	33.66 ± 1.52 b	32.00 ± 2.46 bc
0.75mM	42.33 ± 2.51 a	44.08 ± 2.32 a
1mM	30.00 ± 2.00 c	35.00 ± 2.08 b
Mean	33.58 ± 6.24 A	35.22 ± 7.11 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 6. Impact of salicylic acid on fruit set percentage (%).

Salicylic acid treatments	2021	2022
0 mM	30.83 ± 3.67 c	30.05 ± 3.62 c
0.5mM	33.40 ± 3.66 b	33.19 ± 0.69 bc
0.75mM	37.09 ± 6.38 a	44.85 ± 9.47 a
1mM	31.32 ± 0.51 c	36.14 ± 4.83 b
Mean	33.16 ± 2.77 A	36.06 ± 5.00 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 7. Impact of salicylic acid on fruit size (mm).

Salicylic acid treatments	2021	2022
0 mM	32.97 ± 2.51 c	33.08 ± 1.42 c
0.5mM	46.27 ± 0.97 b	46.73 ± 1.77 b
0.75mM	54.58 ± 2.10 a	54.20 ± 3.70 a
1mM	47.98 ± 2.14 b	48.76 ± 2.68 b
Mean	45.45 ± 9.06 A	45.69 ± 8.97 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 8. Impact of salicylic acid on number of diseased fruits.

Salicylic acid treatments	2021	2022
0 mM	4.000 ± 1.0 a	3.83 ± 1.25 a
0.5mM	2.33 ± 0.57 b	3.50 ± 0.50 ab
0.75mM	0.66 ± 0.57 c	2.16 ± 0.57 b
1mM	3.00 ± 1.00 ab	3.83 ± 0.57 a
Mean	2.5 ± 1.40 B	3.33 ± 0.79 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 9. Impact of salicylic acid on TSS of fruit (°Brix).

Salicylic acid treatments	2021	2022
0 mM	3.86 ± 0.15 c	0.0 ± 0.10 c
0.5mM	4.20 ± 0.26 b	4.16 ± 0.15 bc
0.75mM	4.73 ± 0.25 a	4.80 ± 0.20 a
1mM	4.30 ± 0.15 b	4.36 ± 0.15 b
Mean	4.27 ± 0.32 A	4.33 ± 0.34 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 10. Impact of salicylic acid leaf relative water content (%).

Salicylic acid treatments	2021	2022
0 mM	75.55 ± 1.18 c	76.91 ± 1.48 b
0.5mM	84.52 ± 1.99 ab	85.12 ± 1.00 a
0.75mM	86.40 ± 1.80 a	85.70 ± 3.52 a
1mM	80.63± 1.50 b	79.07 ± 3.04 b
Mean	81.27 ± 5.31 A	81.70 ± 4.37 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

Table 11. Impact of salicylic acid on titrateable acidity (%).

Salicylic acid treatments	2021	2022
0 mM	0.34 ± 0.03 d	0.39 ± 0.01 d
0.5mM	0.56 ± 0.01 c	0.60 ± 0.006 c
0.75mM	0.78 ± 0.01 a	0.81 ± 0.01 a
1mM	0.65 ± 0.02b	0.69 ± 0.005 b
Mean	0.58 ± 0.18 A	0.62 ± 0.17 A

*Means with same letters do not differ significantly at p 0.05 by LSD test; ± values indicate the standard deviation

The results of present research are in agreement with Tian *et al*., (2007), who studied the effect of SA on sweet cherry fruits and reported that SA is involved in controlling fungal diseases by inhibiting mycelium growth on fruit surface. SA controlled the disease incidence by activating systemic acquired resistance and by enhancing the level of ROS within the plant body. SA is involved in the signaling of pathways and has been reported to play an important role in the enhancement of the diseases resistance in plants (Park *et al*., 2007). SA activates the systemic acquired resistance (SAR) of plants and it functions by triggering the distal uninfected parts of the plant and protecting the undamaged tissues of the plant against diseases (Asghari & Aghdam, 2010).

Postharvest parameters

Physiological and biochemical parameters

Total soluble solids (ºBrix): The data depicting the effect of salicylic acid during two growing seasons on TSS of tomato fruit (Table 9). It is noticed that salicylic acid has significantly affected the total soluble solids of tomato fruit and maximum value of TSS (4.73 and 4.80) was attained in fruits that were treated with 0.75 mM of salicylic acid. While the minimum value of TSS (3.86 and 4.00) was observed in fruits that were left untreated. 0.5 mM and 1 mM concentrations of salicylic acid have also significantly enhanced the TSS value (4.20 and 4.16, 4.30 and 4.36) respectively, of tomato as compared to the control plants.

The present research's findings agree with that of Naeem *et al*., (2020), who reported that exogenous application of SA has significantly improved the TSS content of fruit. The increase in TSS was due to elevation in photosynthetic activity and accumulation of more carbohydrates. Karlidag *et al*., (2009) evaluated the effect of foliar application of SA on strawberry plants and reported that it has a significant role in increasing the TSS value of fruit. Yıldırım & Dursun (2008) also reported an increase in TSS value of tomato fruits when treated with SA. Kazemi (2013) also evaluated the effect of foliar spray of SA on strawberry plants and reported that SA causes a significant increase in the TSS content of a strawberry fruit.

Leaf relative water content (%): The data showing the effect of foliar application of SA on leaf relative water content of tomato plants during the two growing seasons (Table 10). The maximum percent of water (86.40 and 85.70) was attained in the leaves of plants that were treated with the 0.75 mM of SA. While the lowest percent of water (75.55 and 76.91) was retained by the leaves of plants that were left untreated and were considered as control plants.

Bidabadi *et al*., (2012) studied the effect of salicylic acid on the morphology and physiology of banana plants and found that SA has significantly improved the RWC.

Titratable acidity of juice (%): The data of titratable acidity of tomato juice that has been collected during the two growing seasons (2021 and 2022) is revealed in (Table 11). The maximum value of TA (0.78 and 0.81) was attained in fruits that were treated with 0.75 mM of SA. While the minimum concentrations of TA (0.34 and 0.39) were observed in fruits that were left untreated. The TA value increases with increasing concentrations of salicylic acid.

The results are in accordance with that of Mohamed *et al*., (2018), who studied the effect of SA on strawberry fruit and observed an increase in the TA of fruit juice with increasing SA concentrations. Davarynejad *et al*., (2015) studied the effect of salicylic acid on plum and observed that salicylic acid has a role in increasing the TA of fruit juice. They stated that TA value increases with increasing SA concentrations.

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