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Impact of Foliar Application of Salicylic Acid and Putrescine on Yield, Fruit Quality, and Storage of Strawberry (*Fragaria* x *ananassa* Duch.) cv. Albion

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KEY WORDS:
Strawberry; Salicylic acid; Putrescine; Fruit quality; Storability

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ABSTRACT

The strawberry plant is a valuable crop because of the high levels of vitamin C, fibre, and antioxidants it contains. In this study, foliar application of salicylic acid and putrescine was conducted on the Albino cultivar of strawberry to assess yield, fruit quality, and storability. The results revealed that a combination treatment of a foliar application of 150 mg L^{-1} of salicylic acid (SA) and 40mg L^{-1} of putrescine (P) significantly improved the leaf area (cm^2), chlorophyll (mg g^{-1} FW), dry vegetable weight (g), fruit number fruit $plant^{-1}$, fruit weight (g), total soluble solid %, total sugar (µg Glu g^{-1} FW), vitamin C (mg $100g^{-1}$ FW), anthocyanin (mg $100g^{-1}$ FW), and total phenol (µg GAE g^{-1}). This treatment also showed the lowest values for weight loss (%), decay (%), non-marketable fruit (%), and titratable acidity (T.A %). Our findings confirmed the effectiveness of foliar application of salicylic acid, putrescine, and their combination in improving strawberry fruit quality and storability.

تأثير الرش الورقي بحمض الساليسيليك والبيوتريسين على صفات الحاصل الكمية والنوعية والخزنية لثمار الشليك (*Fragaria* x *ananassa* Duch..) صنف ألبيون

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الخلاصة

يُعد نبات الشليك من المحاصيل ذات الأهمية الاقتصادية والغذائية العالية، نظرًا لاحتوائه على مستويات مرتفعة من فيتامين C والألياف ومضادات الأكسدة. هدفت هذه الدراسة إلى تقييم تأثير الرشّ الورقي بحمض الساليسيليك والبيوتريسين في الإنتاجية وجودة الثمار والقابلية التخزينية لصنف الفراولة ألبيون (Fragaria × ananassa Duch.). أظهرت النتائج أن المعاملة المشتركة المتمثلة بالرش الورقي بـ 150 ملغم لتر$^{-1}$ من حمض الساليسيليك (SA_3 (150)) و40 ملغم لتر$^{-1}$ من البيوتريسين (P_3 (40)) حققت أعلى القيم لمعظم الصفات المدروسة، والتي شملت مساحة الورقة (سم^2)، محتوى الكلوروفيل (ملغم غ$^{-1}$ وزن طري)، الوزن الجاف الخضري (غم)، عدد الثمار لكل نبات، وزن الثمرة (غم)، المواد الصلبة الذائبة الكلية (%)، السكريات الكلية (ميكروغرام غلوكوز غ$^{-1}$ وزن طري)، فيتامين C (ملغم 100 غ$^{-1}$ وزن طري)، الأنثوسيانين (ملغم 100 غ$^{-1}$ وزن طري)، والفينولات الكلية (ميكروغرام مكافئ حمض الغاليك غم$^{-1}$) .كما أظهرت هذه المعاملة أقل القيم لفقدان الوزن (غم)، ونسبة التلف (%)، وكمية الثمار غير القابلة للتسويق (غم)، والحموضة المعايرة (T.A، %). تؤكد نتائج هذه الدراسة فاعلية الرشّ الورقي بحمض الساليسيليك والبيوتريسين، سواءً بصورة منفردة أو مشتركة، في تحسين جودة ثمار الشليك وتعزيز قابليتها التخزينية.

الكلمات المفتاحية: الفراولة؛ حمض الساليسيليك؛ البيوتريسين؛ جودة الثمار؛ القابلية التخزينية

INTRODUCTION

The strawberry plant (Fragaria × ananassa Duch) is an economically and nutritionally important crop, due to its high content of Vitamin C, fibre and antioxidant compounds such as phenols and anthocyanins, which make it of interest for consumers and growers (Giampieri et al., 2018). Furthermore, the world demand for strawberries in the fresh and processed markets is constantly increasing, adding to their commercial value and making the improvement of fruit quality a strategic goal for the farmers. Therefore, there is an urgent need to develop sustainable agricultural approaches to improve productivity and quality and simultaneously increase the post-harvest shelf life of the fruits (Hancock et al., 2008). Strawberry production is influenced by several environmental stresses, mainly abiotic stresses such as extreme temperatures, nutrient deficiency and salinity that adversely affect the plant growth and yield and result in a decline in the qualitative attributes of the fruits (Aghdam and Bodbasta, 2013; Keutgen and Pawelzik, 2008).

Furthermore, postharvest fruits undergo rapid deterioration in quality due to their high respiration rate and susceptibility to fungal diseases (Nunes et al., 2006), therefore effective treatments must be developed to improve plant resilience and fruit quality. The soft and highly perishable nature of the strawberry fruit also leads to considerable economic losses due to significant post-harvest quality loss and the ease with which fruits spoil (Almutairi et al., 2024a). Because of this, using plant growth regulators like Salicylic Acid (SA) and Putrescine (P) has become an effective tool for improving fruit quality and resistance to spoilage (Jalili et al., 2023). Salicylic Acid is an important signalling molecule in the regulation of plant defence responses, stimulating the synthesis of antioxidants and activating defensive enzymes, which positively impacts the improvement of physical and chemical properties of the fruits (Asghari and Aghdam, 2010; Almutairi et al., 2024b). One of the promising approaches to enhance the physiological performance of plants and to improve their stress tolerance is the application of growth regulating compounds.

Putrescine, a basic polyamine, is particularly effective in promoting cell division, delaying senescence and improving plant tolerance to adverse environmental conditions (Alcázar et al., 2010). Application of salicylic acid on leaves has been reported to increase production, improve content of phenolic compounds and vitamin C in fruits and keep fruit

firmness during storage (Karlidag et al., 2009; Babalar et al., 2007). Recent studies on strawberries show that SA treatments influence the chemical composition of the fruit, including sugars and phenolic compounds, thus improving the overall quality (Gačnik et al., 2021). Putrescine is a polyamine that is important in the stabilisation of cell membranes and increasing resistance to oxidative stress mechanisms, hence contributing to the maintenance of fruit stability post-harvest (Munir and Al-Zahrani, 2025).

Putrescine is an important regulator of fruit ripening through downregulation of ethylene production and changes in hormonal signalling pathways, thus delaying fruit senescence and improving their storage properties (Guo et al., 2018). It has been reported that postharvest application of Putrescine enhances the quality and decreases the rate of deterioration during storage of strawberries (Pérez-Vicente et al., 2002; Khosroshahi et al., 2007). Studies have looked at the effect of each compound individually; however, information on the combined use of Putrescine and Salicylic Acid and its synergistic effect on the Albion cultivar is still scarce. Albion is a high-yielding, continuous-bearing, day-neutral variety known for its superior quality (Shaw, 2015; Larson and Shaw, 2000). Although the individual effects of SA and Putrescine were effective on strawberries (Jalili et al., 2023; Ennab et al., 2020), there is a significant deficiency in research on the combined effects of SA and Putrescine on strawberries, especially on chemical (phenolic compounds, vitamins, sugars) and physical (firmness, weight loss) aspects.Foliar application of Salicylic Acid has been shown to increase the increase in production, phenolic compounds and Vitamin C , as well as the maintenance of fruit firmness during storage (Karlidag et al. , 2009; Babalar et al. , 2007). Recent studies on strawberries show that SA treatments influence the chemical composition of the fruit, including sugars and phenolic compounds, thus improving the overall quality (Gačnik et al., 2021). Putrescine is a polyamine that is important in the stabilisation of cell membranes and increasing resistance to oxidative stress mechanisms, hence contributing to the maintenance of fruit stability post-harvest (Munir and Al-Zahrani, 2025).

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Therefore, the aim of this study is to evaluate the influence of individuals and combined spraying of Salicylic acid and Putrescine on the physical and chemical quality characteristics of strawberries and to reduce post-harvest losses during storage.

MATERIALS AND METHODS

Experiment location

This study was conducted at the Agricultural Research and Experimental Station of the Agriculture College / Kirkuk University, located in the Sayada region of Kirkuk Governorate, during the 2023–2024 growing season. The plants were cultivated on terraces inside an unheated plastic house with an area of 9 × 52 m.

Table 1: Physical and chemical characteristics of the field soil

Soil texture	Clay	Silt	Sand	Organic matter	pH	EC	N	P	K
	($g\ kg^{-1}$)			($g\ kg^{-1}$)		($ds\ m^{-1}$)	($mg\ kg^{-1}$)		
Loomy Sand	41	315	632	7.12	7.45	1.14	1.17	2.2	28

*Soil properties were analyzed in the Kirkuk Agriculture Directorate laboratory - Kirkuk

Table 2: Average temperature and relative humidity inside the greenhouse during the experimental season (2023-2024)

Years	Months	Average Temperature C^o	Humidity Average %
2023	November	27.4	35.19
2023	December	21.6	57.33
2024	January	12.6	72.81
2024	February	17.8	60.72
2024	March	21.2	57.85
2024	April	27.5	32.61
2024	May	28.6	35.13

Source: This data was taken by using KTJ thermos meter.

Experiment performance

The strawberry variety of (Albion) was used in this experiment. The saplings were obtained from a nursery in the Sulaimaniyah Governorate. All plants were uniform in shape and size and suitable for planting. Before transplanting, the plants in the study were soaked in a fungicide solution of Topsin M (70% WP) at 1 g L^{-1} for 3 minutes, ensuring coverage up to the crown, to protect them from fungal pathogens and prevent leaf and root rot. The plants were then transplanted onto the terraces on 10 October 2023.

Land preparation:

After cleaning the plastic house of grasses and weeds, the soil was plowed twice using a tipper plow. The land was then divided into three terraces, each measuring 50 m in length, 1 m in width, and 25 cm in depth. The terraces were covered with polyethylene to prevent weed germination, conserve soil moisture, and protect the fruits from rot. Each terrace contained 9 experimental units, and each unit consisted of 10 plants spaced 25 cm apart.

Experiment Design

To design this investigation using a Randomized Complete Block Design (RCBD) with three blocks. Each block consisted of 9 experimental units, and each unit contained 10 plants distributed randomly. Thus, each block included 90 plants, for a total of 270 plants used in the study. Data were analyzed using one-way ANOVA by the **(SAS, 2001)** software program, and mean comparisons were performed using Duncan's Multiple Range Test at the 5% probability level.

Experimental treatments.

The experiment consisted of the following treatments:

First. The salicylic acid (SA) with the three concentrations.

SA 1. Sprayed the plants with distilled water (Control).

SA 2. Sprayed the plants with 75mg L^{-1} of salicylic acid in water.

SA 3. Sprayed the plants with 150 mg L^{-1} of salicylic acid in water.

Second. The Putrescine (P) with the three concentrations.

P1. Sprayed the plants with distilled water (Control).

P2. Sprayed the plants with 20mg L^{-1} of Putrescine in water.

P3. Sprayed the plants with 40mg L^{-1} of Putrescine in water

The Characteristics Measurement.

1.The Leaf Chlorophyll Content (mg g^{-1}).

Leaf total chlorophyll (SPAD) was measured in the fresh leaves by a Minolta chlorophyll meter (SPAD - 502; Konica Minolta, Osaka, Japan) by taking 10 readings from the mature leaves in the middle part of the shoots around the trees (Almutairi *et al*., 2023).

2. Leaf Area (cm^2).

Leaf area was measured using the middle leaf of the fifth selected plant in each experimental unit after harvesting on 20/4/2024. The leaf images were analyzed using the **(**Digimizer) software according to the procedure described by (Zhang, 2020).

3. Vegetative Dry Matter weight (g).

Two plants from each experimental unit were carefully uprooted with their root systems intact and thoroughly washed several times to remove any adhering soil. The shoots and roots were then separated at the crown region. The samples were initially air-dried at room temperature, then oven-dried at 65 ± 5°C until a constant weight was achieved. Finally, the dry weights were measured using a sensitive digital balance.

4. Root Dry Matter Weight (g): The root systems of the plants were used for vegetative dry matter determination. The samples were oven-dried at 65 ± 5°C for 24 hours, or until a constant weight was achieved. The dry weights were then recorded using a sensitive digital balance.

5. **Average Fruit Weight (g).**

Fruits were collected from the fifth selected plant in each experimental unit. The average fruit weight was then calculated using the following equation:

Average fruit weight (g) = sum of fruit weight in each plot/ number of fruits

6. Average of Fruit Number (Fruit $Plant^{-1}$).

The number of fruits per plant was recorded beginning from the first picking on 20/12/2024 until the final picking on 20/4/2025 for all selected plants in each experimental unit. The average number of fruits per plant was calculated using the following equation:

Average number of fruits per plant = Total fruit of 5 selected plants/5

7. Total soluble solid (TSS), °Brix or %.

The TSS measurement was performed using a handheld refractometer. Ten fully ripened and uniform fruits were selected, chopped with a knife, and homogenized in an electric mixer for 2–3 minutes. The resulting mixture was filtered through a cotton cloth to obtain clear juice, from which the TSS value was immediately measured using the refractometer.

8. Total Titratable Acidity (TA)

To determine titratable acidity (TA%), 100 g fruit samples were randomly selected at the full ripe stage from each experimental plot, and the juice was then titrated with a 0.1 NaOH solution (AOAC 2005).

9 Soluble Sugar Content

The total sugar content was measured by repeatedly diluting the received juice with distilled water. 1 mL of the diluted sample was mixed with 5 mL of 97% phenol-sulfuric acid and 1 mL of 5% phenol. The mixture was then placed in a water bath at 92 °C for 20 minutes. After heating, the sample was allowed to cool to room temperature, filtered, and read the sample using a spectrophotometer at a wavelength of 490 nm, following calibration of the instrument with distilled water (Karim *et al*., 2025).

10. Ascorbic Acid (Vitamin C)

The content of Vitamin C mg/100 mL juice was determined by the titration of 2,6-dichlorophenol-indo-phenol (Huang *et al*. 2023), and calculated as mg/100 mL of juice.

11. Total Anthocyanin in Fruit.

Anthocyanins were determined from fresh fruits using alcoholic hydrochloric acid (Alcoholic HCL), prepared from 95% ethyl alcohol and 1.5 M HCl in an 85:15 ratio. A 1 g portion of the mixed fresh fruits was homogenized in 20 mL of the acidified alcohol and left to stand for 24 hours at 40 °C. The extract was then filtered by filter paper (Whatman No. 1). Anthocyanin content was measured using an EMC Lab V-1100 spectrophotometer at a wavelength of 535 nm, following the method described by Lateef *et al*. (2021).

12. Total Phenol Content (TPC).

The total phenolic content (TPC) of the samples was determined using the Folin–Ciocalteu reagent according to a standard colorimetric method with slight modifications. An aliquot of the sample extract (e.g., 0.5 mL) was mixed with 2.5 mL of 10% (v/v) Folin–Ciocalteu reagent. After 5 minutes of incubation at room temperature, 2 mL of 7.5% (w/v) sodium carbonate (Na_2CO_3) solution was added to the mixture. The reaction mixture was then incubated in the dark at room temperature for 30 minutes to allow color development. The absorbance was measured at 760 nm using a spectrophotometer (Singleton et al., 1999).

13. Fruit firmness.

Fruit firmness (lb/inch^2) was assessed by using a Magness and Taylor pressure tester (mod. FT 02 (0-2 lb, Alfonsine, Italy).

14. Percentage of Fruit weight loss (%)

After the fruits were stored, each treatment group had its initial weight recorded. Following the scheduled storage period of three weeks, the fruits were reweighed for each treatment. The percentage of weight loss was then calculated based on the difference between the initial and final weights.

$$\text{Weight Loss (\%)} = \frac{W_i - W_f}{W_i} \times 100$$

Where**:**

W_i= Initial weight of the fruit

W_f= Final weight of the fruit after storage

15. Percentage of Fruit non-marketable (%):

The weight of fruits damaged due to pathological or physiological disorders during storage was calculated as follows:

$$\text{Percentage of total non-marketable fruits} = \frac{\text{weight of fruits is not marketable}}{\text{Fruit weight at the end of storage}} \times 100$$

RESULTS AND DISCUSSIO

The data presented in Tables (3 and 4) and Figure 1 illustrate the effect of Salicylic Acid (SA) and Putrescine (Put) on vegetative growth parameters, including total chlorophyll content, leaf area, dry vegetative weight, and dry root weight. The results revealed that increasing SA concentrations significantly enhanced all vegetative traits. The highest values were consistently recorded at 150 mg L^{-1} SA, 13.11 mg g^{-1}FW in leaf chlorophyll content, 130.69 cm² in leaf area, 38.99 g in vegetative dry weight , and 10.94 g in dry root weight. In contrast, the control treatment (0 mg L-^{1}) recorded the lowest averages. Similarly, the application of putrescine exhibited a positive and significant effect, with a concentration of 40 mg L^{-1} producing the maximum values of 11.49 mg g^{-1} FW, 114.26 cm², 33.17 g, and 8.79 g for the aforementioned traits, respectively. Regarding the interaction effect, the combination of 150 mg L^{-1} SA and 40 mg L^{-1} Put was the most effective treatment, recording the maximum values of 14.12 mg g^{-1} FW for chlorophyll, 137.49 cm² for leaf area, 42.81 g for dry vegetable

weight, and 11.71 g for dry root weight. These values were significantly higher compared to the control combination (0 mg L^{-1} SA + 0 mg L^{-1} Put), which yielded the lowest values across all parameters.

Table 3: Effects of the Foliar Application of Salicylic Acid and Putrescine on Leaf area (cm^2), Total Chlorophyll Content (mg g^{-1}fresh weight), and Dry Vegetable Weight (g) of Strawberry Plants.

Characteristics	Average of Salicylic Acid			Average of Putrescine		
	SA 0 mg L^{-1}	SA 75mg L^{-1}	SA 150mg L^{-1}	P 0mg L^{-1}	P 20mg L^{-1}	P 40mg L^{-1}
Leaf Area (cm^2)	87.61c	104.92b	130.69a	101.55c	107.41b	114.26a
Total Chlorophyll Content (mg g^{-1}fresh weight)	8.42 c	10.41b	13.11a	9.89c	10.56b	11.49a
Vegetative Dry Weight (g)	23.62c	29.48b	38.99a	28.19c	30.73b	33.17a

Table 4: Effects of the Foliar Application of Salicylic Acid and Putrescine on Dry Root Weight (g) of Strawberry Plants.

Salicylic Acid mg L^{-1}	Putrescine mg L^{-1}			Average of Salicylic Acid
	0	**20**	**40**	
0	3.95h	4.37h	5.48g	4.60c
75	6.91f	8.03e	9.18d	8.04b
150	10.11c	11.00b	11.71a	10.94a
Average of Putrescine	6.99c	7.80b	8.79a	

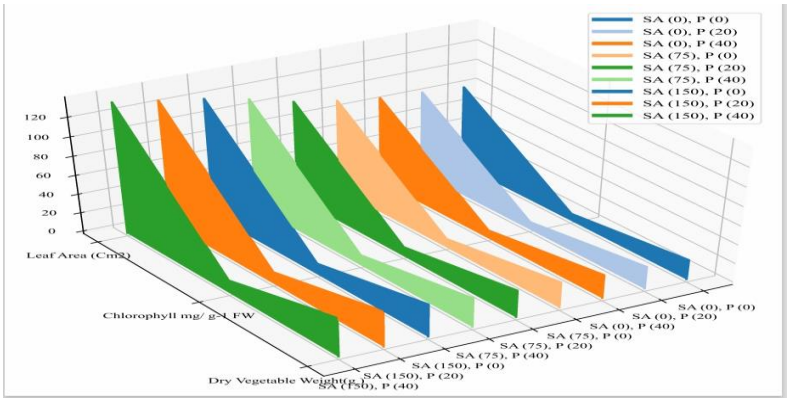

Figure 1: Illustrates the Foliar Application effects of Salicylic Acid and Putrescine on Leaf area (cm^2), Total Chlorophyll Content (mg g^{-1}fresh weight), and Vegetative Dry Weight (g)of strawberry plants.

Table 5 and Figure 2 illustrate the effect of the factors studied on the number of fruits per plant. The statistical analysis showed a significant increase in fruit numbers with the elevation of SA and P levels. The highest average fruit number (22.13 fruit $plant^{-1}$) was obtained at 150 mg L^{-1} SA, while the lowest (10.87 fruit $plant^{-1}$) was found in the control. Likewise, Putrescine at 40 mg L^{-1} recorded the highest average of 18.02 fruit per $Plant^{-1}$, compared to 14.68 fruit per $Plant^{-1}$ at 0 mg L^{-1}. The interaction treatment of 150 mg L^{-1} SA and 40 mg L^{-1} P achieved the peak value of 24.03 fruit $Plant^{-1}$, whereas the lowest value (9.38fruit $Plant^{-1}$) was observed in the control treatment. However, the data about the average fruit weight presented in this statistical analysis revealed significant differences among the treatments. Regarding the effect of Salicylic Acid, the application of 150mg L^{-1} resulted in the highest considerable fruit weight of 22.13 g, whereas the untreated control plants recorded the lowest value of 10.87 g. Similarly, the Putrescine treatments showed a positive influence, with a

concentration of 40 mg L^{-1} recording the maximum value of 18.02 g, which differed significantly from the control treatment, which yielded the lowest average of 14.68 g. The interaction between the two factors was also significant; the combination of 150 mg L^{-1} SA and 40 mg L^{-1} P achieved the highest fruit weight of 24.03 g. In contrast, the control combination (0 mg L^{-1} SA, 0 mg L^{-1} P) recorded the minimum value of 9.38 g.

Table 5 Effects of Foliar Application of Salicylic Acid and Putrescine on Fruit Number (fruit $plant^{-1}$), Fruit Weight (g).

Characteristics	Average of Salicylic Acid			Average of Putrescine		
	SA 0 mg L^{-1}	SA 75mg L^{-1}	SA 150mg L^{-1}	P 0mg L^{-1}	P 20mg L^{-1}	P 40mg L^{-1}
Fruit number (fruit $plant^{-1}$)	20.68c	26.85b	34.14a	25.12c	27.37b	29.18a
Fruit weight(g)	10.87c	15.74b	22.13a	14.68c	16.04b	18.02a

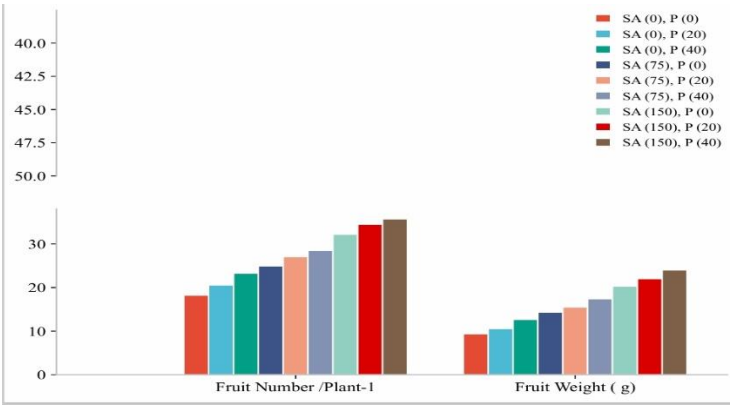

Figure 2: Demonstrate the Foliar Application effects of Salicylic Acid and putrescine on Fruit number (fruit $plant^{-1}$), Fruit weight(g).

The results concerning fruit chemical quality (Total Acidity, TSS, Total Sugars, Vitamin C, Anthocyanin, and Total Phenols) are shown in Figures (3and4) and (5a and 5b), and Tables (6 and 7). Treating plants with 150 mg L^{-1} SA resulted in the highest significant values for TSS (12.02%), Total Sugars (10.23 µg g^{-1}), Vitamin C (18.85 mg $100g^{-1}$), Anthocyanin (37.27 mg $100g^{-1}$), and Total Phenols (28.96 µg g^{-1}). Conversely, this concentration significantly reduced Total Acidity to its minimum value (0.60%) compared to the control (0.80%). Similarly, Putrescine at 40 mg L^{-1} improved fruit quality considerably, recording the highest averages for TSS (10.64%), Sugars (9.23 µg g^{-1}), Vitamin C (16.50 mg $100g^{-1}$), Anthocyanin (30.65 mg $100g^{-1}$), and Phenols (25.37 µg g^{-1}), while recording the lowest acidity (0.66%). The interaction between 150 mg L^{-1} SA and 40 mg L^{-1} P was superior to all other combinations, yielding the highest values for biochemical traits (e.g., 12.56% for TSS and 19.68 mg $100g^{-1}$ for Vit C) and the lowest Total Acidity (0.53%), compared to the control interaction, which showed the opposite trend.

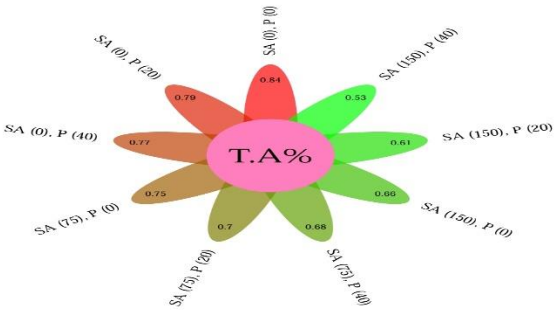

Figure 3: Illustrates the effect of Foliar Application of Salicylic Acid and Putrescine on fruit total acidity

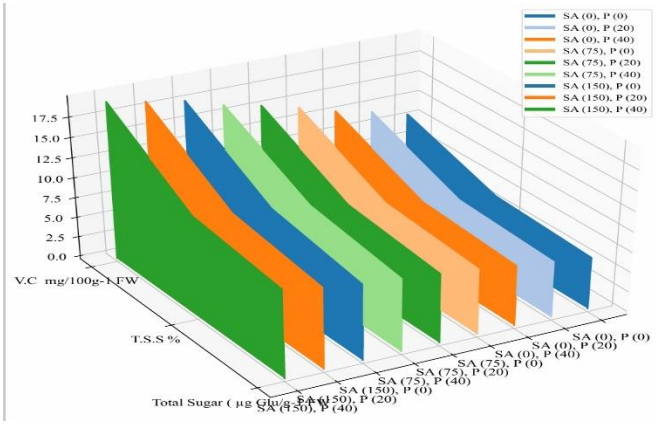

Figure 4: Illustrates the Foliar Application effects of Salicylic Acid and putrescine on Vitamin C (mg 100 g^{-1} FW), Total Soluble Solids (TSS%), and Total Sugar (µg Glu g^{-1} FW) in fruits.

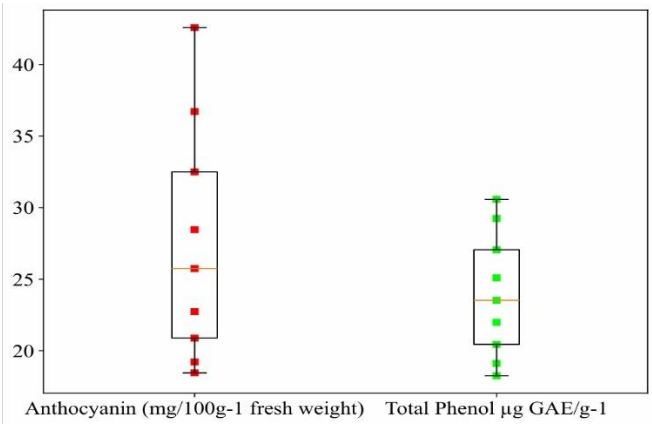

Figure (5a): Illustrates the Foliar Application of Salicylic Acid and Purtrescine on Anthocyanin (mg 100g^{-1} FW) and Total Phenol Content (µg GAE g^{-1}) in Fruits.

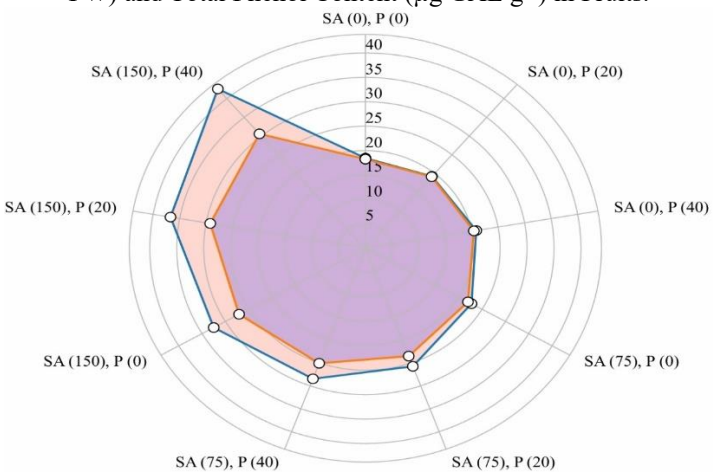

Figure (5b): Illustrates the Foliar Application of Salicylic Acid and putrescine on Anthocyanin (mg 100g^{-1} FW) and Total Phenol Content (µg GAE g^{-1}) in Fruits.

Table 6: Effects of the Foliar Application of Salicylic Acid and Purtrescine on Vitamin C (mg 100 g^{-1} FW), Total Soluble Solids (TSS%), and Total Sugar (µg Glu g^{-1} FW) in Fruits.

Characteristics	Average of Salicylic Acid			Average of Putrescine		
	SA 0mg L^{-1}	SA 75mg L^{-1}	SA 150mg L^{-1}	P 0mg L^{-1}	P 20mg L^{-1}	P 40mg L^{-1}
Vitamin C (mg 100 g^{-1} FW)	12.12c	15.62b	18.85a	14.53c	15.56b	16.50a
Total Soluble Solids (TSS%)	7.75c	10.07b	12.02a	9.31c	9.89b	10.64a
Total Sugar (µg Glu.g^{-1} FW)	7.02c	8.66b	10.23a	8.06c	8.62b	9.23a

Table 7: Effects of the Foliar Application of Salicylic Acid and Putrescene on Anthocyanin (mg 100 g^{-1} FW) and Total Phenol Content (µg GAE g^{-1}) in Fruits.

Characteristics	Average of Salicylic Acid			Average of Putrescine		
	SA 0mg L^{-1}	SA 75mg L^{-1}	SA 150mg L^{-1}	P 0mg L^{-1}	P 20mg L^{-1}	P 40mg L^{-1}
Anthocyanin (mg 100g^{-1} FW)	19.52 c	25.65b	37.27a	24.56c	27.23b	30.65a
Total Phenol Content (µg GAE g^{-1})	19.27c	23.53b	28.96a	22.43c	23.96b	25.37a

The effect of treatments on fruit firmness, weight loss, non-marketable fruits, and decay percentage is presented in Figure 6 and Tables 8 and 9. Results indicated that 150 mg L^{-1} SA significantly increased fruit firmness to 473.7 Kg cm^{-2} and minimized physiological loss of weight (6.66 g), non-marketable fruit weight (0.49 %), and decay percentage (1.73%). In contrast, the control treatment recorded the lowest firmness and the highest values for loss parameters. Putrescine at 40 mg L^{-1} also showed beneficial effects, recording higher firmness (445.7 kg cm^{-2}) and lower weight loss (8.44 g), non-marketable fruits (1.37 %), and decay (1.82%) compared to the control. The interaction of 150 mg L^{-1} SA and 40 mg L^{-1} P provided the best shelf-life indicators, recording the maximum firmness (479.3 Kg cm^{-2}) and the minimum weight loss (5.92 g), as well as non-marketable fruits (0.24 %) and a decay percentage (1.68%), which differed significantly from the control combination.

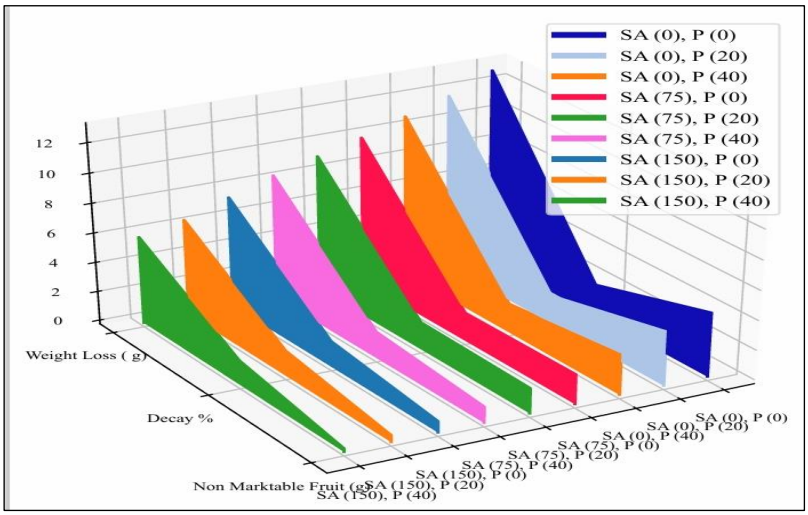

Figure 6: Illustrates the Foliar Application of Salicylic Acid and putrescine on the weight loss (%), Non-marketable (%), and Decay % of fruits.

Table 8: Effect of Foliar Application of Salicylic Acid and Putrescine on the weight loss (%), non-marketable (%), and Decay % of Fruits.

Characteristics	Average of Salicylic Acid			Average of Putrescine		
	SA 0mg L^{-1}	SA 75mg L^{-1}	SA 150mg L^{-1}	P 0mg L^{-1}	P 20mg L^{-1}	P 40mg L^{-1}
Weight Loss (%)	11.92 a	9.24 b	6.66 c	10.18 a	9.20 b	8.44 c
Non-marketable (%)	3.62a	1.60 b	0.49 c	2.37a	1.97b	1.37 c
Decay %	2.04 a	1.86 b	1.73 c	1.94 a	1.87 b	1.82 c

Table 9: Effect of Foliar Application of Salicylic Acid and Putrescine on Firmness of fruit (kg cm^{-2}).

Salicylic Acid mg L^{-1}	Putrescine mg L^{-1}			Average of Salicylic Acid
	0	**20**	**40**	
0	421.6 g	427.4 f	431.7 f	426.9 c
75	438.1 e	446.2 d	456.1 c	446.8 b
150	467.5 b	474.3 a	479.3 a	473.7 a
Average of Putrescine	442.4 c	449.3 b	445.7 a	

The findings of the current study highlight the pivotal role of foliar application of Salicylic Acid (SA) and Putrescine (P) in enhancing the morpho-physiological, yield, and postharvest attributes of strawberry plants. The significant improvement in vegetative growth parameters, including total chlorophyll content, leaf area, and dry matter accumulation, particularly under the interaction of 150 mg L^{-1} SA + 40 mg L^{-1} P, can be primarily attributed to the synergistic effect of these bio-stimulants on plant metabolism. Salicylic Acid acts as a central signaling molecule that regulates physiological processes, playing a vital role in protecting the photosynthetic apparatus and maintaining the integrity of chloroplast membranes. This, in turn, optimizes the activity of the Rubisco enzyme and increases photosynthetic efficiency (Rozbiany and Ibrahim, 2022). Furthermore, the SA application is known to enhance the uptake of essential mineral nutrients and water use efficiency, which directly supports vigorous vegetative growth. Simultaneously, the positive impact of Putrescine is linked to its function as a polyamine that promotes cell division and elongation by stimulating the biosynthesis of nucleic acids (DNA and RNA) and proteins. Putrescine also acts as an anti-senescence agent, delaying the degradation of chlorophyll and stabilizing cellular membranes against oxidative stress (Al-Enzy and Al-Abbasi, 2019). These results align with Al-Hussein and Radhi (2024), who emphasized that bio-stimulants improve the vegetative canopy by regulating endogenous hormonal balance, specifically by increasing auxins and cytokine levels.

Regarding the quantitative characteristics, the substantial increase in fruit number, fruit weight, and total yield is a direct reflection of the improved vegetative growth (Source-Sink Relationship). The increased leaf area provided a larger photosynthetic surface, leading to higher assimilation production and translocation to the developing fruits (the sink). Moreover, Putrescine plays a crucial role in reproductive biology, as it increases pollen viability and the percentage of fruit set while reducing flower abscission (Abdulkadhim and Hussein, 2023).

This is in agreement with Alomar *et al*. (2023), who reported that enhancing the nutritional status of strawberry plants significantly boosts productivity by maximizing the fruit size and weight. In terms of fruit chemical quality, the application of SA and Putrescine resulted in a remarkable accumulation of Total Soluble Solids (TSS), sugars, vitamin C, and anthocyanin, accompanied by a significant reduction in total acidity. This biochemical improvement can be explained by the role of SA in modulating the activity of enzymes involved in sugar metabolism, such as sucrose phosphate synthase, leading to the hydrolysis of starch into simple sugars (Rasheed *et al*., 2018; Mohammed *et al*., 2025; Waheeb *et al.,* 2026). Additionally, the increase in anthocyanin and vitamin C content is likely a response to the activation of the antioxidant defense system triggered by these elicitors. Mohammed and Majeed (2024) also noted that foliar treatments enhance the synthesis of secondary metabolites, improving the nutritional value of fruits. The reduction in acidity is physiologically attributed to the consumption of organic acids as a respiratory substrate during fruit development and maturation processes, facilitated by the treatments.

Finally, the most important results of this study are the extension of shelf life and reduction in physiological weight loss and decay percentage. The higher firmness observed in Putrescine-treated fruits is due to the ability of polyamine to cross-link with pectin substances (pectin methyl esterase activity) in the cell wall, thereby reinforcing the middle lamella and keeping the tissue rigid (Ahmed et al., 2021). Simultaneously Salicylic Acid is an effective compound to slow down the ripening process by inhibiting ethylene biosynthesis and action, which suppresses the activity of cell wall degrading enzymes like polygalacturonase (PG). Also, SA induces Systemic Acquired Resistance (SAR) and synthesis of Pathogenesis-Related (PR) proteins, hence protecting from fungal pathogens in storage. These results are in favour of the findings of Khazaal and Al-Hayany (2023) who showed that the use of salicylic acid significantly reduced weight loss and preserved the quality of stored strawberry fruits.Finally, some of the most important conclusions of this work are the increase of shelf-life and the decrease of physiological weight loss and decay percentage. The higher firmness observed in Putrescine-treated fruits is due to the ability of polyamine to cross-link with pectin substances (pectin methyl esterase activity) in the cell wall, thereby reinforcing the middle lamella and keeping the tissue rigid (Ahmed et al., 2021). Simultaneously Salicylic Acid is an effective compound to slow down the ripening process by inhibiting ethylene biosynthesis and action, which suppresses the activity of cell wall degrading enzymes like polygalacturonase (PG). Also, SA induces Systemic Acquired Resistance (SAR) and synthesis of Pathogenesis-Related (PR) proteins, hence protecting from fungal pathogens in storage. These results are in good agreement with the findings of Khazaal and Al-Hayany (2023) who showed that the application of salicylic acid significantly minimised weight loss and maintained the quality of stored strawberry fruits.

CONCLUSION

In conclusion, foliar applications of salicylic acid and putrescine significantly enhance the yield, nutritional quality, and shelf life of strawberries. While both substances are effective individually, their combined application yields the most robust results. These findings suggest that integrated foliar treatments are a highly effective strategy for producers seeking to optimize fruit performance and post-harvest durability.

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