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Research Article

EFFECT OF SALICYLIC ACID APPLICATION ON GROWTH, PRODUCTION, FUNGAL DECAY, AND OVERALL QUALITY OF STRAWBERRY

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ABSTRACT

Salicylic acid (SA), a plant growth regulator, induces various physiological and metabolic processes that affect plant growth and development. A study conducted at PMAS-Arid Agriculture University in 2017-2018 and 2018-2019 examined the preharvest application of SA on the growth and fruit quality of strawberry (cv. Chandler). A 4 mM concentration of SA was found to be the most effective, improving plant height (14.60 cm), average number of leaves per plant (5.27), leaf area (68.40 cm^2), and average fruit weight (13.53 g). In terms of postharvest parameters, SA-treated strawberries showed higher total soluble solids (5.10 °Brix), ascorbic acid content (12.41 mg/100 ml of juice), and total sugar content (6.54%). A similar trend was observed in the activity of antioxidant enzymes (SOD, POD, and CAT) as well as physiological parameters such as photosynthetic rate, transpiration rate, and stomatal conductance. The SA treatments helped maintain the overall quality of the strawberries and also reduced damage caused by fungal decay. The data revealed that the minimum mean fungal decay (4.28%) was recorded after 4 days of storage, while the maximum percentage of fungal decay (20.38%) was observed after 12 days of storage. Therefore, foliar application of SA at 4 mM is recommended as the most effective treatment for enhancing strawberry growth and fruit quality. The study explains how SA can be used to preserve the quality of strawberries before harvest. An additional goal of this research is to provide growers with detailed information about the influence of SA on strawberry crop growth and production.

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INTRODUCTION

Strawberries belong to the Rosaceae family. China is the leading producer of strawberries, with a total production of 3,801,865 metric tons, accounting for 41% of the total global production. In Pakistan, the total area cultivated with strawberries is 387 ha, yielding a total of 795 tons (Anonymous, 2019). Strawberries are rich in essential minerals, vitamins, and a component called ellagic acid, which has anti-cancer properties (Morgan, 2005). They are also rich in ascorbic acid, secondary metabolites, acids, and sugars (Perez et al., 1996; Wang et al., 2002).

The strawberry variety known as “Chandler” is derived from two parent species: *Fragaria chiloensis* and *F. virginiana*. In Pakistan, it is primarily grown in distinct areas of Punjab, the Islamabad region, and some parts of Khyber Pakhtunkhwa. Recently, strawberries have started to gain recognition among growers in Pakistan on a commercial scale. As a short-duration crop, strawberries have an urgent need for readily available nutrients to support their growth and development. They are prone to micronutrient deficiencies, especially in alkaline soils. Due to their soft texture and high rate of softening, strawberries are highly perishable and susceptible to fungal attacks. However, as non-climacteric fruits, they do not ripen after harvest; therefore, they must be handpicked to ensure better eating quality (Shin et al., 2008).

The perishable nature of fruit makes it highly susceptible to fungal infections. Moreover, the high metabolic rate of fruit leads to quality deterioration post-harvest (Olias et al., 2000; Mohamed et al., 2018). Lolaei et al. (2012) observed that salicylic acid plays a key role in delaying ripening and improving both fruit yield and quality in strawberries. Strawberries are attacked by various phytopathogenic fungi, viruses, and bacteria. It has been noted that in response to pathogen attacks, a defense mechanism called systemic acquired resistance is activated, helping to control the disease (Aman et al., 2013). Salicylic acid is linked to key plant defense components via a network that is typically activated after infection by biotrophic pathogens, which depend on living host tissues. It acts through the non-expressor of pathogenesis-related protein (NPR1), a crucial component in plant defense signaling. The comprehensive mechanism of salicylic acid-mediated defense regulation through NPR1-mediated signaling and its cytoplasmic regulation is well documented (Dong, 2004; Mukhtar et al., 2009; Withers and Dong, 2016). Researchers have found that salicylic acid enhances the plant's systemic acquired resistance. Moreover, the level of internal salicylic acid in plants may be influenced by the exogenous application of salicylic acid (Van Loon et al., 2006). It has also been observed that external application of salicylic acid increases the internal salicylic acid content.

Gray mold, caused by the pathogen *Botrytis cinerea*, is a highly destructive disease of strawberries worldwide, responsible for approximately 25% of yield losses. The fungus affects various stages of the plant, including flowering, fruit setting, mature leaves, and mature fruit (Sutton, 1990; Sutton and Peng, 1993; Mohamed et al., 2018). As a result, gray mold is a major contributor to postharvest losses during storage and transportation (El-Sghaier et al., 2009). Babalar et al. (2007) found that salicylic acid application effectively reduces ethylene production in fruit, prevents fungal decay, and preserves overall fruit quality. Therefore, this study aims to assess the effects of foliar application of salicylic acid on growth, yield, quality, and control of gray mold disease in the strawberry cultivar "Chandler".

MATERIAL AND METHODS

The studies were conducted at the field site of the Horticulture Department, PMAS-Arid Agriculture University Rawalpindi, Pakistan, during the fall seasons of 2017-18 and 2018-19 to examine the effect of salicylic acid (SA) on the morphological and physiological characteristics of strawberry. The soil analysis was conducted prior to experimentation (Table 1).

Table 1. Physical and chemical of the soil used for the experiments.

Parameters analysis	Results
Soil texture	Loamy
Saturation	50%
pH	7.2
Organic matter	0.75%
Available P	3.5mg kg^{-1}
Available K	120 mg kg^{-1}

The vegetative traits evaluated included plant height (cm), number of leaves per plant, and leaf area (cm^2), while the reproductive traits assessed were fruit size, fruit weight, and fruit number. Estimating fruit quality parameters is crucial for determining the final quality of a commodity. Therefore, parameters such as total soluble solids (TSS), total sugars (TS), and ascorbic acid content (AAC) were measured in the post-harvest laboratory. Different treatments of Salicylic acid (Control, 2 mM, 4 mM & 6 mM) were applied at Preharvest stage. Pre-harvest application of SA was carried out at the flowering and fruit-setting stages, 30, 20, and 10 days prior to fruit harvest. For storage analysis, fruits were harvested and brought to the laboratory for further examination. The fruits were stored at 4°C for 16 days, with samples evaluated for physicochemical characteristics at 4-day intervals. The experiment was laid out in a completely randomized design with three treatments and three replications (five plants per replication), totaling 15 plants per treatment. Evaluations were conducted, and the results were compiled for treatment comparison. Uniform cultural practices were followed to ensure optimal growth and development of the plants. Data were analyzed using Statistical Software 10, and means were compared using the Least Significant Difference (LSD) test at a 5% probability level (Steel et al., 1997).

RESULTS AND DISCUSSION

Vegetative and yield parameters

Data on vegetative growth parameters, such as stem length (14.80 cm), number of leaves per plant (5.37), average leaf area (14.79 cm^2), and fruit weight (14.43 g), demonstrated a statistically significant improvement with salicylic acid compared to the control treatment. The most notable difference was observed in treatment T3 (4 mM salicylic acid) (Figures 1, 2, 3, 4). A 2 mM concentration also showed better results, while the 6 mM concentration did not further improve vegetative and yield parameters. The lowest values were recorded in the control treatment.

After years of experimentation, researchers concluded that salicylic acid has a positive effect on plant height and shoot length in various plant species, as also observed by Niakan et al. (2010) and Bano and Qureshi (2017). Furthermore, salicylic acid application has been shown to increase the number of leaves in carrot and strawberry. Niakan et al. (2010) also observed a positive response of salicylic acid on stem height. Raskin (1992) concluded that salicylic acid triggers vegetative growth parameters, positively influencing plant development. The beneficial effect of salicylic acid can be attributed to its regulation of vital processes, leading to improved plant growth (Raskin, 1992; Mohamed et al., 2018).

Salicylic acid has an anti-senescence effect on plants, thus its treatment extends the growth of vegetative parts, resulting in an increase in leaf area (Jamali et al., 2011). Regarding fruit weight, the best results were obtained with 4 mM SA, followed by 2 mM, while the lowest weight was observed in the control. The maximum fruit weight (14.43 g) was recorded with T3 (4 mM SA), followed by T2 and T4 (2 mM and 4 mM SA, respectively), with the minimum weight observed in the control group. This trend was consistent across both study seasons. Previous studies have reported an 11% increase in chlorophyll content with SA application compared to the control, indicating improved fruit yield (Raskin, 1992; Jamali et al., 2011). The increase in yield can be attributed to protein synthesis, cell division, and differentiation induced by SA application (El-Tayeb, 2005; Askari and Ehsanzadeh, 2015; Sarinana-Aldaco et al., 2020).

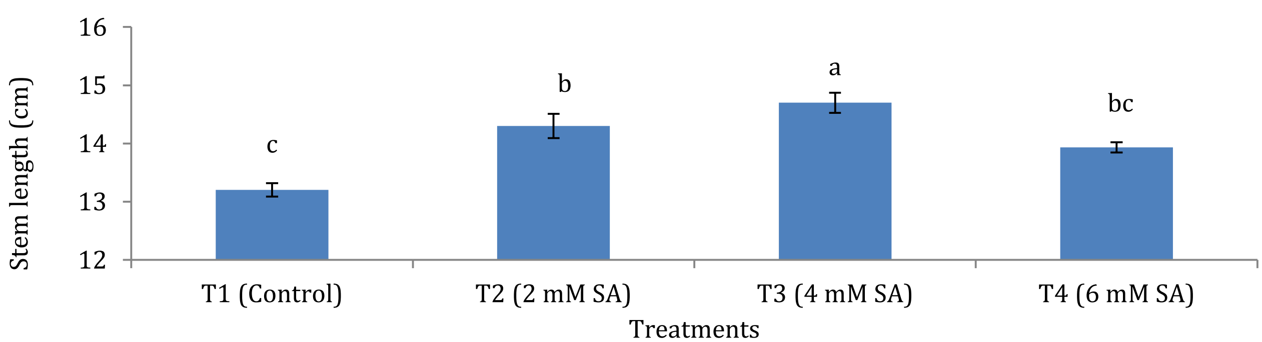


Figure 1. Effect of salicylic acid on stem length (cm) of strawberry.

Salicylic acid has been reported to enhance the concentrations of copper and zinc in the shoots, which also affect the dry weight of the leaves. The application of salicylic acid accelerates vegetative growth, a finding supported by previous research that demonstrated an increase in the dry weight of cucumber leaves when salicylic acid was applied exogenously (Khayyat et al., 2009).

Fruit quality parameters

The data on fruit quality parameters revealed significant differences between salicylic acid-treated plants and control plants. The 4 mM SA concentration yielded the best results for total soluble solids (6.46), total sugars (6.61%), reducing sugars (4.64%), non-reducing sugars (1.90%), and ascorbic acid (12.59 mg/100 ml juice) (Figures 5, 6, 7, 8, 9). The 2 mM SA concentration also showed favorable results; however, increasing the salicylic acid concentration to 6 mM did not result in a significant improvement in postharvest parameters. The minimum values were observed in the control group.

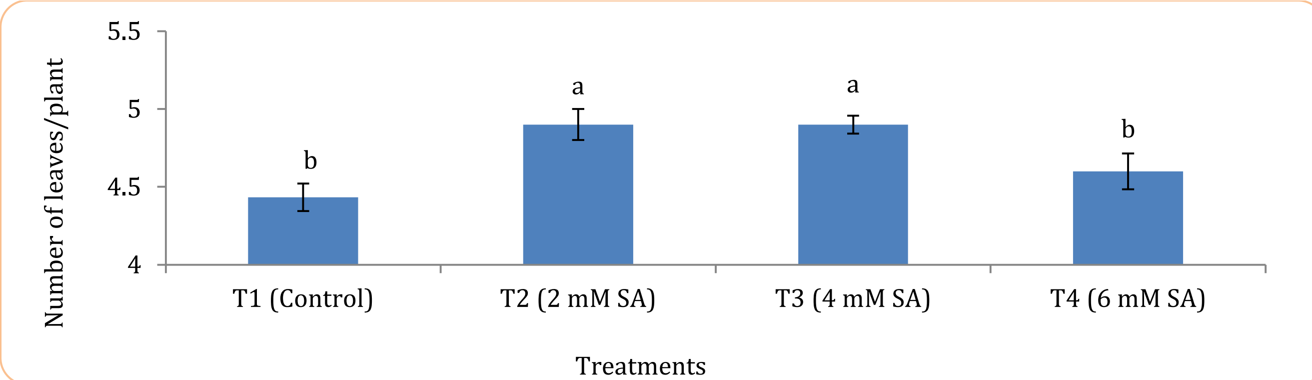


Figure 2. Effect of SA (mM) on leave number per plant of strawberry.

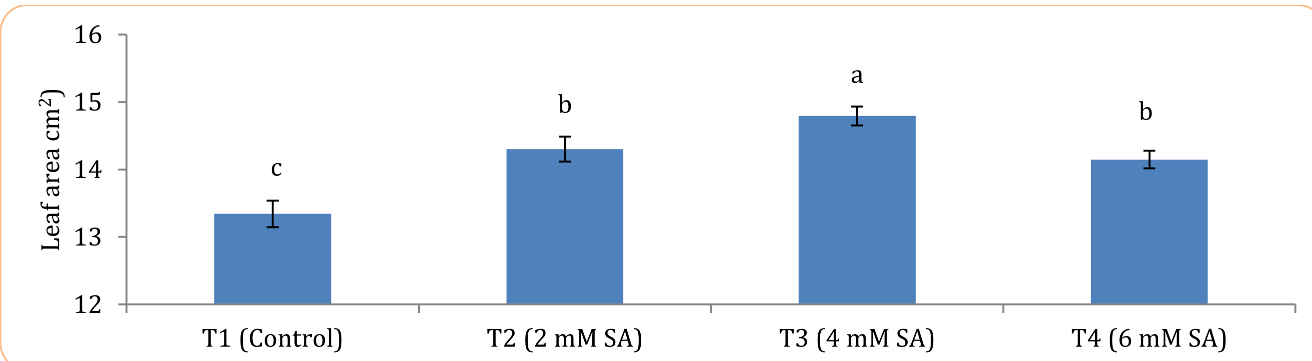


Figure 3. Effect of SA levels (mM) on leaf area (cm^2) of strawberry.

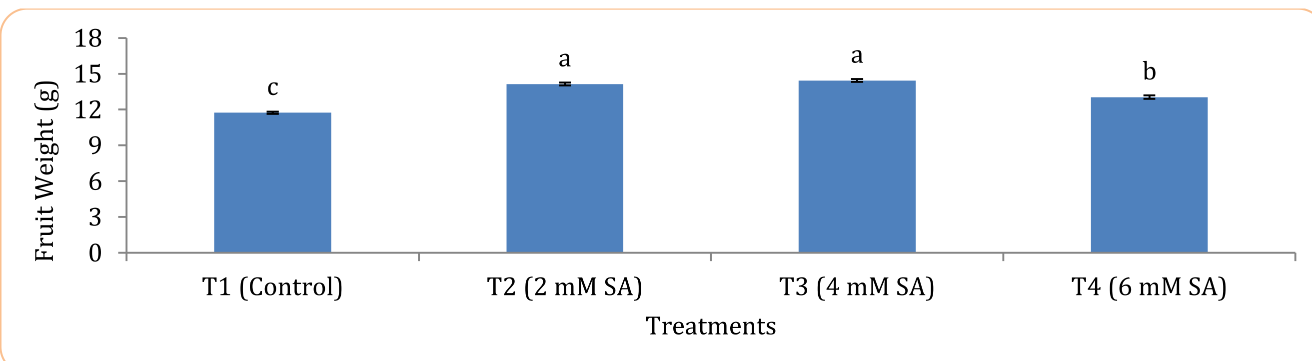


Figure 4. Effect of SA levels on fruit weight (g) of strawberry.

Mohamed et al. (2018) reported an increase in total soluble solids content in strawberries, as well as an overall improvement in fruit quality. Sayyari et al. (2009) found that SA affects TSS content in pomegranate. Similarly, Bano and Qureshi (2017) noted that SA enhances TSS levels in strawberry fruits. The current study also found that plants treated with 4 mM SA (T2) had the highest ascorbic acid content, followed by those treated with 2 mM SA (T1). Mohamed et al. (2018) also observed that increasing salicylic acid levels boosts ascorbic acid content in strawberries. Strawberries are a rich source of ascorbic acid, containing higher levels of Vitamin C compared to oranges (Ayub et al., 2010). Kazemi et al. (2011, 2013) noted that fruits treated with salicylic acid exhibited the highest vitamin C content.

The results of the present study demonstrated an increase in total sugar content in treated samples compared to the control group (Figures 7, 8, and 9). Among the treatments, the highest total sugar content was observed with T3 (4 mM SA), followed by T2 (2 mM SA).

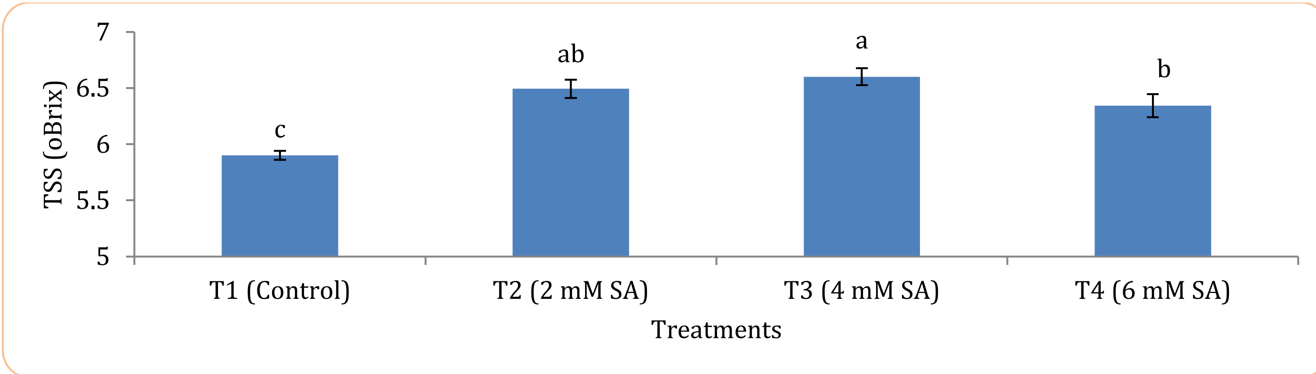


Figure 5. Effect of SA on TSS (°Brix) contents of strawberry.

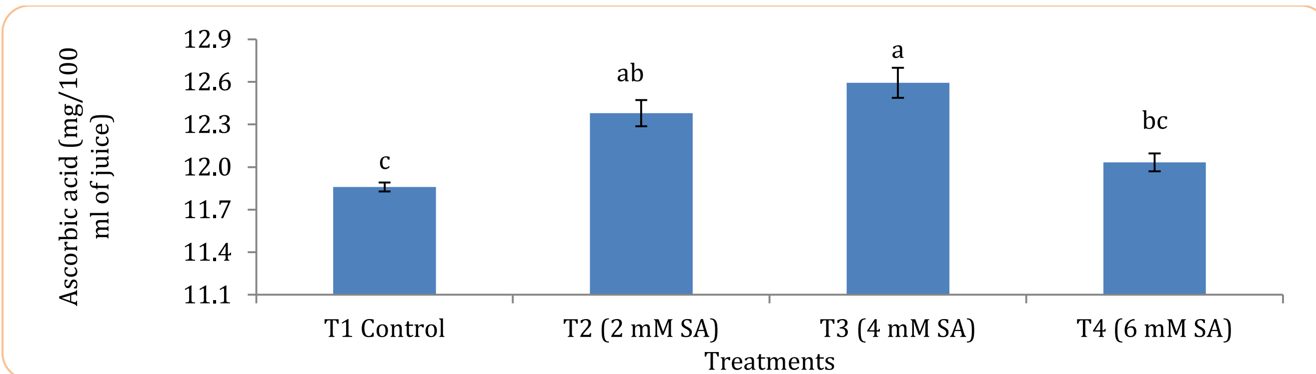


Figure 6: Effect of SA levels (mM) on ascorbic acid contents of strawberry.

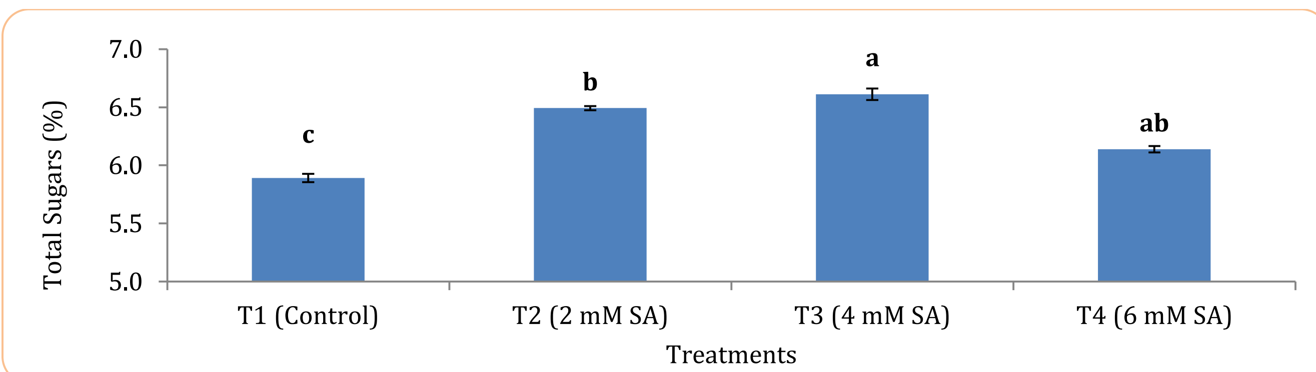


Figure 7. Effect of SA levels (mM) on total sugar (%) of strawberry.

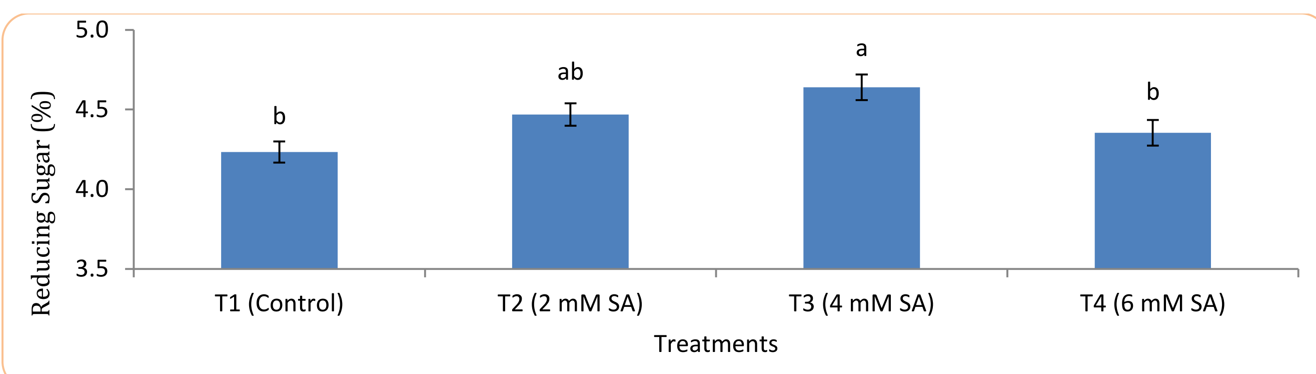


Figure 8. Influence of SA levels (mM) on reducing sugar (%) of strawberry.

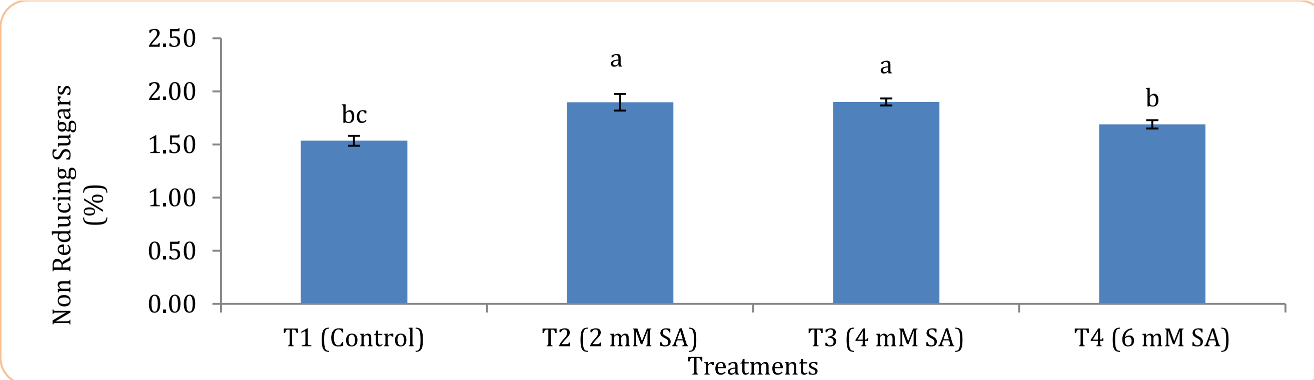


Figure 9: Effect of SA levels (mM) on non-reducing sugar (%) of strawberry.

The trend is consistent across both study seasons. Wozniak et al. (1996) suggested that the sugar and acid content are key taste characteristics of strawberries that significantly attract consumers. The composition of fresh strawberries is primarily made up of sucrose, fructose, and glucose, which together account for approximately 99% of the total sugar content.

Antioxidant enzymes

Statistical analysis revealed that the application of SA at a 4 mM concentration significantly enhanced the activities of antioxidant enzymes, including POD, SOD, and CAT, compared to the control treatment (Figure 10).

The treated plants exhibited enhanced antioxidant activity compared to the control, which can be attributed to the improved growth resulting from their ability to scavenge free radicals. SA acts as an electron donor for catalase (CAT) and peroxidase (POD), thereby influencing the oxidative potential of these enzymes and protecting cells from oxidative stress. Furthermore, SA plays a role in enhancing the activity of auxins and cytokinins in fruit development (Shakirova et al., 2003).

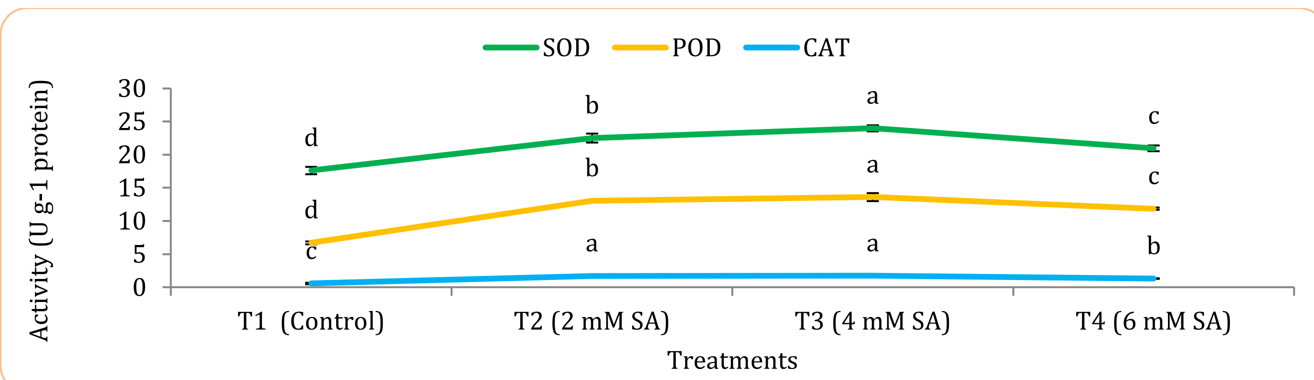


Figure 10. Influence of various SA levels on antioxidants (SOD, POD and CAT) enzymes.

Physiological parameters

In terms of physiological parameters, including stomatal conductance (gs), photosynthetic rate (A), and transpiration rate (E), salicylic acid treatment demonstrated significant improvements compared to the control. Among the treatments, SA at 4 mM yielded the most favorable results, with stomatal conductance at 42.33, transpiration rate at 1.85, and photosynthetic rate at 3.83 (Figure 11). The other two treatments, 2 mM SA and 6 mM SA, also showed notable improvements over the control, contributing to enhanced physiological performance in strawberries.

Singh and Usha (2003) reported that SA functions as a growth regulator, influencing various physiological processes in plants. SA promotes flowering in a wide range of plant species, regulates ion uptake by roots, and modulates stomatal conductance. Significant effects were observed in all physiological characteristics concerning SA concentration. Among different treatments, foliar application of SA at a concentration of 4 mM yielded the best results, enhancing the rate of photosynthesis, stomatal conductance, and transpiration rate (Figure 11). However, increasing SA concentration beyond this level did not result in further improvements in physiological parameters.

The antioxidant properties of SA protect the photosynthetic machinery from the harmful effects of reactive oxygen species (ROS) (Vazirimehr and Rigi, 2014). SA plays a vital role in regulating physiological activities throughout the plant's life cycle. Furthermore, the application of SA has been shown to enhance chlorophyll content in rose plants. According to Zamani et al. (2011), SA improves the water-retention capacity of leaves by stimulating sap production in the leaf lamella, resulting in higher water content levels.

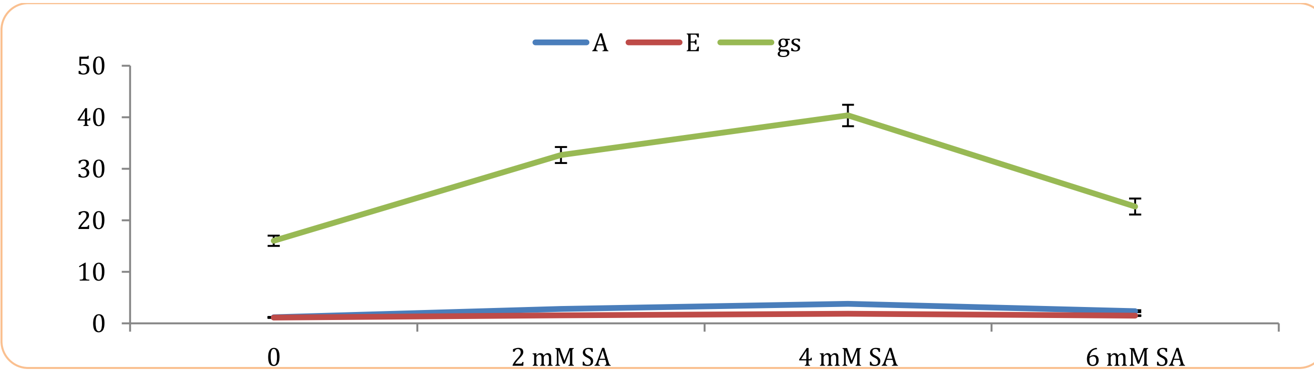


Figure 11. Influence of SA levels on physiological parameters of strawberry.

Fungal decay

The results revealed that fruits treated with T2 (SA 2 mM) and T3 (SA 4 mM) exhibited no fungal decay. In contrast, the control fruits recorded the highest level of fungal decay at 11.73% (Table 2). This can be attributed to the ability of SA to induce systemic acquired resistance, likely through enhanced production of hydrogen peroxide (H_2O_2), as reported by Cai and Zheng (1999) and Kumar and Kaur (2019).

The data also showed that the minimum mean fungal decay (4.28%) was observed after 4 days of storage, whereas the maximum fungal decay (20.38%) occurred after 12 days of storage. These findings align with the studies conducted by Babalar et al. (2007) and Kumar and Kaur (2019) on strawberry fruits.

Table 2: Effect of application of salicylic acid on fungal decay (%) of strawberry cv. Chandler.

Treatments	Storage intervals					
	0 days	4 days	8 days	12 days`	16 days	Mean
T_1 (Control)	0	10.65	17.5	30.52	-	11.73
SA (2mM)	0	0	5.90	14.45	-	4.07
SA (4mM)	0	0	5.10	12.56	-	3.532
SA (6 mM)	0	6.50	8.0	24.0	-	7.7
Mean	0	4.28	9.125	20.38	-	

CD (p = 0.05) Treatments - 0.62 Days - 0.40 Interaction - 1.24.

Spoilage percentage

The results revealed that the lowest mean spoilage (17.85%) was observed in fruits treated with SA 4 mM, which was significantly lower compared to other treatments. In contrast, the highest mean spoilage (49.36%) was recorded in the control group (T_1), as shown in Table 3. Salicylic acid significantly reduced spoilage by enhancing antioxidant enzyme activity (Abbasi et al., 2010). These findings align with the results of Samra et al. (2015) and Shafiee et al. (2010) in strawberry fruits. Moreover, the data indicate that the minimum mean spoilage percentage (14.67%) occurred after 4 days of storage, while the maximum mean spoilage percentage (100%) was observed after 16 days of storage.

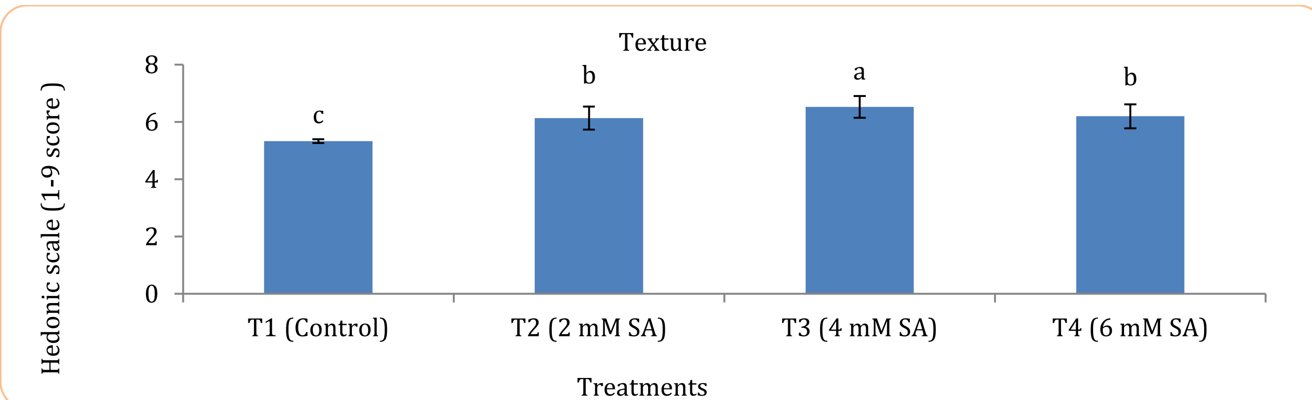
Organoleptic parameters

Regarding the organoleptic parameters, namely texture, overall acceptability, flavor, and appearance, as evaluated by experienced judges, strawberries treated with SA at the pre-harvest stage received significantly higher scores compared to untreated samples (Figures 12, 13, 14, and 15). The control treatment exhibited lower scores across all parameters. On average, strawberries treated with SA achieved 16% higher scores for texture compared to the control group. A similar trend was observed for all other parameters. Specifically, the highest flavor score was recorded with 4 mM SA, followed by 2 mM SA. Likewise, the overall acceptability and appearance also showed statistically significant improvements with 4 mM SA treatment.

Table 3: Effect of application of salicylic acid on Spoilage (%) of strawberry cv. Chandler

Treatments	Storage intervals					
	0 days	4 days	8 days	12 days`	16 days	Mean
T_1 (Control)	0	17.85	40.05	88.90	100	49.36
SA (2mM)	0	12.25	16.60	47.50	100	35.27
SA (4mM)	0	12.10	13.65	40.52	100	33.25
SA (6 mM)	0	16.50	27.30	60.86	100	40.93
Mean	0	14.67	24.4	59.44	100	

CD (p = 0.05) Treatments - 0.65 Days - 0.41 Interaction - 1.31.



12. Influence of SA levels on texture of strawberry.

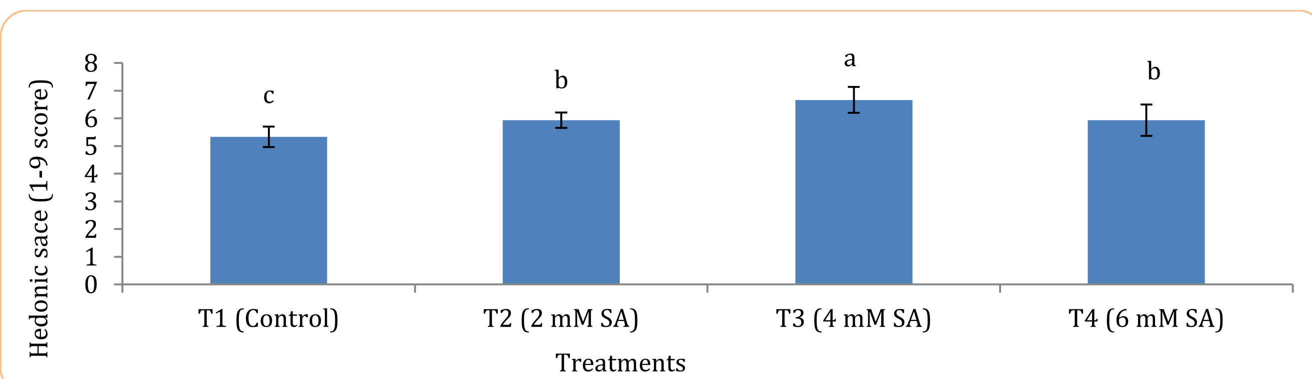


Figure 13. Influence of SA levels on flavor of strawberry.

According to Barrett et al. (2010), judgment can be made by individuals or through the use of instruments; however, sensory evaluation remains one of the most reliable methods for assessing the quality attributes of harvested fruits. Salicylic acid, known for its role in delaying ripening and reducing postharvest losses, has emerged as a promising option for enhancing fruit quality (Asghari and Aghdam, 2010). Similarly, Wu et al. (2011) reported improvements in the texture and appearance scores of fresh strawberries treated with salicylic acid.

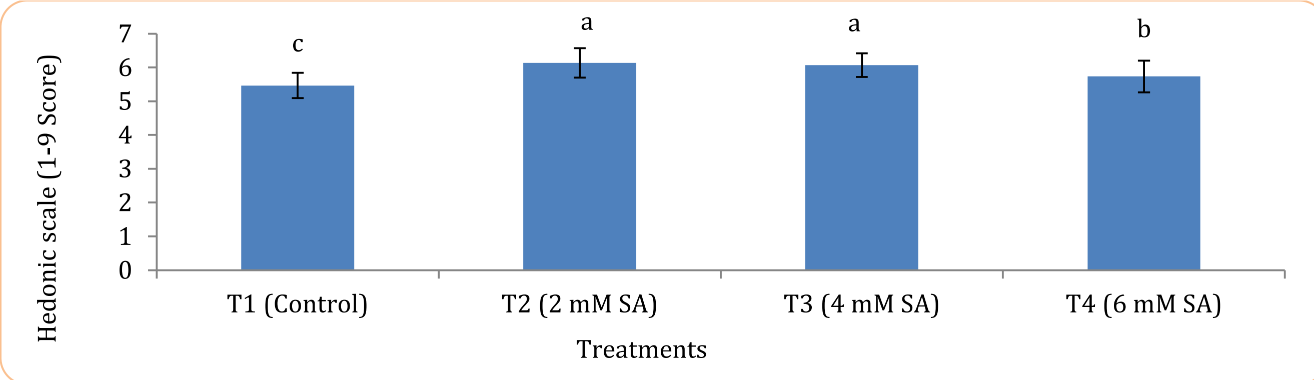


Figure 14. Influence of SA levels on overall acceptability of strawberry.

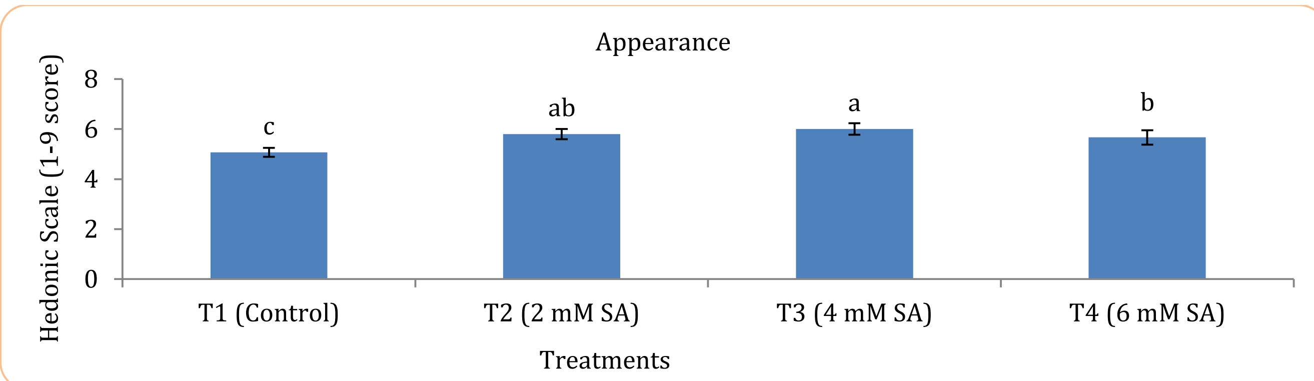


Figure 15. Influence of SA levels on appearance of strawberry.

CONCLUSIONS

The study provides a comprehensive analysis of various pre- and post-harvest parameters of strawberries. The findings reveal that a dose of 4 mM salicylic acid is the most effective in improving all the parameters studied in this research. SA induces systemic acquired resistance in plants, enhancing their ability to withstand stress conditions. Furthermore, salicylic acid-treated plants consistently outperformed control plants in terms of growth and quality.

The study concludes that lower doses of SA, such as 2 mM and 4 mM, are more beneficial for strawberry growth and quality than higher doses, which may have detrimental or toxic effects. Doses exceeding 4 mM SA did not yield further improvements in growth or yield parameters. These findings establish a benchmark for future studies aimed at improving the quality of strawberries.

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AUTHORS' CONTRIBUTIONS

SZUH, IH, MAK and GJ designed the study, SZH and IH formulated the experiments, and executed them; SZUH and IH collected and organized the data, analyzed the results, and wrote the manuscript; IH, MAK and GJ assisted in writing the manuscript and proofreading the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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