Assiut Journal of Agricultural Sciences 55 (4) 2024 (153-163) Website: http://ajas.journals.ekb.eg/
ISSN: 1110-0486 / EISSN: 2356-9840 E-mail: ajas@aun.edu.eg

(Original Article)

Effect of Foliar Application of Boron, Salicylic Acid, and Chitosan on Growth and Fruiting of "Festival" Strawberry

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DOI: 10.21608/AJAS.2024.314303.1393
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Abstract

The effects of boron, salicylic acid, and chitosan on growth, yield components, and fruit quality of a strawberry variety (Festival) were investigated during the 2022 and 2023 seasons. A randomized complete block design was used.

The results showed that application of boron, salicylic acid and chitosan significantly increased plant height, number of leaves/plants, number of elongations, leaf area, total chlorophyll, number of fruits per plant and yield per plant compared to water spraying (control).

The results also showed that fruit physical characteristics, i.e., fruit weight, fruit height, fruit diameter, and fruit hardness increased significantly due to the application of boron, salicylic acid, or chitosan compared to the sprayed water (control).

The results also showed that spraying with boron, salicylic acid and chitosan significantly improved the chemical composition of the fruits in terms of increasing the percentage of total soluble solids, sugar content, and vitamin C in addition to decreasing acidity compared to the control treatment.

It was suggested that foliar application of chitosan or boron may significantly improve plant growth, yield, and fruit quality.

Keywords: *Boron, Chitosan, Festival cv, Foliar application, Salicylic acid, Strawberry.*

Introduction

Strawberry (*Fragaria x ananassa* Duch.) is one of the most important fruit crops grown in Egypt for fresh consumption, export, and processing due to its high nutritional and medicinal value. It is classified as small fruit crop belonging to the rosecea family. Strawberry cultivation area in Egypt has increased, reaching about 45,714 fed. (1 fed. = 4200m^2), with a total production of 687,653 tons. According to statistics from M.A.L.R. (2022), the total amount of exportable fruit was 54,000

Received: 19 August 2024/ Accepted: 22 October 2024/ Published online: 25 October 2024

tons of fresh fruit and about 140,000 tons of frozen strawberries. Recently, the UN World Trade Center reported that Egypt is the world's number one exporter of frozen strawberries. Exports reached 140,000 tons, accounting for 20% of global exports and $165 million in value, or 14.3% of total global exports in 2020 (FAO, 2020).

Strawberries are important for human health because they are a rich source of vitamin C, along with potassium, iron, and comprehensive antioxidants (Halvorsen *et al*., 2002). It also contains high amounts of dietary fiber, secondary metabolites, and sugars. The high content of these compounds is beneficial to health as they could inhibit blood clotting and reduce cardiovascular disease (Mohamed *et al*., 2021). However, the quality and quantity of these compounds are influenced by genetic, environmental, and agricultural factors (Kallio *et al*., 2000).

Festival is an important strawberry variety that has been widely grown in Egypt in recent years. A short-day variety, the fruit is mostly conical in shape. The outside of the ripe fruits is dark red and shiny, while the inside is bright red. It has a firm, crunchy texture and excellent flavor. Increasing yield while maintaining fruit quality is an important goal, which can be achieved by foliar application of nutrients widely used to promote growth and fruit set in many crops.

Foliar application of micronutrients is clearly an ideal method to avoid nutrient availability problems. Boron has effects on cell wall structure, cell elongation, and root elongation. It is also believed to be a nutrient that increases phloem carbohydrate translocation, which may increase the soluble solids content of fruit (Marschner, 2012). Boron applications have increased yield and fruit quality (Wojcik and Lewandowski, 2003).

Furthermore, boron is an important micronutrient that is essential for stabilizing certain components, such as cell wall structure and function, cell membrane activity, improved cell division, tissue differentiation, and increased net photosynthetic rates throughout increasing leaf chlorophyll content (Rafeii and Pakkish, 2014 and Mohamed *et al*., 2018).

Salicylic acid (SA), a naturally occurring phytohormone, acts as an important signaling molecule and increases the resistance of treated plants to abiotic stresses (Khan *et al*. 2012). Salicylic acid also plays an important role in plant growth, ion uptake and nutrient transport in the plant body. The phenolic compound salicylic acid is present in many plants and is also involved in local and systemic resistance to fungal pathogens (Meena *et al*., 2001).

Exogenous application of salicylic acid improved growth and productivity of strawberry cultivar Fern, with one, two, three or four foliar applications of 1.0 mM salicylic acid resulting in the highest values of leaf chlorophyll, leaf elements, initial yield, and total yield. (Karlidag *et al*., 2009 and Kazemi, 2013).

Chitosan is a linear polysaccharide with a random distribution of β-(1-4)-linked D-glucosamines (deacetylated units) and N-acetyl-D-glucosamines

(acetylated units); it is a polysaccharide called 2-amino-2-deoxyβ-D-glucosamine; it is also known as chitosan, a highly aminated polysaccharide. Chitosan can be obtained from marine crustaceans such as shrimp, clams, and pinfish, or from the exoskeletons of most insects called chitin, which can be converted to chitosan by isolating acetyl groups and aminating them (Sugiyama *et al*., 2001).

Chitosan is a chemical biopolymer derived from crustaceans and is soluble in organic acids. Chitosan is considered environmentally safe for use in agriculture because it readily degrades in the environment and is non-toxic to humans. Chitosan and its derivatives have been reported to induce a natural defense response in plants and are used as natural compounds to control pathogenic diseases before and after harvest. Antimicrobial activity of chitosan against various plant pathogens has been reported (Rahman *et al*., 2014).

The aim of this study is to investigate the effect of foliar application of boron, salicylic acid and chitosan on growth and fruiting of Festival strawberry plants.

Materials and Methods

The experiment was conducted for two consecutive seasons in 2022 and 2023 at the farm of Agricultural Research Institute in Arab Al-Awamir, Abnub district Assiut governorate. Festival transplants were obtained as cold storage (frigo) plants from a local nursery.

The soil was sandy and prepared by plowing, sowing and fertilizer application. A drip irrigation system was used in the experiment.

The area of each experimental plot was 12.80 m^2 and included one bed 8.0 m long and 1.6 m wide. Each bed consisted of four rows and plants were transplanted at 0.25 m inter-row spacing and 0.15 m within one row. Transplanting was carried out on September 20 (60 days after sowing) when plants reached 3-4 true leaves. The four treatments were done in a completely randomized block design with four replications, with each experimental plot consisting of five 2 m rows. All other cultural practices required for strawberry cultivation were carried out according to the recommendations of the Egyptian Ministry of Agriculture.

These experiment treatments were control (water spray), boron as boric acid (17%B) at 3.4 mg/L, salicylic acid at 2 mm/L and chitosan at 5 mg/L.

For boric acid and salicylic acid treatment, the powders were dissolved in hot water, allowed to cool and then applied to the plant material.

Stock solution (2%w/v) of chitosan, was prepared by dissolving chitosan in 0.5 % (v/v) glacial acetic acid, under continues stirring, and the pH was adjusted to 5.6 using 1N NaOH. The stock solution was sterilized at 121˚ C for 20 minutes, and then lower concentrations i.e. (5 mg /L) were made by appropriate dilution with distillated water (Du *et al*., 1997)

Three spraying applications of each treatment were applied with one-month intervals. The first application was carried out 6 weeks after transplanting. Triton B as wetting agent was added at a rate of 0.05% to all spraying solution before the

application. Foliar applications were carried out until run off using manual pump sprayer.

1. Characteristics of Vegetative growth

Ten flowering plants were randomly selected from each plot; the average of ten plants was taken as one replicate. The following characteristics were recorded for each plant

-Plant height (cm).

-Number of leaves per plant.

-Number of elongations per plant.

-Leaf area (cm^2)

-Total chlorophyll count (SAPD)

2. Yield components

The number of fruits per plant were measured and total yield weight (g) per plant was calculated by measuring the weight of fruits harvested at full ripeness (full red color) during the growing season.

3. Physical characteristics

20 fruits from each replicate were randomly collected at harvest time and the following traits were measured

- **Average fruit weight (g):** calculated by dividing the total harvest weight (g) by the number of fruits on the plant.
- **Fruit length (L) (cm) and Fruit diameter (D) (cm):** They were estimated by using Vernier caliper
- **Fruit firmness (kg/cm^2):** It was estimated by using a penetrometer.

4. Chemical characteristics of fruits: The same samples used for physical characterization were used to measure the following attributes:

- Total soluble solids % (TSS): Measured with a hand refractometer.

- Total sugars % and reducing sugars%: Determined according to the Lane and Eynon method described in (AOAC (1990).

- Total titratable acidity%: Determined by titration of pure fruit juice with 0.1 N NaOH with phenolphthalein as indicator (AOAC, 1990). The acid content was calculated as g citric acid/100 ml of juice.

- The content of vitamin C: Analysis was performed according to the standard method described in AOAC (1990) and expressed as mg/100 g.

All data obtained were analyzed statistically. Analysis of variance (ANOVA) was performed according to the method of Snedecor and Cochran (1991).

Results

Plant growth parameters

The data in Tables (1) and (2) show the effect of boron, salicylic acid and chitosan on plant growth parameters of Festival strawberry plants during the seasons of 2022 and 2023. It is evident from the data that similar trends were observed during the two seasons under study.

The results showed that application of boron, salicylic acid, and chitosan significantly increased plant height, number of leaves/plants, number of elongations, leaf area, and total chlorophyll compared to water spraying (control). In this regard, application of boron, salicylic acid, and chitosan resulted in the highest plant height (20.05, 20.45 and 21.80 cm, respectively) and number of leaves per plant (22.35, 22.95 and 25.35, averaged over two seasons, respectively). Plants sprayed with water had the least significant values, recording averages of 16.85 and 19.85 cm for the two seasons. No significant differences were observed when boron and salicylic acid were applied. Thus, it can be concluded that the application of salicylic acid or chitosan was preferred from an economic point of view.

Regarding leaf area and total chlorophyll; boron, salicylic acid, and chitosan had a positive effect on these growth parameters compared to the control. Salicylic acid and chitosan had the highest leaf area (188.0 and 200.1 cm^2) and total chlorophyll, followed by boron (46.7 and 47.2 SAPD averaged over two seasons). In contrast, the control had the lowest leaf area (172.7 cm^2) and total chlorophyll (40.3 SAPD). Leaf areas of 172.7, 190.9, 188.0 and 200.1 cm^2 were recorded for control, boron salicylate, and chitosan, respectively. The percentage increase in leaf area as a result of treatments compared to control were 10.54, 8.86, and 15.87%, respectively.

Table 1. Effect of boron, salicylic acid, and chitosan spraying on growth traits of Festival strawberry plants during 2022 and 2023 seasons

Char.	Plant height (cm)			leaves number/plant			Number of elongations		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Control	18.70	15.00	16.85	18.70	21.00	19.85	3.70	5.30	4.5
Boron	21.20	18.90	20.05	21.20	23.50	22.35	4.10	5.40	4.75
Salicylic Acid	22.20	18.70	20.45	22.20	23.70	22.95	4.10	5.90	5
Chitosan	24.20	19.40	21.8	24.20	26.50	25.35	4.20	5.60	4.9
LSD 5%	0.88	0.64	0.54	0.96	1.13	0.75	0.16	0.21	0.13

Table 2. Effect of boron, salicylic acid, and chitosan spraying on leaf area and total chlorophyll of Festival strawberry plants during 2022 and 2023 seasons

Char.	Leaf area (cm^2)			Total chlorophyll (SPAD)		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean
Control	178.5	166.9	172.7	41.3	39.2	40.3
Boron	198.2	183.5	190.9	45.4	43.3	44.4
Salicylic Acid	196.8	179.1	188.0	47.6	45.8	46.4
Chitosan	208.9	191.2	200.1	48.2	46.1	47.2
LSD 5%	11.24	10.83	6.52	2.45	2.11	1.65

Yield components

Data in Table (3) show the effect of boron, salicylic acid and chitosan on yield components of Festival strawberry in seasons 2022 and 2023.

The results showed that the application of boron, salicylic acid, and chitosan significantly increased the number of fruits per plant and yield per plant compared to water spraying (control). While the highest yield component was obtained with boron application which proved to be the best remedy.

The recorded number of fruits per plant was (15.3, 19.4, 18.6, and 17.9 fruits, respectively) and yield per plant (average values for the two studied seasons were (309.8, 432.8, 423.9, and 405.0, respectively) due to spraying with water (control), boron, salicylic acid and chitosan, respectively.

Yield per plant increased by the corresponding percentages (average values for the two seasons studied were 39.70, 36.83 and 30.73%, respectively) due to the achieved treatments compared to the control. No significant differences were found due to spraying boron or salicylic acid.

Table 3. Effect of boron, salicylic acid and chitosan spraying on yield components of Festival strawberry plants during 2022 and 2023 seasons

Char.	Fruit number / plant			Yield weight / plant (g)		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean
Control	15.7	14.9	15.3	332.8	286.7	309.8
Boron	19.2	19.6	19.4	462.5	403.1	432.8
Salicylic Acid	18.4	18.8	18.6	432.3	415.5	423.9
Chitosan	17.1	18.0	17.9	431.9	378.1	405.0
LSD 5%	1.05	0.98	0.78	28.25	22.31	18.29

Fruit quality

A. Fruit physical characteristics

The data in Table (4) show the effects of boron, salicylic acid, and chitosan on the physical characteristics of Festival strawberry fruit during the 2022 and 2023 seasons. It is obvious from the data that results took similar trend during the two studied seasons.

The results showed that fruit physical characteristics, i.e., fruit weight, length, diameter and firmness, were significantly increased by the application of boron, salicylic acid, or chitosan compared to the sprayed with water (control). The highest values in this respect were obtained with the chitosan application. The fruit weights recorded were (20.35, 23.50, 22.88, and 23.90 g) and fruit length (4.18, 4.54, 4.51, and 4.81 cm as averages for the two study seasons). The percentage increase in fruit weight was 15.20%, 11.76%, and 17.16% in the treatment compared to the control, respectively. Chitosan showed the highest fruit diameter (3.38 cm), followed by boron (3.33) cm and Salicylic Acid 3.31 compared to the control (3.22) on average over the two seasons. On the other hand, the control had the lowest fruit firmness (1.40 kg/cm^2 on average over the two seasons).

Regarding fruit firmness, boron, salicylic acid and chitosan all had a positive effect on fruit firmness compared to the control. Chitosan showed the highest fruit firmness (1.92% kg/cm^2), followed by boron (1.68% kg/cm^2 on average over the two seasons). On the other hand, the control had the lowest fruit firmness (1.40 kg/cm^2 on average over the two seasons). Fruit firmness was 1.40, 1.68, 1.54, and 1.92 kg/cm^2 for control, boron, salicylic acid, and chitosan, respectively. The percentage increase in fruit firmness was (20.0, 10.0, and 37.14%) for the treatments compared to the control, respectively. There were statistically significant differences as a result of the application of boron or chitosan. Therefore, it was concluded that from a general economic point of view, it is desirable to apply boron or chitosan.

Table 4. Effect of boron, salicylic acid and chitosan spraying on fruit traits of Festival strawberry during 2022 and 2023 seasons

Char.	Fruit weight (g)			Fruit length (cm)			Fruit diameter (cm)			Fruit firmness (kg/ cm^2)		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Control	21.2	19.5	20.4	4.22	4.14	4.158	3.11	3.32	3.22	1.40	1.40	1.40
Boron	24.3	22.7	23.5	4.49	4.58	4.54	3.29	3.36	3.33	1.67	1.69	1.68
Salicylic Acid	23.5	22.1	22.8	4.46	4.56	4.51	3.24	3.38	3.31	1.53	1.55	1.54
Chitosan	24.7	23.1	23.9	4.60	5.01	4.81	3.36	3.40	3.38	1.90	1.94	1.92
LSD 5%	0.84	0.91	0.63	0.19	0.16	0.13	0.12	0.08	0.06	0.08	0.06	0.05

B. Fruit chemical characteristics

The results in Tables (5) and (6) show that application of boron, salicylic acid and chitosan significantly improved the chemical composition of fruits in terms of increase in T.S.S. %, sugar and vitamin C (V.C) content and decrease in acidity as compared to control treatment. Table (5) shows that foliar application of chitosan and boron in that order gave better results in terms of TSS (8.99 and 8.59%), total sugar (6.89 and 6.58%) and reducing sugars (5.18 and 4.95%) respectively. On the other hand, the control plants were the lowest in this regard for the three measured traits (7.63, 5.85, and 4.40%, respectively).

TSS was (7.63, 8.59, 8.32, and 8.99) and total sugar content was (5.85, 6.58, 6.40, and 6.86 % (mean of two seasons)). The percentage increase in total sugar content was (12.48, 9.40, and 17.78 %) as a result of boron, salicylic acid and chitosan were compared with control, respectively.

When sprayed with water (control), boron, salicylic acid and chitosan, V.C. content was 168.1, 184.3, 180.5, and 188.3 mg/100 g, respectively (averaged over two seasons). The percent increase in V.C content (6.93, 7.38 and 12.02 %) with boron, salicylic acid and chitosan application, respectively, compared to the control.

Regarding % acidity, all treatments reduced this parameter compared to the control, with lower values produced from chitosan and boron (0.699 % and 0.724 % averaged over the two seasons, respectively). On the other hand, the control treatment showed the highest value in this respect (0.813 % average over two seasons).

In general, the chemical composition of fruits, except acidity, showed the lowest percentage in the control. On the other hand, fruits sprayed with chitosan or boron had the highest values in this respect.

Table 5. Effect of boron, salicylic acid and chitosan spraying on TSS and sugar contents of Festival strawberry fruits during 2022 and 2023 seasons

Char.	TSS %			Total sugar %			Reducing sugar %		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Control	7.61	7.65	7.37	5.83	5.86	5.85	4.39	4.41	4.40
Boron	8.46	8.71	8.59	6.48	6.67	6.58	4.88	5.02	4.95
Salicylic Acid	8.21	8.43	8.32	6.31	6.48	6.40	4.75	4.87	4.81
chitosan	8.86	9.11	8.99	6.79	6.98	6.89	5.11	5.24	5.18
LSD 5%	0.32	0.29	0.18	0.19	0.16	0.11	0.12	0.11	0.07

Table 6. Effect of boron, salicylic acid and chitosan spraying on acidity and V.C of Festival strawberry fruits during 2022 and 2023 seasons

Char.	Acidity %			V.C (mg / 100g)		
Seasons / Treat.	2022	2023	Mean	2022	2023	Mean
Control	0.825	0.801	0.813	160.8	175.3	168.1
Boron	0.735	0.713	0.724	175.7	192.8	184.3
Salicylic Acid	0.798	0.738	0.791	163.6	187.3	180.5
Chitosan	0.710	0.688	0.699	180.5	196.1	188.3
LSD 5%	0.023	0.031	0.016	6.34	7.11	4.10

Discussion

From this study, it is observed that foliar application of boron significantly increased the growth traits. This may be due to the physiological role of boron and its involvement in protein metabolism, pectin synthesis, maintenance of proper water relations in the plant, adenosine triphosphate (ATP) resynthesis, and sugar translocation during flowering and fruiting (Meena *et.al.*, 2001). Boron application was very beneficial in the photosynthesis process, promoting carbohydrate accumulation and ultimately improving fruit quality (Singh *et al.*, 2012 and Mohamed *et al.*, 2021).

Salicylic acid is a phenolic endogenous growth regulator normally produced in plants in very small amounts that regulates a number of physiological and biochemical processes in plants, including seed germination, plant growth, flowering induction, nutrient uptake and transport, water-plant relations, membrane permeability, stomatal conductance, photosynthesis, and enzyme activity (Arfan *et al.* (2007); Hayat *et al*. (2010); Youssef *et al*. (2017) and Mohamed *et al*. (2018)).

Chitosan is widely used in agriculture, mainly to promote plant defense (Naeem *et al*., 2010). Chitosan also promotes plant growth, development and productivity and improves yield components of various crops (El-Tantawy (2009); El-Tanahy *et al*. (2012) and El-Miniawy *et al*. (2013)).

In the current study, chitosan, boron or salicylic acid played an important role in regulating a number of vital processes including plant growth and increased the

vegetative growth traits. Then these attributed to increasing yield and improving fruit quality.

The results of this study are in agreement with other researchers such as Martin-Mex *et al.*, 2005; Arfan *et al.*, 2007; Hayat *et al.*, 2010; Singh *et al.*, 2012; El-Miniawy *et al*., 2013; Youssef *et al*., 2017; Mohamed *et al*., 2018 and Mohamed *et al*., 2021.

Conclusion

The results of this study indicated the effects of boron, salicylic acid and chitosan on plant growth, yield, and fruit quality. It is suggested that foliar application of chitosan or boron could significantly improve plant growth, yield and fruit quality of Festival strawberry.

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تأثير الرش الورقي بالبورون وحامض الساليسيليك والشيتوزان على نمو واثمار نباتات الفراولة فستفال

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الملخص

تم دراسة تأثير الرش الورقي للبورون وحمض الساليسيليك والشيتوزان على النمو ومكونات المحصول وخصائص الثمار نباتات الفراولة (فستفال) خلال موسمي 2022، 2023. حيث تم الرش الورقي بالبورون بتركيز3.4 ملجم / لتر وحمض الساليسيليك بتركيز 2مليمول / لتر والشيتوزان. بتركيز5 ملجم / لتر وقد تم تصميم التجربة بنظام القطاعات كامله العشوائية.

وقد أظهرت النتائج أن رش البورون وحمض الساليسيليك والشيتوزان أدى إلى زيادة معنوية في طول النبات وعدد الأوراق / النباتات وعدد المدادات ومساحة الورقة والكلوروفيل الكلي مقارنة بالكنترول المعامل بالماء. كما أظهرت النتائج أن رش البورون وحمض الساليسيليك والشيتوزان أدى إلى زيادة معنوية في عدد الثمار لكل نبات وكمية المحصول لكل نبات مقارنة بالكنترول.

كما أظهرت النتائج أن الخصائص الفيزيائية للثمار، من وزن الثمار وارتفاع الثمار وقطر الثمار وصلابة الثمار، زادت معنويا عند رش البورون أو حمض الساليسيليك أو الشيتوزان مقارنة بالكنترول. كما أن إضافة البورون وحمض الساليسيليك والشيتوزان أدى إلى تحسين التركيب الكيميائي للثمار بشكل ملحوظ من حيث زيادة نسبة المواد الصلبة الذائبة الكلية ومحتوى السكر وفيتامين ج وخفض الحموضة مقارنة بمعاملة الكنترول .

ومن ناحية أخرى أظهرت الثمار المرشوشة بالشيتوزان أو المعاملة بالبورون أعلى القيم في هذا الصدد. وعليه يمكن التوصية بأهمية الرش الورقي بالشيتوزان أو البورون وذلك لتحسين النمو الخضري للنباتات مع زيادة الإنتاجية وجودة الثمار.

الكلمات المفتاحية: *البورون، الرش الورقي، الشيتوزان، حمض الساليسيليك، فراولة فستيفال*