Effect of Silicon on Yield and Fruit Quality of Tomato Grown Under Sandy Soil Conditions

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Abstract
An experiment was carried out in a greenhouse in Ismailia Agricultural Research Station in 2019/2020 to investigate the impact of salicylic acid (SA)spraying leaves as a silicon source on the growth, yield, and fruit quality of two tomatoes cultivars (Wadistar and Alissa). The design of the experiment was split plots in two factors with three replications. The first factor was two different tomato cultivars, Wadistar and Alissa. The other factor was spraying with SA at (0, 50, 100, 150 mg/ liter) as a source of silicon three times every 15 days, the first spraying after 15 days after transplanting, the chemicals are applied in the early morning using a spray. Duncan's test was applied to compare the means at 5% probability. Foliar spraying with SA at all levels significantly increased growth, yield, and quality parameters compared to the control. All morphological features (including plant height, leaves and branches numbers, leaf area, fresh and dry weight stems, fresh and dry weight leaves) and the content of chlorophyll pigments in leaves improved with an increase in salicylic acid concentration up to 100 mg/ liter. The productivity and quality characteristics of tomato fruits, notably firmness, improved. When the salicylic acid content was raised to 150 mg/liter, all of these characteristics decreased. Finally, the application of 100 mg of SA/liter increased tomatoes productivity and fruit quality.
Keywords: Tomato, Salicylic acid, Silicon, Sandy soil, Yield, Fruit firmness
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1. Introduction

Tomatoes are one of the maximum fruits extensively grown and eaten by the world. They included an excellent amount of different vitamins like A, C, E additionally, a higher amount of potassium and antioxidants. They are also cholesterol-free and protect the body from illnesses (Perveen et al., 2015). Despite this, it deteriorates rapidly due to its weak juicy texture, which contributes to an increased loss during transport and the inability of the fruits to bear for extended periods after harvest due to their weak texture, as well as infection with many diseases that cause fruit damage. Therefore, the pectin production should be increased further, and a thicker texture should be created. Easy-to-use and low-cost technologies are also highly suggested. This may be accomplished through various ways, including low nitrogen fertilization (Bénard et al., 2009), genetic engineering (Davuluri et al., 2005), careful temperature radiation management (Gautier et al., 2008), and finally, by supplementing with appropriate micronutrients (Fanasca et al., 2006). Silicon is essential for the structural stiffness of cell walls (Tisdale et al., 1985). Silicon generates Si-enzyme complexes, which function as guardians and photosynthetic regulators while also regulating other enzymatic activity. The second common component in the Earth's crust is Silicon (Debona et al. 2017). Silicon activates the plant's antioxidant defense technique (Gunes et al. 2008), maintain mineral balancing (Kaya et al., 2006), Promotes root water absorption (Liu et al., 2014), boost photosynthetic enzyme activity (Gong and Chen, 2012), and control growth substance levels (Zhu and Gong, 2014). Regulation of plant nutrition with silicon (Si) increases plant tolerance to bio and non-bioagent challenges, including saline stress, according to (Matichenkov & Bocharnikova, 2001). They described the action of (Si) due to increased photosynthetic activity; higher potassium (K) to sodium (Na) selectivity ratio; raised enzyme activity; and improved soluble compounds content in the xylem, which results in decreased sodium absorption by plants. Amorphous silica is joined with pectin and calcium ions, which are abundant in thin epidermal tissues, resulting in stiffness. Adding silicon (Si) to plant nutrition may support plant defenses against pests, diseases, and adverse environmental conditions. Using silicon fertilizers enhances crop quality and yield in several field studies conducted under varying climatic and soil conditions (Barker et al., 2007). Silicon is soaked up in the shape of SA. Monosalicylic acid fertilizer enhanced the productivity and quality of cherry tomato crops planted on rock wool in a greenhouse (Toresano-Sánchez et al., 2012). They discovered that SA fertilization increased the fruits in the plant, yield, and cell wall stiffness. SA has been discovered as one of the signaling pathway's components, and it contributes to the control of various physiological processes in plants. According to (Abd El-al., 2009), application of foliar SA improves sweet pepper yield output significantly. Because of the low firmness of tomato fruits, they are susceptible to damage both on the plant and during transit and handling, resulting in a drop in quantity and quality. As a result, efforts must be achieved to enhancement the firmness of the fruits, as well as production and quality. As a result, the goal of this study is to see how foliar spraying of SA as a source of silicon affects tomato fruit growth, yield, in addition, quality.

2. Materials and methods

2.1. Plant materials and treatments

The experiment was performed in the Agricultural Research Station in Ismailia, Egypt, during the 2019/2020 seasons. The experimental soil was sandy with pH 6.72, organic matter (1.8 g/kg), EC (1.11dSm^{-1}) at 25 °C, total N (0.03 g/kg), and total phosphorous (0.02 g/kg). On January 2, the seedlings of Wadistar and Alissa F1 tomatoes were planted. The design of the experiment was split plots, with eight treatments, three replicates, 24 experimental plots, and a plot area of 10 m^2. Each plot had 20 plants. The spacing between plants and rows was 50 cm and 100 cm, respectively. This study aims to see how foliar spraying salicylic acid (0, 50, 100, and 150 mg/L) as a silicon source affects tomato growth, quality, and yield. After 15 days of transplanting, spraying was done three times every 15 days, with the chemicals applied early in the morning using a spray pump. Number of branches and leaves, plant height, leaf area, shoot fresh weight, shoot dry weight, leaves fresh weight, leaves dry weight, chlorophyll a, b, carotenoids, plant yield, plot yield, yield per fed., TSS, pH, acidity %, vitamin C, total phenols, and fruit firmness were all calculated.

2.2. Measurements

During the flowering stage, a random selection of three plants from each plot was chosen to evaluate plant length, numbers of leaves and branches, leaf area, stem fresh weight, leaf fresh weights, in addition to total fresh weight. The dry weight disc technique established by Rhoads and Bloodworth (1964) was used to estimate the leaf area. The stems and leaves were dry under 70 °C until they were constant in weight to calculated the stem and leaves' dry weights. The chlorophyll pigments were collected from the fourth leaf and analyzed according to (Lichtenthaler and Buschmann, 2001) procedures to identify chlorophyll pigments. Plant yield, plot yield, and total yield/fed. were all measured during the harvesting time. TSS % was measured after passing 10 g juice of tomato through cheesecloth and determined at 20°C using an Abbe (C10) refractometer made in the United States. The pH was determined using the Jenway instrument 3510, which was manufactured in (UK) by Bibby Scientific. Acidity % and vitamin C were estimated by titration of sodium hydroxide (0.1 N) and the indophenol method according to (Horvitz et al., 1970). Total phenolic compounds were identified by Folin–Ciocalteu way, as reported by (Osorio-Esquivel et al., 2011). Fruit firmness was determined by the FHT-1122 Tester by calculating the average penetration force for five fruits per plot.

2.3. Statistical analysis

Analyses were done with SPSS 16 software, and means were compared using Duncan's test with a probability of 5%.

3. Results and Discussion

Table 1 shows the influence of SA spraying on plant height, branches and leaves numbers, and leaf area, at a significant level (p0.05).

Table 1. The effect of silicon on tomato plant height, branches and leaves numbers, and leaf area.

Treatments	Plant height (cm)			Number of branches			Number of leaves			Leaf area (cm^2)		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	62.0	65.3	63.7^{f1}	4.3	4.5	4.4^{e}	45.0	46.0	45.5^{d}	33.6	34.2	33.9^{g}
50	65.0	68.1	66.6^{d}	5.0	5.2	5.1^{b}	48.3	49.2	48.8^{c}	35.6	37.4	36.5^{f}
100	70.3	75.4	72.9^{a}	6.0	6.3	6.2^{a}	58.0	59.4	58.7^{a}	39.4	41.5	40.5^{d}
150	69.7	73.9	71.8^{b}	4.7	5.1	4.9^{c}	54.0	56.8	55.4^{b}	38.4	40.5	39.5^{e}
Mean	66.7^{b3}	70.7^{a3}	68.7^{A2}	5.0^{b}	5.3^{a}	5.1^{A}	51.3^{b}	52.9^{a}	52.1^{A}	36.8^{b}	38.4^{a}	37.6^{B}
Alissa												
0	61.3	64.5	62.9^{g1}	3.7	3.9	3.8^{g}	31.3	33.2	32.3^{h}	39.5	41.8	40.6^{d}
50	64.0	66.2	65.1^{e}	4.3	4.6	4.5^{f}	37.7	39.8	38.8^{g}	41.4	42.6	42.0^{c}
100	66.6	69.7	68.2^{c}	5.0	5.3	5.2^{b}	43.0	45.1	44.1^{e}	48.1	53.1	50.6^{a}
150	65.3	67.6	66.5^{d}	4.7	4.9	4.8^{d}	41.7	43.6	42.7^{f}	46.1	49.8	47.9^{b}
Mean	64.3^{b}	67.0^{a}	65.7^{B2}	4.4^{b}	4.7^{a}	4.6^{B}	38.4^{b}	40.4^{a}	39.4^{B}	43.8^{b}	46.8^{a}	45.3^{A}

[1]Different lower - case characters over the same column denotes significant difference between the concentrations of salicylic acid for two cultivars.

[2]Different capital letters over the same column denotes a significant difference between the cultivar factor's means.

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All SA levels used considerably outperformed the control for the two cultivars understudied in plant height, branches and leaves numbers, and leaf area. The same results were reported on plant height, branches and leaves numbers, and leaf area (Gharib, 2006; Ertan et al., 2008; Yildirim and Dursun, 2009) on basil, cucumber plant, and tomato. The most plant height, branches and leaves numbers, and leaf area were achieved by using100 mg SA/liter for the two tomato varieties. The plant height of the cultivar Wadistar, branches and leaves numbers (68.7cm, 5.1, and 52.1), were superior at Alissa (65.77cm, 4.6, and 43.8), respectively. Despite this, leaf area of the Alissa cultivar (45.3 cm^2) was larger than that of Wadistar. It is noted also, that all the estimated parameters increased thru second season for both cultivars compared to the first season.

Table 2. The effect of silicon on tomato plants' fresh and dry shoots and leaves.

Treatments	Shoot fresh weight (g)			Shoot dry weight (g)			Leaves fresh weight (g)			Leaves dry weight (g)		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	37.1	39.2	38.2^{d1}	10.31	12.35	11.33^{d}	34.43	35.67	35.05^{d}	9.29	10.52	9.91^{d}
50	38.2	39.8	39.0^{c}	10.64	12.96	11.80^{c}	35.51	36.74	36.13^{c}	9.58	10.88	10.23^{c}
100	40.7	42.3	41.5^{a}	10.99	13.52	12.26^{a}	36.68	38.52	37.60^{a}	9.90	11.52	10.71^{a}
150	39.4	41.7	40.6^{b}	10.85	13.06	11.96^{c}	36.23	37.16	36.70^{b}	9.77	11.21	10.49^{b}
Mean	38.9^{b3}	40.8^{a3}	39.8^{A2}	10.70^{b}	12.97^{a}	11.84^{A}	35.71^{b}	37.02^{a}	36.37^{A}	9.64^{b}	11.03^{a}	10.33^{A}
Alissa												
0	30.7	32.2	31.5^{h1}	9.13	9.33	9.23^{h}	27.67	28.65	28.16^{h}	8.22	9.34	8.78^{g}
50	32.3	34.1	33.2^{g}	9.34	9.58	9.46^{g}	31.18	32.20	31.69^{f}	8.41	9.68	9.05^{f}
100	34.6	38.4	36.5^{e}	10.31	10.72	10.52^{e}	31.90	33.64	32.77^{e}	9.02	9.93	9.48^{e}
150	33.8	36.5	35.2^{f}	9.56	10.33	9.95^{f}	29.11	33.44	31.28^{g}	8.61	9.72	9.17^{f}
Mean	32.9^{b}	35.3^{a}	34.1^{B2}	9.59^{b}	9.99^{a}	9.79^{B}	29.97^{b}	31.98^{a}	30.97^{B}	8.57^{b}	9.67^{a}	9.12^{B}

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Table 2 shows that all SA applications (50, 100, and 150 mg SA /liter) significantly enhanced tomatoes shoot fresh weight, shoot dry weight, leaves fresh weight, and leaves dry weight for two cultivars compared with control. Kazemi discovered a comparable increase in fresh and dry weight of shoot as well as in fresh and dry leaves weight in 2014 by the SA foliar spray. The findings also reveal that at various levels, the vegetative growth of the cultivar Wadistar exceeds that of the cultivar Alissa. The findings also show that a high SA concentration of 150 mg/liter reduced vegetative growth when compared to 100 mg/liter level. The foliar spray at 100 mg SA /liter resulted in the maximum vegetative growth for the two cultivars, with increases in shoot fresh weight, shoot dry weight, leaves fresh and dry weight in the second season compared to the first.

Table 3 displays the impact of different doses of SA spraying on tomato leaves pigments.

Table 3. The effect of silicon on tomato leaves' pigments.

Treatments	Chlorophyll a (mg/g DW)			Chlorophyll b (mg/g DW)			Carotenoids (mg/g DW)		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	18.4	18.9	18.6^{g1}	7.3	8.1	7.7^{g}	2.8	3.1	2.9^{f}
50	19.4	21.3	20.4^{f}	8.4	8.8	8.6^{f}	3.3	3.4	3.4^{e}
100	23.2	26.8	25.0^{c}	9.5	10.6	10.1^{c}	4.0	4.3	4.2^{c}
150	21.5	23.7	22.6^{d}	9.3	10.1	9.7^{d}	3.9	4.2	4.0^{d}
Mean	20.6^{b3}	22.7^{a3}	21.6^{B2}	8.6^{b}	9.4^{a}	9.0^{B}	3.5^{b}	3.8^{a}	3.6^{B}
Alissa									
0	20.5	21.4	20.9^{e1}	8.4	8.8	8.6^{f}	3.1	3.4	3.3^{e}
50	22.0	23.4	22.7^{d}	9.1	9.6	9.4^{e}	4.0	4.5	4.3^{c}
100	26.0	28.1	27.1^{a}	11.4	12.5	11.9^{a}	4.9	5.4	5.2^{a}
150	24.2	26.9	25.5^{b}	10.2	11.2	10.7^{b}	4.8	5.2	5.0^{b}
Mean	23.2^{b}	25.0^{a}	24.1^{A2}	9.8^{b}	10.5^{a}	10.1^{A}	4.2^{b}	4.6^{a}	4.4^{A}

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When SA was applied to tomato leaves, it enhanced the level of pigments relative to the control. The current findings are consistent with previous findings of (Sweify and Abdel-Wahid 2008; Zaki and Radwan, 2011; Kazemi, 2014), who observed that the employing of SA improved the amounts of different chlorophyll types. This may be due to perfected antioxidant protection and lessened oxidative damage by added silicon as reported by (Shi et al. 2016). Chlorophyll content increased considerably in the presence of silicon which improving the process photochemical efficiency (Chen et al. 2011). Additionally, (Zhang et al., 2018) found that adding silicon improved the quantities of chlorophyll and carotenoids. The maximum pigments concentrations for three types in tomato leaves were achieved when 100 mg SA /liter was sprayed on both cultivars. However, increasing the SA level to 150 mg/liter significantly lowered the amount of different chlorophyll types. These findings corroborate those by Singh and Singh (2008), who discovered that lower concentrations of SA considerably enhance different chlorophyll types compared with greater concentrations. The Alissa cultivar has a higher content of different chlorophyll types than Wadistar.

Table 4. The effect of silicon on tomatoes yield of plant, plot, and fed.

Treatments	Plant yield kg/plant			Pilot yield kg			Yield ton /fed		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	4.6	4.8	4.7^{e1}	92.5	98.3	95.4^{g}	38.9	42.8	40.8^{h}
50	4.9	5.2	5.1^{d}	98.7	102.3	100.5^{f}	41.5	47.6	44.5^{g}
100	6.7	7.1	6.9^{b}	133.7	141.9	137.8^{b}	56.2	61.8	59.0^{b}
150	6.6	6.9	6.8^{b}	131.5	136.4	134.0^{c}	55.2	58.7	57.0^{d}
Mean	5.7^{b3}	6.0^{a3}	5.9^{B2}	114.1^{b}	119.7^{a}	116.9^{B}	47.9^{b}	52.7^{a}	50.3^{B}
Alissa									
0	5.9	6.2	6.1^{c1}	117.1	123.2	120.2^{e}	49.2	54.1	51.7^{f}
50	6.0	6.5	6.3^{c}	120.2	126.7	123.5^{d}	50.5	58.2	54.3^{e}
100	6.9	7.3	7.1^{a}	138.3	145.3	141.8^{a}	58.1	61.2	59.7^{a}
150	6.7	7.0	6.9^{b}	134.5	138.2	136.4^{b}	56.5	60.4	58.4^{c}
Mean	6.4^{b}	6.8^{a}	6.6^{A2}	127.5^{b}	133.4^{a}	130.4^{A}	53.6^{b}	58.5^{a}	56.0^{A}

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Table 4 provides data about tomatoes yield of plant, plot, and fed. after spraying by SA with different levels. As varied doses of SA were sprayed on leaves plants increased plant yield, pilot yield, and yield per fed. when compared to the control. According to researches (Zaghlool et al., 2001; Khodary, 2004; El- Tayeb, 2005; Yildirim et al., 2008), external SA spray has a wide range of impacts on growth yield and fruits per plant. Additionally, (Kazemi, 2014) indicated that using SA increased tomato growth, yield, and fruit quality. Furthermore, foliar employing of SA significantly rose the output of corn, basil, and marjoram (Abdel-Wahed et al., 2006; Gharib, 2006). The yield of plant, plot, and fed. have increased due to silicon applied, which promoted plant growth, raised chlorophyll pigments content, and plays a function in changing some genes connected to photosynthesis, controlling the photochemical process, and encouraging photosynthesis (Zhang et al., 2018). The yield of plant, plot, and fed. were considerably reduced by spraying with 150 mg SA/liter compared to spraying with 100 mg SA/liter. Alissa sprayed with 100 mg SA producing the greatest plant yield, pilot yield, and fed. yield (6.6 kg/plant, 130.4 kg/pilot, and 56 ton/fed., respectively) compared to Wadistar's yield of plant, pilot, and fed. (5.9 kg/plant, 116.9 kg/ pilot, and 50.3 ton/fed., respectively).

Table 5. The effect of silicon on tomato fruits TSS, acidity %, and pH.

Treatments	TSS			Acidity%			pH		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	4.3	4.5	4.4^{f1}	0.53	0.57	0.55^{f}	4.24	4.18	4.21^{a}
50	4.5	4.6	4.6^{e}	0.66	0.68	0.67^{e}	4.01	3.98	4.00^{b}
100	4.8	4.9	4.9^{b}	0.79	0.81	0.80^{c}	3.82	3.78	3.80^{e}
150	4.7	4.8	4.8^{c}	0.71	0.75	0.73^{d}	3.94	3.85	3.90^{d}
Mean	4.6^{a3}	4.7^{a3}	4.6^{A2}	0.67^{a}	0.70^{a}	0.69^{A}	4.00^{a}	3.95^{a}	3.98^{A}
Alissa									
0	4.0	4.2	4.1^{g1}	0.66	0.68	0.67^{e}	3.97	3.92	3.95^{c}
50	4.2	4.5	4.4^{f}	0.73	0.76	0.75^{d}	3.82	3.71	3.77^{e}
100	4.8	5.1	5.0^{a}	0.89	0.94	0.92^{a}	3.65	3.63	3.64^{g}
150	4.5	4.8	4.7^{d}	0.79	0.83	0.81^{b}	3.72	3.68	3.70^{f}
Mean	4.4^{b}	4.7^{a}	4.5^{A2}	0.77^{a}	0.80^{a}	0.79^{B}	3.79^{a}	3.74^{a}	3.76^{B}

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Table 6. The effect of silicon on tomato fruits vitamin c, total phenols, and firmness.

Treatments	Vitamin C mg/100g			Total phenols mg/100g			Fruits firmness (newteen)		
Wadistar	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
0	103.2	110.1	106.7^{d1}	171.8	175.1	173.4^{e}	51.6	55.3	53.4^{h}
50	123.5	128.3	125.9^{c}	177.5	193.5	185.5^{c}	53.8	57.4	55.6^{g}
100	133.6	139.7	136.6^{a}	227.7	234.2	230.9^{a}	61.0	63.1	62.1^{e}
150	126.8	131.1	129.0^{b}	210.3	221.4	215.8^{b}	56.1	60.1	58.1^{f}
Mean	121.8^{b3}	127.3^{a3}	124.5^{A2}	196.8^{b}	206.0^{a}	201.4^{A}	55.6^{b}	59.0^{a}	57.3^{B}
Alissa									
0	39.8	52.8	46.3^{h1}	151.7	162.5	157.1^{f}	72.7	75.5	74.1^{d}
50	55.6	68.1	61.8^{g}	173.7	185.5	179.6^{d}	76.8	79.4	78.1^{c}
100	98.5	101.3	99.9^{e}	181.2	197.9	189.5^{c}	84.2	86.3	85.3^{a}
150	90.2	94.5	92.4^{f}	179.1	193.3	186.2^{c}	82.2	85.4	83.8^{b}
Mean	71.0^{b}	79.2^{a}	75.1^{B2}	171.4^{b}	184.8^{a}	178.1^{B}	79.0^{b}	81.6^{a}	80.3^{A}

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The chemical analysis of tomato plant fruits sprayed with SA at various levels (0, 50, 100, and 150 mg/L) is shown in Tables 5 and 6. In compared to the control (0 mg SA/liter), the mean TSS, acidity %, vitamin c, phenolic compounds, and fruit firmness increased considerably in all three treatments (50,100, and 150 mg SA /liter). Similarly, the treatment (100 mg SA/liter) showed significantly higher means of TSS, acidity %, vitamin C, total phenols, and fruit firmness than the other treatments. SA spray improved tomatoes firmness and quality. Our findings are like that of (Kazemi, 2014), who stated that applying SA significantly improved tomato fruit quality.

4. Conclusions

Finally, foliar spraying with SA as a silicon source for tomato plant leaves at levels (50,100,150 mg/liter) increased plant growth, yield, fruit quality, and firmness comparison with non-sprayed plants. However, spraying tomato leaves at level (150 mg/L) decreased plant growth, yield, fruit quality, and firmness compared to spraying tomato leaves at a dosage of (100 mg/liter). Therefore, we recommend spraying with SA as a source of silicon at a concentration of 100 mg / liter after 15 days of transplanting tomatoes in the permanent ground at a rate of once every 15 days for three time to improve the firmness and quality of the fruits while obtaining the highest possible yield with excellent vegetative growth features.

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