Archives of Agriculture Sciences Journal
Print ISSN: 2535-1680
Online ISSN: 2535-1699

ARCHIVES OF AGRICULTURE SCIENCES JOURNAL
Volume 6, Issue 2, 2023, Pages 122–140
Available online at www.agricuta.edu.eg
DOI: https://dx.doi.org/10.21608/aasj.2023.314998

The use of potassium silicate and fulvic acid to mitigate the effects of heat stress in tomato plants

Abdel-Zaher A., Abd El-Rehim G. H., Abd Elmotagly M., Yousef A. F.*

Department of Horticulture, Faculty of Agriculture, Al-Azhar University, (Assiut branch), Assiut 71524, Egypt

Abstract

In the summer season, the heat poses a challenge to open-field tomato production, leading to decreased yields. As a result, we conducted a study to examine the impact of various foliar spray compositions on enhancing nutrient absorption and increasing fruit yield in tomato plants. The experiment consisted of two factors: Hybrids [Nirouz (TH99806) and 023] as the main factor, while the sub-main factor was potassium silicate (P3: 3 mL L^{-1}) or/and fulvic acid (F2: 2 mL L^{-1}), and CK (H_2O) as a control. The plants were sprayed three times, the first time was after 30 days from transplanting the seedlings, the second time was after 20 days from the first time, and the third time was after 20 days from the second time. As a result, P3 generated the highest yield in plants compared with the other treatments. Also, Foliar spraying with P3+F2 increased the leaf content of chlorophyll *a*, carotene and TSS. Thus, P3 and P3+F2 stimulated the plant nutrient uptake, which improved the marketable yield. So, we recommend foliar spraying with potassium silicate at a rate of 3 mL per liter of water to avoid heat stress on tomato plants.

Keywords: chlorophyll pigments, leaf spray, tomato fruit quality, total yield, TSS.

*Corresponding author: Yousef A. F.,
E-mail address: ahmedyousuf@azhar.edu.eg

1. Introduction

In the southern region of Egypt, summer open-field tomato production faces significant difficulties due to persistently high temperatures from May to August. These elevated temperatures negatively affect plant reproduction by reducing the fertility of tomato pollen, leading to a decrease in fruit setting rates and an increase in abnormal fruits caused by imbalanced osmosis (Pham *et al*., 2020). Specifically, during the flower stage and pollination phase, high temperatures negatively impact tomato plants by delaying gamete development, sterilizing pollen, interfering with pollen tube growth, and shortening the time available for flower mating. This results in reduced fruit set and an increased percentage of abnormal fruits due to difficulties in successful pollination and reproductive processes (Hedhly *et al*., 2009; León-Osper *et al*., 2020). While the heat-induced decrease in yield occurred and there were corresponding enhancements in certain fruit quality factors, such as total soluble content and total acid levels (Mesa *et al*., 2022; Vijayakumar *et al*., 2021), it could not compensate for the overall loss in total production. Furthermore, the heat also affects the uptake and transportation of nutrients, leading to physiological disorders such as fruit blossom end rot caused by calcium deficiency (Saure, 2014; Suzuki *et al*., 2015) and yellow shoulder resulting from potassium deficiency (Zhang *et al*., 2018). These nutrient-related issues further contribute to the challenges faced in tomato production under high-temperature conditions (Amirahmadi *et al*., 2023; Guo *et al*., 2022*)*. The length of tomato fruit development and ripening can also be prolonged by low vapour pressure deficits, which can reduce fruit number, fruit diameter, and yield per truss (Doan and Tanaka, 2022). Moreover, it can also result in reduced concentrations of N, P, and K in tomato plant stems, leaves, and fruits (Suzuki *et al*., 2015), as well as hinder the uptake of Ca and K in vigorously growing plant organs (Ding *et al*., 2022). Leaf spraying is a frequently used technique for reducing plant heat stress. It works well as a physical light film, metabolic regulator, and excessive sunlight reflector (Mphande *et al*., 2020). Additionally, it can act as a biostimulant to enhance crop aboveground biomass and improve photosynthesis-related performance under heat stress conditions (Niu *et al*., 2022). As an example, the application of leaf-sprayed silicon has been shown to have several positive effects on crops under various stress conditions. It can increase crop leaf chlorophyll content, the maximum quantum transport efficiency of photosystem II (PSII), and the activity of antioxidant enzymes when administered in conditions of water scarcity (Verma *et al*., 2021). In shaded conditions, leaf-sprayed silicon promotes leaf photosynthesis, increases leaf total soluble sugar content, and enhances biomass accumulation (Hussain *et al*., 2021). Moreover, it strengthens the leaf cortex wax layer and increases stomatal conductance, which can be beneficial under heat stress (Hu *et al*., 2020). While, polymerized silicon can strengthen the epidermal cell wall, stabilising the lipid layers of epidermal cells and preserving membrane function can be accomplished by increasing plant silicon absorption during environmental stress (Agarie *et al*., 1998). The application of silicate to plant roots may help alleviate the biotoxicity of antibiotics present in the soil, thereby reducing root damage and limiting antibiotic absorption (Lv *et al*., 2021). During heat stress, silicon enhances various aspects of plant performance. It improves plant transpiration, increases leaf chlorophyll concentration, enhances photosystem core protein levels, reinforces cell wall rigidity, and increases cortical wax thickness. Importantly, these effects occur without altering the content of abscisic acid (ABA), a key stress-related hormone (Saha *et al*., 2021). Regarding fruiting, silicon has specific benefits as well. It can enhance the plant's anthesis rate (the rate at which flowers open), increase pollen fertility, and improve membrane stability during the reproductive process (Nahar *et al*., 2015). Moreover, there is evidence to suggest that spraying silicate at low dosages (ranging from 50 to 100 mg dm^{-3}) may have positive effects on flowering. For some species in the Asteraceae family, this treatment can lead to the enlargement of the flower diameter and even accelerate the flowering process (Attia and Elhawat, 2021; Kamenidou *et al*., 2010). In contrast to the previously mentioned substances, fulvic acid is a complex mixture comprising various components such as amino acids, carbohydrates, organic acids, minerals, and phytohormone-like compounds. When plants are subjected to stress, fulvic acid can play a beneficial role by enhancing the uptake of essential mineral nutrients like Fe, Zn, and Mn. Additionally, it increases leaf chlorophyll content, which leads to an improvement in the plant's photosynthesis capacity (Wang *et al*., 2019). It has the ability to expedite plant recovery from water stress. It helps maintain a higher photosynthesis rate and enhances the activity of antioxidant enzymes, which ultimately helps in preserving yield and reducing losses caused by water stress (do Rosário Rosa *et al*., 2021). Fulvic acid acts as an antitranspirant, yet its positive impact on water use efficiency and leaf water content makes it advantageous for over-summer production. These properties enable effective water management in plants during hot and water-limited conditions, making it a favorable choice for cultivation during such periods (AbdAllah *et al*., 2018). In addition, the application of fulvic acid through leaf spraying can enhance the effects of paclobutrazol (PBZ) in suppressing gibberellin synthesis. This leads to improved flower uniformity and increased accumulation of carbohydrates, proteins, and amino acids within the plant (dos Santos Silva *et al*., 2021). Our study focuses on ensuring plant nutrition acquisition and achieving marketable yield. The objective is to compare the effectiveness of various combinations of potassium silicate and fulvic acid when applied through foliar spraying. Our hypothesis is that these substances can enhance the uptake of nutrients by the plants and their subsequent translocation to the fruit, ultimately leading to improved fruit yield.

2. Materials and methods

2.1 Experimental site and treatments description

The experimental design followed a randomized complete block design (RCBD) with three replicates. It consisted of two factors: Hybrids [Nirouz (TH99806) and 023] as the main factor, while sub-main factor was potassium silicate (P3: 3 mL L^{-1}) or/and fulvic acid (F2: 2 mL L^{-1}), and CK (H_2O) as a control, in total 4 treatments. The field experiments were conducted during the summer seasons of 2021 and 2022 at a private farm in Isna city, Aswan Governorate, Egypt (located at 25°18′N 32°33′E). The experimental plots had dimensions of 1 meter in width and 10.5 meters in length (10.5 m^2). The soil was sterilized before planting using 100 kg per feddan (4200 m^2) of agricultural sulfur produced by Abu Qir Fertilizer and Chemical Industries. The prescribed basal dose of P_2O_5 i.e., 60 kg $feddan^{-1}$ (15.5% $CaH_6O_9P_2$) and 30 m^3 of decomposed organic fertilizer were incorporated into the soil. While 120 kg N $feddan^{-1}$ (33.5% NH_4NO_3) and 100 kg $feddan^{-1}$ K_2O (50% potassium sulfate) were divided into two equivalent splits at 30 and 60 days after transplanting, as recommended by the Ministry of Agriculture, Egypt (Hassan, 2011). Certified tomato seedlings of the hybrids were obtained from a private greenhouse for the production of tomato seedlings. The tomato seedlings were then manually planted at a spacing of 30 cm between hills on 14th June 2021 and 2022. The plants were sprayed three times, the first time was after 30 days from transplanting the seedlings, the second time was after 20 days from the first time, and the third time was after 20 days from the second time.

2.2 Data collection

During the harvest stage, plant samples were gathered on 28th September 2021, growing season, and 2nd October 2022 growing season, and the growth parameters, including plant height and the number of branches, were documented.

2.3 Biochemical analysis

2.3.1 Photosynthetic pigments content

Chlorophyll contents were measured spectrophotometrically using fresh leaves from six different plants in each treatment, taken 80 days after transplanting. For analysis, 0.2 grammes of fresh leaf tissue were finely ground and immersed in 5 mL of 95% ethanol. The mixture was filtered, and the volume was adjusted to 25 mL using 95% ethanol. The spectrophotometer (Model BTS-45, United Kingdom) was utilized to assess the absorbance values of chlorophyll *a*, chlorophyll b, and carotinoid at three different wavelengths: 665 nm, 649 nm, and 470 nm. Subsequently, the obtained data were computed employing the provided formulas (Knight and Mitchell, 1983):

$$\text{Chlorophyll } a \text{ (mg g}^{-1}) = (13.95\ OD_{665} - 6.88\ OD_{649})\ V/200\ W \quad 1$$

$$\text{Chlorophyll } b \text{ (mg g}^{-1}) = (24.96\ OD_{649} - 7.32\ OD_{663})\ V/200\ W \quad 2$$

$$\text{Carotinoid (mg g}^{-1}) = (1000\ OD_{470} - 2.05\ \text{Chl } a\text{-}114.80\ \text{Chl } b)\ V/(245 \times 200\ W). \quad 3$$

Where (V) = volume (25 mL) and (W) = sample weight (g).

2.3.2 Total soluble solids (T.S.S.) analysis

In the T.S.S. analysis of tomato fruit, ripe and defect-free tomatoes were selected. The tomatoes were washed, prepared, and homogenized to obtain a smooth puree. The supernatant was separated from the sediment, and the extracted tomato juice was optionally filtered. T.S.S. content was measured using a refractometer (Model: Milwaukee MA873 Digital, Milwaukee Co., United States), and the results were recorded in Brix (°Bx) units. Standard protocols were followed for the analysis.

2.4 Statistical analysis

The data obtained from these experiments were subjected to statistical analysis using the software Statistix 8.1**.** Two-way ANOVA (Analysis of Variance) was performed on the growth parameters and yield data to examine the significance of the effects of different factors (Hybrids and treatments). To further explore and compare the means that showed significant differences, Duncan's multiple range tests were employed. These tests allow for a detailed examination of the variations between treatment means with a 95% confidence level (Gomez and Gomez, 1984).

3. Results

3.1 Morphological traits

The results of the study indicate that the application of potassium silicate and fulvic acid had a significant impact on the morphology of tomato plants (Tables 1, 2, and 3). In both the first and second growing seasons, the tallest tomato plants were observed with H1, measuring 63.00 cm and 63.32 cm, respectively (Table 1). Additionally, during both seasons, plants treated with P3 exhibited the greatest height, measuring 72.13 cm and 72.05 cm, respectively. When considering the combined effect of tomato hybrids and treatments, the H1 treated with P3 demonstrated the highest plant height, measuring 76.33 cm and 77.20 cm during the first and second growing seasons, respectively.

Table (1): Effect of foliar spraying with potassium silicate and fulvic acid on plant height (cm) of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	43.33 e	39.67 f	41.50 c	44.03 f	39.33 g	41.68 c
P3	76.33 a	67.93 b	72.13 a	77.20 a	66.90 bc	72.05 a
F2	63.67 c	62.62 c	63.14 b	63.60 cd	61.47 d	62.53 b
P3+F2	68.67 b	54.28 d	61.48 b	68.43 b	56.67 e	62.55 b
Mean (Hybrids)	63.00 a	56.13 b		63.32 a	56.09 b	
LSD 0.05 A (Hybrids)		1.08		1.22		
LSD 0.05 B (Treatments)		2.07		2.33		
LSD 0.05 A*B (Interaction)		3.55		4.00		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (2): Effect of foliar spraying with potassium silicate and fulvic acid on number of branches of tomato plant during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	5.00 e	3.13 e	4.07 b	6.13 e	3.23 f	4.68 c
P3	10.30 abc	3.13 bcd	9.38 a	10.87 ab	9.30 bcd	10.08 a
F2	10.53 ab	8.03 cd	9.28 a	9.77 bc	8.03 cde	8.90 b
P3+F2	11.13 a	7.47 d	9.30 a	11.87 a	7.53 de	9.70 ab
Mean (Hybrids)	9.24 a	6.78 b		9.66 a	7.03 b	
LSD 0.05 A (Hybrids)		0.69		0.60		
LSD 0.05 B (Treatments)		1.32		1.15		
LSD 0.05 A*B (Interaction)		2.27		1.97		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}

During the first and second growing seasons, the tomato plants of H1 had the highest number of branches, measuring 9.24 and 9.66 branches plant^{-1}, respectively (Table 2). Additionally, in both seasons, plants treated with P3 showed the most abundant branches, with 9.38 and 10.08 branches plant^{-1}, respectively. When examining the combined effect of tomato hybrids and treatments, the H1 treated with P3 exhibited the maximum number of branches, with 11.13 and 11.87 branches plant^{-1} during the first and second growing seasons, respectively. In the first and second growing seasons, H1 had the highest number of leaves, with 72.67 and 69.69 leaves, respectively (Table 3). Additionally, during both seasons, plants treated with P3 exhibited the most abundant number of leaves, with 65.22 and 64.93 leaves, respectively. When examining the combined effect of tomato hybrids and treatments, the H1 treated with P3 demonstrated the maximum number of leaves, with 82.97 leaves during the first growing season. On the other hand, during the second growing season, H1 treated with P3+F2 exhibited the highest number of leaves, with 86.97 leaves.

Table (3): Effect of foliar spraying with potassium silicate and fulvic acid on number of leaves of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	47.00 b	21.53 c	34.27 b	43.70 cd	22.73 e	33.22 c
P3	82.97 a	47.47 b	65.22 a	78.00 ab	51.87 c	64.93 a
F2	81.10 a	42.50 b	61.80 a	70.10 b	43.80 cd	56.95 b
P3+F2	79.60 a	38.57 bc	59.08 a	86.97 a	39.20 d	63.08 ab
Mean (Hybrids)	72.67 a	37.52 b		69.69 a	39.40 b	
LSD 0.05 A (Hybrids)		5.69		3.34		
LSD 0.05 B (Treatments)		10.90		6.40		
LSD 0.05 A*B (Interaction)		18.70		10.99		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*$p \leq 0.05$*). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

3.2 Yield traits

The results of the study indicate that the application of potassium silicate and fulvic acid had a significant impact on the yield traits of tomato plants (Tables 4, 5, 6, 7, 8, 9, and 10). In the first and second growing seasons, the maximum number of fruits per feddan was with H1 (171950 and 278450), respectively (Table 4). During the first and second growing seasons, the plants treated with P3 exhibited the tallest number of fruits per feddan (159767 and 240000), respectively. When considering the interactive effect of hybrids and treatments, H1 treated with F2 showed the maximum number of fruits per feddan (192067) during the first growing season, while H1 treated with P3 showed the maximum number of fruits per feddan (378000) during the second growing season. In the first and second growing seasons, the maximum number of non-marketing fruits per feddan was with H2 (600.00 and 1150.00), respectively (Table 5). During the first and second growing seasons, the plants treated with CK exhibited the tallest number of non-marketing fruits per feddan (1200.00 and 1300.00), respectively. When considering the interactive effect of hybrids and treatments, the H2 treated with CK showed the number of non-marketing fruits per feddan (1600.00) during the first growing season, while the H2 treated with P3 showed the maximum number of non-marketing fruits per feddan (2000.00) during the second growing season.

Table (4): Effect of foliar spraying with potassium silicate and fulvic acid on number of fruits feddan^{-1} of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	134000 b	75400 d	104700 c	190200 d	67400 f	128800 d
P3	190133 a	129400 bc	159767 a	378000 a	102000 e	240000 a
F2	192067 a	109000 c	150533 ab	279600 b	104600 e	192100 b
P3+F2	171600 a	110000 c	140800 b	266000 c	106400 e	186200 c
Mean (Hybrids)	72.67 a	37.52 b		69.69 a	39.40 b	
LSD 0.05 A (Hybrids)		6461.70		1529.70		
LSD 0.05 B (Treatments)		12379.00		2930.50		
LSD 0.05 A*B (Interaction)		21242.00		5028.50		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (5): Effect of foliar spraying with potassium silicate and fulvic acid on number of non-marketing fruits feddan^{-1} of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	800.00 b	1600.00 a	1200.00 a	800.00 c	1800.00 b	1300.00 a
P3	0.00 e	0.00 e	0.00 d	200.00 f	2000.00 a	1100.00 b
F2	600.00 c	400.00 d	500.00 b	600.00 d	400.00 e	500.00 c
P3+F2	0.00 e	400.00 d	200.00 c	0.00 g	400.00 e	200.00 d
Mean (Hybrids)	350.00 a	600.00 a		400.0 b	1150.0 a	
LSD 0.05 A (Hybrids)		60.11		34.07		
LSD 0.05 B (Treatments)		115.15		65.27		
LSD 0.05 A*B (Interaction)		197.59		112.00		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

In the first and second growing seasons, the maximum number of marketing fruits per feddan was with H1 (171600 and 278050), respectively (Table 6). During the first and second growing seasons, the plants treated with P3 exhibited the highest number of marketing fruits per feddan (159767 and 238900), respectively. When considering the interactive effect of hybrids and treatments, the H1 treated with F2 showed the highest number of marketing fruits per feddan (191467) during the first growing season, while the H1 treated with P3 showed the maximum number of marketing fruits per feddan (377800) during the second growing season.

Table (6): Effect of foliar spraying with potassium silicate and fulvic acid on number of marketing fruits feddan^{-1} of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	133200 b	73800 d	103500 c	189400 d	65600 g	127500 d
P3	190133 a	129400 bc	159767 a	377800 a	100000 f	238900 a
F2	191467 a	108600 c	150033 ab	279000 b	104200 ef	191600 b
P3+F2	171600 a	109600 c	140600 b	266000 c	106000 e	186000 c
Mean (Hybrids)	171600 a	105350 b		278050 a	93950 b	
LSD 0.05 A (Hybrids)		6454.00		1527.50		
LSD 0.05 B (Treatments)		12365.00		2926.40		
LSD 0.05 A*B (Interaction)		21216.00		5021.40		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (7): Effect of foliar spraying with potassium silicate and fulvic acid on weight of non-marketing fruits (kg feddan^{-1}) of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	10.30 b	19.38 a	14.84 a	10.30 cd	38.00 a	24.15 a
P3	0.00 c	0.00 c	0.00 c	4.03 de	6.70 cde	5.37 c
F2	13.38 ab	6.70 bc	10.04 b	13.38 bc	19.38 b	16.38 b
P3+F2	0.00 c	5.80 bc	2.90 c	0.00 e	5.80 cde	2.90 c
Mean (Hybrids)	5.92 a	7.97 a		6.93 b	17.47 a	
LSD 0.05 A (Hybrids)		2.47		2.61		
LSD 0.05 B (Treatments)		4.74		5.00		
LSD 0.05 A*B (Interaction)		8.13		8.59		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

In the first and second growing seasons, the heaviest weight of non-marketing fruits was with H2 (7.97 and 17.47 kg feddan^{-1}), respectively (Table 7). The plants treated with CK exhibited the heaviest weight of non-marketing fruits (14.84 and 24.15 kg feddan^{-1}) during the first and second growing seasons, respectively. When considering the interactive effect of hybrids and treatments, the H2 treated with CK showed the heaviest weight of non-marketing fruits (19.38 and 38.00 kg feddan^{-1}) during the first and second growing seasons, respectively. In the first and second growing seasons, the heaviest weight of marketing fruits was with H1 (10.53 and 10.58 ton feddan^{-1}), respectively (Table 8). During the first and second growing seasons, the plants treated with P3 exhibited the heaviest weight of marketing fruits (9.45 and 8.65 ton feddan^{-1}), respectively. When considering the interactive effect of hybrids and treatments, H1 treated with P3 showed the heaviest weight of marketing fruits (15.80 and 14.99 ton feddan^{-1}) during the first and second growing seasons, respectively.

Table (8): Effect of foliar spraying with potassium silicate and fulvic acid on weight of marketing fruits (ton feddan^{-1}) of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	3.48 d	0.88 h	2.18 d	3.68 d	0.68 g	2.18 d
P3	15.80 a	3.10 e	9.45 a	14.99 a	2.30 ef	8.65 a
F2	11.56 b	2.59 f	7.08 b	11.26 c	2.44 f	6.85 c
P3+F2	11.30 c	2.39 g	6.85 c	12.40 b	2.19 f	7.30 b
Mean (Hybrids)	10.53 a	2.24 b		10.58 a	1.90 b	
LSD 0.05 A (Hybrids)	0.02			0.04		
LSD 0.05 B (Treatments)	0.04			0.08		
LSD 0.05 A*B (Interaction)	0.06			0.14		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*p ≤ 0.05*). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (9): Effect of foliar spraying with potassium silicate and fulvic acid on weight of one fruit (g) of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	26.22 c	11.93 d	19.08 c	19.46 e	10.35 f	14.90 c
P3	83.15 a	23.97 c	53.56 a	39.68 b	23.04 c	31.36 b
F2	60.56 b	23.83 c	42.20 b	40.37 b	23.42 c	31.90 b
P3+F2	65.97 b	21.83 c	43.90 b	46.63 a	20.68 d	33.65 a
Mean (Hybrids)	58.99 a	58.98 a		36.54 a	19.38 b	
LSD 0.05 A (Hybrids)	1.75			0.37		
LSD 0.05 B (Treatments)	3.35			0.71		
LSD 0.05 A*B (Interaction)	5.75			1.22		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*p ≤ 0.05*). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

In the first and second growing seasons, the heaviest weight of one fruit cultivar was with H1 (58.99 and 36.54 g), respectively (Table 9). The plants treated with P3 exhibited the heaviest weight of one fruit (53.56 g) during the first season, while the plants treated with P3+F2 exhibited the heaviest weight of one fruit (33.65 g) during the second season. When considering the interactive effect of hybrids and treatments, the H1 treated with P3 showed the heaviest weight of one fruit (83.15 g) during the first growing season, while during the second growing season the H1 treated with P3+F2 showed the heaviest weight of one fruit (46.63 g). In the first and second growing seasons, the highest total yield was with H1 (10.55 and 10.60 ton feddan^{-1}), respectively (Figure 1 A). During the first and second growing seasons, the plants treated with P3 exhibited the highest total yield (9.45 and 8.68 ton feddan^{-1}), respectively (Figure 1 B). When considering the interactive effect of hybrids and treatments, the H1 treated with P3 showed the highest total yield (15.80 and 15.00 ton feddan^{-1}) during the first and second growing seasons, respectively (Figure 1 C).

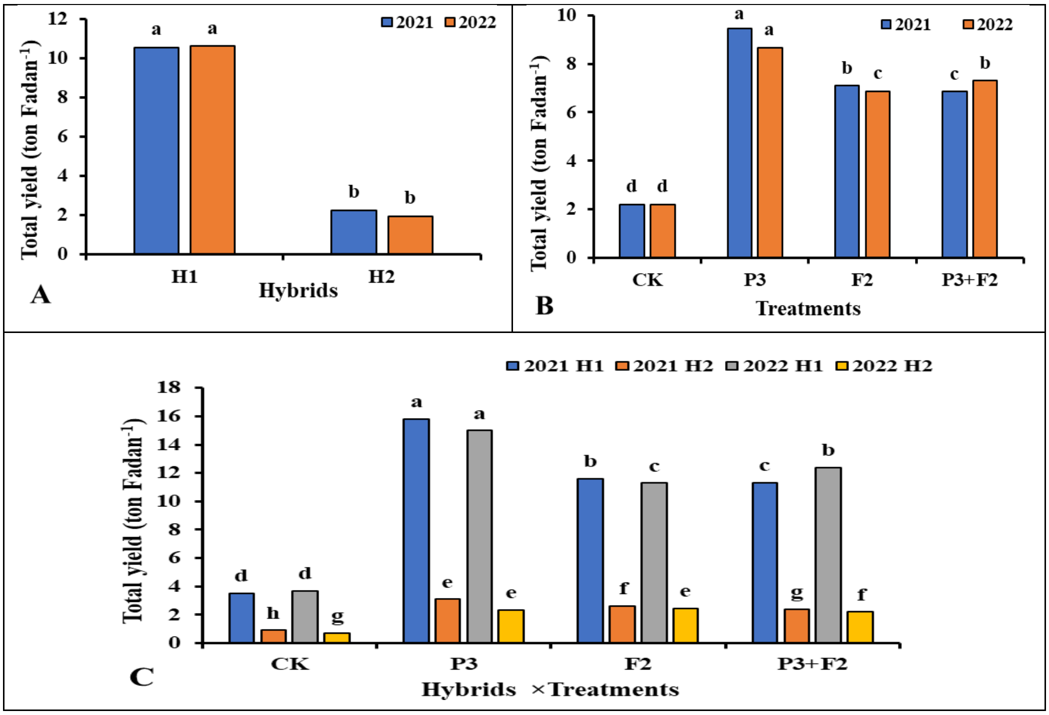

Figure 1. Effect of hybrids (A), treatments (B), and the interaction between them (C) on total yield (ton Fadan^{-1}) of tomato plants during the 2021 and 2022 growing seasons. The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different ($p \leq 0.05$). Where: Feddan= is an area unit equal to 4200 square meters; H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment (H_2O); P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

3.3 Biochemical analysis

The results of the study indicate that the application of potassium silicate and fulvic acid had a significant impact on the biochemical analysis of tomato plants (Tables 10, 11, 12, and 13). In the first and second growing seasons, the maximum chlorophyll *a* content with H1 was (1.09 and 1.06 mg g^{-1}), respectively (Table 10). During the first and second growing seasons, the plants treated with P3+F2 exhibited the highest chlorophyll *a* content (1.23 and 1.19 mg g^{-1}), respectively. Moreover, when examining the combined effect of hybrids and treatments, H1 treated with P3+F2 exhibited the greatest chlorophyll *a* content, measuring 1.44 and 1.40 mg g^{-1}, in the first and second growing seasons, respectively. The H1 plant had the greatest chlorophyll *b* level during the first and second growth seasons (0.21 and 0.19 mg g^{-1}, respectively) (Table 11). The plants treated with P3 had the greatest chlorophyll *b* concentration during the first and second growth seasons (0.23 and 0.20 mg g^{-1}, respectively). The H1 treated with P3 had the highest plant chlorophyll *b* content (0.26 and 0.23 mg g^{-1}) during the first and second growing seasons, respectively, while taking into account the interaction impact of hybrids and treatments.

Table (10): Effect of foliar spraying with potassium silicate and fulvic acid on chlorophyll *a* (mg g^{-1}) in leaves of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	0.75 c	0.36 d	0.56 d	0.72 c	0.33 d	0.53 c
P3	1.07 b	0.82 c	0.94 c	1.05 b	0.80 c	0.92 c
F2	1.10 b	1.05 b	1.08 b	1.07 b	1.01 b	1.04 b
P3+F2	1.44 a	1.03 b	1.23 a	1.40 a	0.99 b	1.19 a
Mean (Hybrids)	1.09 a	0.82 b		1.06 a	0.78 b	
LSD 0.05 A (Hybrids)		0.05		0.05		
LSD 0.05 B (Treatments)		0.10		0.10		
LSD 0.05 A*B (Interaction)		0.17		0.17		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*p ≤ 0.05*). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment; P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (11): Effect of foliar spraying with potassium silicate and fulvic acid on chlorophyll *b* (mg g^{-1}) in leaves of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	0.20 ab	0.08 b	0.14 b	0.21 a	0.07 b	0.14 a
P3	0.26 a	0.19 ab	0.23 a	0.23 a	0.16 ab	0.20 a
F2	0.22 a	0.20 ab	0.21 ab	0.20 ab	0.18 ab	0.19 a
P3+F2	0.15 ab	0.18 ab	0.17 ab	0.13 ab	0.16 ab	0.15 a
Mean (Hybrids)	0.21 a	0.16 b		0.19 a	0.14 b	
LSD 0.05 A (Hybrids)		0.04		0.04		
LSD 0.05 B (Treatments)		0.08		0.08		
LSD 0.05 A*B (Interaction)		0.13		0.14		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*p ≤ 0.05*). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment; P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

Table (12): Effect of foliar spraying with potassium silicate and fulvic acid on carotinoid (mg g^{-1}) in leaves of tomato plants during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	0.18 e	0.14 e	0.16 d	0.17 e	0.12 e	0.15 d
P3	0.28 d	0.28 cd	0.29 c	0.24 d	0.26 cd	0.25 c
F2	0.32 bcd	0.36 b	0.34 b	0.29 bcd	0.33 b	0.31 b
P3+F2	0.47 a	0.34 bc	0.40 a	0.44 a	0.31 bc	0.37 a
Mean (Hybrids)	0.31 a	0.28 b		0.29 a	0.25 b	
LSD 0.05 A (Hybrids)		0.02		0.02		
LSD 0.05 B (Treatments)		0.03		0.03		
LSD 0.05 A*B (Interaction)		0.06		0.06		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*p ≤ 0.05*). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment; P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

The cultivar (H1) with the highest carotenoids content throughout the first and second growing seasons was (0.31 and 0.29 mg g^{-1}, respectively) (Table 12). The plants treated with P3+F2 showed the highest levels of carotenoids during the first and second growth seasons (0.40 and 0.37 mg g^{-1}, respectively). The H1 treated with P3+F2 had the highest carotenoids content (0.47 and 0.44 mg g^{-1}) throughout the first and second growing seasons, respectively, while taking into account the interaction impact of hybrids and treatments.

Table (13): Effect of foliar spraying with potassium silicate and fulvic acid on total soluble solids (T.S.S.) of tomato fruits during the 2021 and 2022 growing seasons.

Treatments	2021			2022		
	H1	H2	Mean (Treatments)	H1	H2	Mean (Treatments)
CK	2.97 b	3.06 b	3.02 c	2.99 c	3.00 b	3.00 c
P3	4.03 a	4.13 a	4.08 b	4.05 b	4.18 b	4.12 b
F2	4.11 a	3.99 a	4.05 b	4.09 b	4.00 b	4.05 b
P3+F2	4.72 a	4.46 a	4.59 a	4.79 a	4.51 a	4.65 a
Mean (Hybrids)	3.96 a	3.91 a		3.98 a	3.92 a	
LSD 0.05 A (Hybrids)		0.23		0.09		
LSD 0.05 B (Treatments)		0.44		0.18		
LSD 0.05 A*B (Interaction)		0.75		0.31		

The values shown in table are means of three replicates. Means followed by the same letters are non-significantly different (*$p \leq 0.05$*). Where: H1= Nirouz hybrid; H2= 023 hybrid; CK= control treatment; P3= potassium silicate 3 mL L^{-1}; F2= Fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3 mL L^{-1}+ Fulvic acid 2 mL L^{-1}.

In the first and second growing seasons, the maximum total soluble solids with H1 were (3.96 and 3.98), respectively (Table 13). During the first and second growing seasons, the plants treated with P3+F2 exhibited the maximum total soluble solids (4.59 and 4.65), respectively. When considering the interactive effect of hybrids and treatments, the H1 treated with P3+F2 showed the maximum plant total soluble solids (4.72 and 4.79) during the first and second growing seasons, respectively.

4. Discussion

The goal of the current study was to assess how foliar applications of potassium silicate and fulvic acid affected tomato plants and how they interacted with one another to produce the most fruits with the best quality under heat stress. Our findings demonstrated that foliar spraying with potassium silicate alone or in conjunction with fulvic acid boosted the physical characteristics of the plant and fruit, such as plant height, leaf count, and overall yield. Applying potassium fertilizer to the field has positive effects on plant health and productivity. It can improve various aspects such as SPAD (chlorophyll content), photosynthesis, transpiration, and fruit yield (Yang *et al*., 2017). Conversely, a deficiency of potassium negatively impacts the plant's leaf growth and expansion, leading to stunted development (El-Mageed *et al*., 2023). Fulvic acid is known to contain nitrogen, and the quantity of nitrogen in fulvic acid varies based on the parent material from which it is derived (Winkler and Ghosh, 2018). As a complex macromolecular compound, fulvic acid comprises aromatic and nitrogen compounds synthesized by certain microorganisms present in the soil (Geng *et al*., 2020). Correct, nitrogen is a crucial element in plants used for the synthesis of various essential components, including amino acids, chlorophyll, enzymes, and DNA (Stein and Klotz, 2016). On the other hand, potassium plays a vital role in enzyme activation, ATP synthesis (energy production), and the regulation of stomatal opening and closure (Hawrylak-Nowak *et al*., 2018). Both nitrogen and potassium are essential nutrients for the healthy growth and functioning of plants. The promotion of nitrogen and potassium uptake in plants has a positive impact on biomass accumulation. Research has shown that when plants receive a higher potassium supply under the same nitrogen source, it leads to increased plant photosynthesis, stomatal conductance, transpiration, and overall biomass accumulation. Conversely, when potassium supply is reduced at the same nitrogen level, these processes are negatively affected (Guo *et al*., 2019). In early serial studies, the effectiveness of potassium on nitrate absorption, root-to-shoot translocation, and plant assimilation was demonstrated. Specifically, a higher potassium supply was found to increase shoot nitrate concentration and enhance nitrate reductase activity (Blevins *et al*., 1978). At the same time, nitrate supply also stimulates the absorption and assimilation of potassium, particularly when light is present (Blevins *et al*., 1974). The difference is that early studies supplied potassium silicate or fulvic acid through the root system, while our study considered foliar application (P3= potassium silicate 3mL L^{-1}; F2= fulvic acid 2 mL L^{-1}; P3+F2= potassium silicate 3mL L^{-1}+ fulvic acid 2 mL L^{-1}). Leaf-sprayed potassium fertilizer has shown the ability to enhance crop yield and overall plant biomass under stress conditions (Amanullah *et al*., 2016). However, its specific relationship with nitrogen uptake remains uncertain. On the other hand, Xu *et al*. (2022) reported that foliar spray with potassium fulvate (0.5 g dm^{-3}) resulted in a significant improvement in fruit yield, with a 17% better performance compared to the control group (CK) that received only water (H_2O). Foliar spraying with a mixture of potassium silicate and fulvic acid increased the leaf content of chlorophyll *a*, carotene, and TSS, while foliar spraying with potassium silicate only increased the leaf content of chlorophyll *b*. High temperatures have various effects on plant physiological processes. Specifically, they can lead to changes in plant membrane stability, chloroplast function, and Rubisco activity (Maestri *et al*., 2002). Additionally, under heat stress conditions, gas exchange rates and the effectiveness of photosystem II (PSII) are likely to decrease, and chlorophyll degradation may occur

(Ferguson *et al*., 2020). Based on the findings from our study, we can conclude that foliar spraying with potassium silicate and fulvic acid improved heat stress tolerance in the plants. Additionally, one of the functions of potassium metabolism is to enhance the positive transportation of photosynthates in the phloem by promoting ATP production (Haddad *et al*., 2016). This increased ATP production facilitates the movement of photosynthates from source organs (such as leaves) to sink organs (such as fruits), as suggested by Mengel (1980). This process likely contributed to the improved overall performance and fruit yield observed in our experiment.

5. Conclusion

For open-field tomato production in the summer, periodically spraying the plant with P3 is more effective than other treatments. Foliar application of P3 (3 mL L^{-1}) increases tomato yield by improving plant osmosis balance and interacting with endogenous phytohormones. Foliar spraying with potassium silicate increased fruit size and weight, which improved the marketable yield. Further study of the dosage targets and refined combinations between P3 and F2 (potassium silicate 3 mL L^{-1} + fulvic acid 2 mL L^{-1}) is still needed. Furthermore, there is a need to link the biochemical analyzes with some physiological and molecular analyses for an accurate understanding of the effect of these compounds on the plant to avoid heat stress.

References

AbdAllah, A. M., Burkey, K. O. and Mashaheet, A. M. (2018), "Reduction of plant water consumption through anti-transpirants foliar application in tomato plants (*Solanum lycopersicum* L)", *Scientia Horticulturae*, Vol. 235, pp. 373–381.

Agarie, S., Hanaoka, N., Ueno, O., Miyazaki, A., Kubota, F., Agata, W. and Kaufman, P. B. (1998), "Effects of silicon on tolerance to water deficit and heat stress in rice plants (*Oryza sativa* L.), monitored by electrolyte leakage", *Plant Production Science*, Vol. 1 No. 2, pp. 96–103.

Amanullah, Iqbal, Irfanullah, A. and Hidayat, Z. (2016), "Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition", *Scientific Reports,* Vol. 6 No. 1, Article ID 34627.

Amirahmadi, E., Ghorbani, M., Moudrý, J., Konvalina, P. and Kopecký, M. (2023), "Impacts of environmental factors and nutrients management on tomato grown under controlled and open field conditions", *Agronomy*, Vol. 13 No. 3, Article ID 916.

Attia, E. A. and Elhawat, N. (2021), "Combined foliar and soil application of silica nanoparticles enhances the growth, flowering period and flower characteristics of marigold (*Tagetes erecta* L.)", *Scientia Horticulturae*, Vol. 282, Article ID 110015.

Blevins, D. G., Hiatt, A. J. and Lowe, R. H. (1974), 'The influence of nitrate and chloride uptake on expressed sap pH, organic acid synthesis, and potassium accumulation in higher plants", *Plant Physiology*, Vol. 54 No. 1, pp. 82–87.

Blevins, D. G., Hiatt, A. J., Lowe, R. H. and Leggett, J. E. (1978), "Influence of K on the Uptake, Translocation, and Reduction of Nitrate by Barley Seedlings 1", *Agronomy Journal*, Vol 70 No. 3, pp. 393–396.

Ding, J., Jiao, X., Bai, P., Hu, Y., Zhang, J. and Li, J. (2022), "Effect of vapor pressure deficit on the photosynthesis, growth, and nutrient absorption of tomato seedlings", *Scientia Horticulturae*, Vol. 293, Article ID 110736.

do Rosário Rosa, V., Dos Santos, A. L. F., da Silva, A. A., Sab, M. P. V., Germino, G. H., Cardoso, F. B. and de Almeida Silva, M. (2021), "Increased soybean tolerance to water deficiency through biostimulant based on fulvic acids and *Ascophyllum nodosum* (L.) seaweed extract.", *Plant Physiology and Biochemistry*, Vol. 158, pp. 228–243.

Doan, C. C. and Tanaka, M. (2022), "Relationships between tomato cluster growth indices and cumulative environmental factors during greenhouse cultivation", *Scientia Horticulturae*, Vol. 295, Article ID 110803.

dos Santos Silva, L., de Sousa, K. Â. O., Pereira, E. C. V., Rolim, L. A., da Cunha, J. G., Santos, M. C. and Cavalcante, Í. H. L. (2021), "Advances in mango ‘Keitt’ production system: PBZ interaction with fulvic acids and free amino acids", *Scientia Horticulturae*, Vol. 277, Article ID 109787.

El-Mageed, T. A. A., Semida, W. M., Abdou, N. M. and El-Mageed, S. A. A. (2023), "Coupling Effects of potassium fertilization rate and application time on growth and grain yield of wheat (*Triticum aestivum* L.) plants grown under cd-contaminated saline soil", *Journal of Soil Science and Plant Nutrition*, Vol. 23 No. 1, pp. 1070–1084.

Ferguson, J. N., McAusland, L., Smith, K. E., Price, A. H., Wilson, Z. A. and Murchie, E. H. (2020), "Rapid temperature responses of photosystem II efficiency forecast genotypic variation in rice vegetative heat tolerance", *The Plant Journal*, Vol. 104 No. 3, pp. 839–855.

Geng, J., Yang, X., Huo, X., Chen, J., Lei, S., Li, H. and Liu, Q. (2020), "Effects of controlled-release urea combined with fulvic acid on soil inorganic nitrogen, leaf senescence and yield of cotton" *Scientific Reports*, Vol. 10 No. 1, Article ID 17135.

Gomez, K. A. and Gomez, A. A. (1984), *Statistical procedures for agricultural research*, John Wiley & Sons, New York, USA.

Guo, J., Jia, Y., Chen, H., Zhang, L., Yang, J., Zhang, J. and Zhou, Y. (2019), "Growth, photosynthesis, and nutrient uptake in wheat are affected by differences in nitrogen levels and forms and potassium supply", *Scientific Reports*, Vol. 9 No. 1, Article ID 1248.

Guo, T., Gull, S., Ali, M. M., Yousef, A. F., Ercisli, S., Kalaji, H. M. and Radwan, N. S. (2022), "Heat stress mitigation in tomato (*Solanum lycopersicum* L.) through foliar application of gibberellic acid. *Scientific Reports*, Vol. 12 No. 1, Article ID 11324.

Haddad, M., Bani-Hani, N. M., Al-Tabbal, J. A. and Al-Fraihat, A. H. (2016), "Effect of different potassium nitrate levels on yield and quality of potato tubers", *Journal of Food, Agriculture and Environment*, Vol. 14 No. 1, pp. 101–107.

Hassan, A. A. (2011), *Post Harvest Technology and Physiology of Fruit Vegetables (In Arabic)*, Al-Dar Al-Arabiah Lil Nashr Wa Al-Tawsia, Cairo, Egypt.

Hawrylak-Nowak, B., Hasanuzzaman, M. and Matraszek-Gawron, R. (2018), "Mechanisms of selenium-induced enhancement of abiotic stress tolerance in plants", *Plant Nutrients and Abiotic Stress Tolerance*, Springer, Singapore pp. 269–295.

Hedhly, A., Hormaza, J. I. and Herrero, M. (2009), "Global warming and sexual plant reproduction", *Trends in Plant Science*, Vol. 14 No. 1, pp. 30–36.

Hu, J., Li, Y. and Jeong, B. R. (2020), "Silicon alleviates temperature stresses in poinsettia by regulating stomata, photosynthesis, and oxidative damages", *Agronomy*, Vol. 10 No. 9, Article ID 1419.

Hussain, S., Mumtaz, M., Manzoor, S., Shuxian, L., Ahmed, I., Skalicky, M. and Shafiq, I. (2021), "Foliar application of silicon improves growth of soybean by enhancing carbon metabolism under shading conditions", *Plant Physiology and Biochemistry*, Vol. 159, pp. 43–52.

Kamenidou, S., Cavins, T. J. and Marek, S. (2010), "Silicon supplements affect floricultural quality traits and elemental nutrient concentrations of greenhouse produced gerbera", *Scientia Horticulturae*, Vol. 123 No. 3, pp. 390–394.

Knight, S. and Mitchell, C. (1983), "Enhancement of lettuce yield by manipulation of light and nitrogen nutrition", *HortScience*, Vol. 108 No. 5, pp. 750–754.

León-Osper, M., Infante-Izquierdo, M. D., Soriano-Bermúdez, J. J., Nieva, F. J. J., Grewell, B. J., Castillo, J. M. and Muñoz-Rodríguez, A. F. (2020), "Heat stress effects on sexual reproductive processes of a threatened halophyte", *South African Journal of Botany*, Vol. 133, pp. 184–192.

Lv, Y., Li, Y., Liu, X. and Xu, K. (2021), "Effect of soil sulfamethoxazole on strawberry (*Fragaria ananassa*): Growth, health risks and silicon mitigation", *Environmental Pollution*, Vol. 286, Article ID 117321.

Maestri, E., Klueva, N., Perrotta, C., Gulli, M., Nguyen, H. T. and Marmiroli, N. (2002), "Molecular genetics of heat tolerance and heat shock proteins in cereals", Plant molecular biology, Vol. 48, pp. 667–681.

Mengel, K. (1980), "Effect of potassium on the assimilate conduction to storage tissue", *Berichte der Deutschen Botanischen Gesellschaft*, Vol. 93 No. 1, pp. 353–362.

Mesa, T., Polo, J., Arabia, A., Caselles, V. and Munné-Bosch, S. (2022), "Differential physiological response to heat and cold stress of tomato plants and its implication on fruit quality", *Journal of Plant Physiology*, Vol. 268, Article ID 153581.

Mphande, W., Kettlewell, P. S., Grove, I. G. and Farrell, A. D. (2020), "The potential of antitranspirants in drought management of arable crops: A review", *Agricultural Water Management*, Vol. 236, Article ID 106143.

Nahar, K., Hasanuzzaman, M., Ahamed, K. U., Hakeem, K. R., Ozturk, M. and Fujita, M. (2015), "Plant Responses and Tolerance to High Temperature Stress: Role of Exogenous Phytoprotectants", In: Hakeem, K. (eds) *Crop Production and Global Environmental Issues*, Springer, Cham, Switzerland.

Niu, C., Wang, G., Sui, J., Liu, G., Ma, F. and Bao, Z. (2022), "Biostimulants alleviate temperature stress in tomato seedlings", *Scientia Horticulturae*, Vol. 293, Article ID 110712.

Pham, D., Hoshikawa, K., Fujita, S., Fukumoto, S., Hirai, T., Shinozaki, Y. and Ezura, H. (2020), "A tomato heat-tolerant mutant shows improved pollen fertility and fruit-setting under long-term ambient high temperature", *Environmental and Experimental Botany*, Vol. 178, Article ID 104150.

Saha, G., Mostofa, M. G., Rahman, M. M., and Tran, L. S. P. (2021), "Silicon-mediated heat tolerance in higher plants: A mechanistic outlook", *Plant Physiology and Biochemistry*, Vol. 166, pp. 341–347.

Saure, M. C. (2014), "Why calcium deficiency is not the cause of blossom-end rot in tomato and pepper fruit–a reappraisal", *Scientia Horticulturae*, Vol. 174, pp. 151–154.

Stein, L. Y. and Klotz, M. G. (2016), "The nitrogen cycle", *Current Biology*, Vol. 26 No. 3, pp. 94–98.

Suzuki, M., Umeda, H., Matsuo, S., Kawasaki, Y., Ahn, D., Hamamoto, H. and Iwasaki, Y. (2015), "Effects of relative humidity and nutrient supply on growth and nutrient uptake in greenhouse tomato production", *Scientia Horticulturae*, Vol. 187, pp.

44–49.

Verma, K. K., Song, X.-P., Zeng, Y., Guo, D.-J., Singh, M., Rajput, V. D. and Li, D. P. (2021), "Foliar application of silicon boosts growth, photosynthetic leaf gas exchange, antioxidative response and resistance to limited water irrigation in sugarcane (*Saccharum officinarum* L.)", *Plant Physiology and Biochemistry*, Vol. 166, pp. 582–592.

Vijayakumar, A., Shaji, S., Beena, R., Sarada, S., Rani, T. S., Stephen, R. and Viji, M. M. (2021), "High temperature induced changes in quality and yield parameters of tomato (*Solanum lycopersicum* L.) and similarity coefficients among genotypes using SSR markers", *Heliyon*, Vol. 7 No. 2, Article ID 05988.

Wang, Y., Yang, R., Zheng, J., Shen, Z. and Xu, X. (2019), "Exogenous foliar application of fulvic acid alleviate cadmium toxicity in lettuce *(Lactuca sativa* L.)", *Ecotoxicology and Environmental Safety*, Vol. 167, pp. 10–19.

Winkler, J. and Ghosh, S. (2018), "Therapeutic potential of fulvic acid in chronic inflammatory diseases and diabetes", *Journal of Diabetes Research*, Vol. 2018, Article ID 5391014.

Xu, X., Lei, X., Liao, S., Li, Y. and Sun, Y. (2022), 'Foliar application of potassium silicate, potassium fulvate and betaine improve summer-time tomato yield by promoting plant nitrogen and potassium uptake", *Folia Horticulturae*, Vol. 34 No. 2, pp. 125–138.

Yang, X., Li, C., Zhang, Q., Liu, Z., Geng, J. and Zhang, M. (2017), "Effects of polymer-coated potassium chloride on cotton yield, leaf senescence and soil potassium", *Field Crops Research*, Vol. 212, pp. 145–152.

Zhang, Y., Suzuki, K., Liu, H., Nukaya, A. and Kiriiwa, Y. (2018), "Fruit yellow-shoulder disorder as related to mineral element uptake of tomatoes grown in high temperature", *Scientia Horticulturae*, Vol. 242, pp. 25–29.