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Effect of foliar-applied potassium silicate on growth, yield, fruit quality and antioxidant activity of tomato plants grown under deficit irrigation

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***Abstract*---**When water is scarce, it is highly important to provide plants with water at critical stages to improve yield with high water use efficiency (WUE). Transpiration reduction is an effective and necessary procedure for conserving irrigation water while ensuring plant survival and protecting foliage from drought damage, and thus increasing water productivity. Foliar application of growth stimulators is one of the most important ways for lowering transpiration rates and reducing the negative effects of drought stress. The effects of foliar potassium silicate application as a growth stimulator, as well as water-sprayed plants, on growth, some physiological parameters, yield components, and water use efficiency of tomato (*Solanum lycopersicum L.*) cultivar "Elisa" grown during summer season under three irrigation levels (100, 75 or 50% ETc, of the estimated crop evapotranspiration) were investigated. The field experiment was conducted during 2019 and 2020 seasons at the Experimental Farm of Vegetable Crops Department, Faculty of Agriculture, University of Cairo. Giza Governorate, Egypt. The results showed that Both deficit irrigation (DI) and the exogenously exogenous spray application of potassium silicate at 5 ml/1 l water had a substantial impact on plant vegetative development, chlorophyll content in the leaves, antioxidant content, yield, fruit nutritional quality, and WUE (PS). The combination of (25%) deficit irrigation + PS therapy reduced the

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negative effects of DI and improved all of the aforementioned parameters. It also yielded plants with the same yields and WUE as plants grown under full watering circumstances without PS treatment. Based on these findings, we believe that using exogenously application of 5 ml/1 l SA, the 25 percent deficit irrigation approach examined here might be successfully employed during the summer for commercial tomato production, allowing for a 25% water savings without compromising plant development or output.

Keywords---foliar-applied, fruit quality, antioxidant, tomato plants, deficit irrigation.

Introduction

Tomato (*Solanum lycopersicum* L.) is among the most economically important vegetables globally and is the most vegetable crop in Egypt (FAO 2020). It is a rich food commodity with phytochemicals, vitamins, minerals, and essential amino acids. It is cultivated both in open field conditions and under protected cultivation. The amount of fresh tomato production was over 180 million tons in 2019 (FAOSTAT, 2021). The estimated annual global production in 2017 was 182 million tonnes (21 million tonnes in Africa), and tomato is the sixth most valuable cultivated crop, worth US$ 87.9 billion in 2016. In Africa, total production amounts to 37.8 million tonnes annually, with the biggest producers being Egypt, Nigeria, Tunisia, and Morocco (FAOSTAT 2020). Production of tomatoes is challenged by various pests and pathogens (Miyao et al. 2020). Egypt is subjected to a Mediterranean climate characterized by variability in the air temperature. It has been divided into several agro-climatic regions according to the average temperature values.

The most important agroclimatic regions are the Nile Delta; and Middle and the Upper Egypt region (Farag et al., 2014). Drought and salinity stress lead to water deficits, ionic toxicity, nutrient imbalances, and the occurrence of oxidative stress. General responses include reduced growth, which is reflected in downregulation of genes that encode proteins involved in cell wall expansion, protein synthesis, and DNA synthesis (Skirycz and Inzé, 2010). Plant physiology is significantly affected by abiotic/climatic stresses. It is well known that climate change and environmental extremes induce and enhance the impact of abiotic stresses (particularly drought and salinity) on plant fitness and performance (Singh et al., 2018). Wherever the water constituents about 90% of the plant weight and 97% of the absorbed water is lost in the process of transpiration (Nobel, 2009). To cope with the negative effects of water deficit in tomato plants, numerous strategies have been proposed. Among these strategies, foliar applications of antitranspirants are used to reduce the transpiration rate and reduce these deleterious impacts of drought stress (Degif and Woltering, 2015).

Silicon is the second most abundant element in the earth's crust (Debona et al. 2017). Although it is not considered as an essential element for higher plants, it is beneficial for plants, especially when they are subjected to environmental stresses (Debona et al. 2017). Drought is one of the major threats to crop production worldwide. Drought affects crop growth and development, leading to decreased crop yield and low quality (Wang et al. 2015, 2017). Most tomato varieties are sensitive to drought stress, especially at early growth stages (Foolad et al. 2003). Tomato accumulates much less silicon when compared to the monocotyledons such as rice and wheat and is classified as silicon excluder (Nikolic et al. 2007). Si addition can increase the photosynthesis and relevant carboxylase activities under field drought conditions, as observed in wheat (Gong and Chen, 2012). the positive effect of Si on salt tolerance of tomato has been reported (Muneer and Jeong, 2015). However, there have been few reports about the possible role of Si on tolerance of tomato under drought/water stress conditions.

Therefore, tomato may be an ideal plant to study the exact physiological and biochemical mechanism for silicon mediated tolerance to drought stress. In a previous study, it was observed that exogenous silicon could increase water stress tolerance by enhancing root hydraulic conductance and decreasing oxidative damage in tomato seedlings (Shi et al. 2016), suggesting the involvement of silicon in physiological and biochemical processes. However, the mechanism for silicon-mediated water stress tolerance in tomato still needs to be explored. The optimization of proper water status plays a crucial role in plants survival during drought stress. Osmotic adjustment is a prime mechanism adopted by plants, which maintains the water balance and turgor potential under drought stress. Leaf osmotic adjustment is linearly related to drought tolerance in plants (DaCosta et al. 2006). K^+ as a prime osmoticum in plants plays a major contribution in adjustments under water deficient conditions. Moreover, the proper availability K^+ improves the solute accumulation and decreases the osmotic potential, thereby maintains the cell turgor even under water limited conditions (Marschner et al. 2012).

In conclusion, the proper availability of K^+ favors the osmotic adjustments that maintain the cellular turgor, relative water contents and also lowers the osmotic potential, and therefore, improves the plants' ability against the drought stress (Egilla et al. 2001). A combined high temperature and drought tolerance induced by potassium was reported (Halford et al. 2009). The role of K as a nutrient has been recognized for a long time. However, its arrays of biological functions in plant physiological processes have still not been fully explored. In recent years, the correlation between phytohormones and K has been studied (Wang et al. 2013); phytohormones interact with one another and other signaling molecules, which regulate biochemical processes and metabolism, exerting physiological responses in relation to almost all the features of plant growth and development and enhancing stress tolerance. Auxin-regulated genes regulate proteins that affect the transcriptional repressors of stress responses in plants (Shani et al. 2017). Abscisic acid (ABA) influences the expression of genes that modulate complex stress-responsive regulatory networks (Song et al. 2016).

Material and Methods

This study was conducted during the spring seasons of 2019/ 2020 and 2020/2021 in clay soil in net houses at the Agricultural Experimental Station. Faculty of Agriculture, University of Cairo. Giza Governorate, Egypt. The aim of this experiment was to study the effect of using potassium silicate at 5 ml/1l on the alleviating drought impacts on tomato (*Solanum lycopersicum* L.) cultivar Alisa (Nunhems Seed Com. Netherland). Seeds were sown in foam try (209) containing mixture of peat-moss and vermiculite (1:1). Trays were kept in the greenhouse. Normal agriculture practices for tomato seedlings production were carried out. On February 14th in both seasons and seedlings were transplanted after 40 days from sowing with spacing at 50 cm. between plants in row. The experimental unit consisted of three rows each of 1 m. Drip irrigation was applied at three irrigation levels including 25%, 50% and 100% drought levels. The soil of the experimental area was loamy clay in texture with 7.89, EC 1.65 (mmohs/cm) and contained 42 ppm N, 22 ppm P, 187 ppm K. The experimental design was split plot (3 Drought levels (Main-plot) – potassium silicate and water treatments (Sub-plot) with three replications. So, this experiment included 6 treatments; 3 irrigation levels X 2 treatments (Spraying with PS and spraying with water). The size of the experimental unit were 10 plants. Soil preparation and all cultural practices were done as recommended for production of tomato (Hassan, 1988)

Climatic conditions

Climatic data from Giza meteorological station managed by the Egyptian Ministry of Agriculture indicates weather experienced during the spring and summer of 2019 – 2020 are indicated in Table 1 and Table 2.

Table 1
Monthly averages of maximum and minimum air temperature, relative humidity (RH), wind speed (WS), Wind direction dig and Solar radiation Dgt for 2019

2019	Temperature (°C)			RH	WS (m/s)		Wind direction dig [deg]		Solar radiation Dgt
	avg	Max	Min	(%)	avg	Max	avg	Max	[MJ/m^2]
APR	20.99	27.39	14.83	48.39	0.63	2.25	244.56	226.23	0.74
MAY	27.30	34.89	19.74	38.28	0.59	2.21	225.29	219.03	0.80
JUN	29.61	36.10	23.89	50.36	0.64	2.09	237.6	228.73	0.82
JUL	30.33	36.66	24.78	52.78	0.58	2.00	233.90	223.74	0.79
AUG	30.39	36.68	24.85	53.86	0.63	1.97	237.70	214	0.79
SEP	28.03	33.81	23.42	57.64	0.71	2.08	225.86	219.4	0.62

Table 2
Monthly averages of maximum and minimum air temperature, relative humidity (RH), wind speed (WS), Wind direction dig and Solar radiation Dgt

2020.	Temperature (°C)			RH	WS (m/s)		Wind direct on dig [deg]		Solar radiation Dgt
	avg	Max	Min	(%)	avg	Max	avg	Max	[MJ/m2]
APR	21.39	27.85	15.39	54.20	0.81	2.40	249.73	224.36	0.81
MAY	26.19	33.36	19.35	46.05	0.72	2.22	233.03	219.93	0.89
JUN	28.43	35.89	21.9	47.40	0.67	2.07	233.96	225.16	0.84
JUL	29.71	37.04	24.05	58.37	0.61	1.97	226.38	218.25	0.68
AUG	30.31	36.91	24.99	57.87	0.63	1.96	228.87	218.41	0.74

SEP	29.80	35.50	25.23	61.11	1.01	2.4	221.16	218.56	0.72

Data Recorded
Vegetative growth parameters

Samples of five plants from each plot were randomly taken 60 days after transplanting and the following characteristics were recorded.

- Plant height (cm). (On soil serves to top plant)
- Number of leaves per plant.
- Leaf area: Average leaf area of the fifth leaf from the top was measured by portable leaf area meter (Biovis Leaf Av., Expert Vision Labs Pvt. Ltd., India).
- Leaf dry matter %, was determined according to A.O.A.C. (1990).

Physiological parameters
Determination of physiological parameters in leaves

The physiological parameters in leaves included relative water content (RWC), and chlorophyll % of leaves, 60 days after transplanting.

- **Relative water content (RWC)** was estimated using 2-cm-diameter fully expanded leaf disks (Hayat et al., 2007). The disks were weighed (fresh mass; FM) and immediately floated on double-distilled water in Petri dishes for 24 h, in the dark, to saturate them with water. Any adhering water was blotted dry and the turgid mass (TM) was measured. The dry mass (DM) was recorded after dehydrating the disks at 70 °C until the constant weight. The RWC was then calculated using the following formula:
  (RWC % = [(FM - DM)/ (TM- DM)]/ X 100
- **Chlorophyll 'a', chlorophyll 'b' and carotenoid concentrations** were extracted and determined (in mg g^{-1} FW) following the procedure given by Arnon (1949). Fresh leaf samples (0.2 g) were homogenized in 50 ml 80% (v/v) acetone, and then centrifuged at 10,000 × g for 10 min. The absorbance of the acetone extract was measured at 663, 645, and 470 nm using a UV-160A UV–visible recording spectrometer (Shimadzu, Kyoto, Japan).

Determination of physiological parameters in roots

The physiological parameters in roots included non-enzymatic components (Carbohydrate, total free amino acids total indoles, total phenols, Proline) and enzymatic activity (Peroxidase, Polyphenol oxidase and Catalase) and they were determined 60 days after transplanting as follows:

- **Total free amino acids and total phenols** were determined according to Yemm, and Cocking (1955)
- **Carbohydrate** were determined according to Miller (1959)
- **Determination of total free amino acids** (g/100gm dried weight) was conducted according to Yemm and Cocking, 1955)
- **Total indoles content** was determined according to Larsen (1962).

- **Determination of proline concentration** was proceeded in root according to Marin et al. (2010).
- **Enzymes (Peroxidase, Polyphenol oxidase and Catalase) activity** was determined according to Sadasivam and Manickam (1996) by using spectrophotometer model UV-Vis spectronic 601

Yield characteristics

- Early yield, it was estimated as the weight of fruits for all harvested fruits of the first 4 pickings.
- Total yield, date of total yield included weight of fruits all over the harvesting season.

Water use efficiency (WUE)

WUE values as kg fruits yield m− 3 of applied water were calculated for different treatments after harvest according to the following equation (Jensen, 1983):

WUE = Fruit yield (kg. Fed-1/ water applied (m3 Fed-1).

Physical characters of fruits (100 days after transplanting)

Ten fruits were taken from each experimental plot at the third harvest to estimate fruit characters (fruit weight, fruit length, fruit diameter, fruit firmness)

Chemical analysis of Fruit (100 days after planting)

The Chemical analysis of fruit included total soluble solids (TSS) % using Zeiss laboratory refractometer), Ascorbic acid (Vitamin C) content (determined by the titration method (AOAC, 1980), Lycopene and β-Carotene. Lycopene and β-Carotene in hydroponically grown tomatoes were determined according to Nagata and Yamashita (1992).

Statistical analysis

All obtained data were statistically analyses according to the method described by (Gomes and Gomes 1984).

Results

Effect of potassium silicate under different drought levels on plant characteristic
Plant growth

Data in Table (3) showed that the plant high, No. leaf, leaf area and Leaf water values content were affected by different treatments application in two seasons. It was found that the highest values of all plant height, No. leaf and Leaf relative water were at full irrigation (100 %) irrigation requirements /fed.) and lowest values were achieved with irrigation at 75 % available moisture depletion in two seasons. The potassium silicate application increased values all plant height, No.

leaf and Leaf relative water compared with untreated plants in both seasons. The interaction between irrigation levels and the treatments of potassium silicate, it noticed that the spraying tomato plants with potassium silicate with irrigation at zero drought levels gave the highest values of the all studied vegetative growth characters (plant height, No. of leaves/plant and leaf area) compared with the control treatment.

Table 3
Effect of potassium silicate application on some vegetative growth of tomato plants grown under three drought levels, after 60 days transplanting, seasons 2019 and 2020

Treatments		seasons 2019				seasons 2020			
Drought level	Stimulants	Plant Height (cm)	No. of leaf/ plant	Leaf area (cm^2)	Leaf relative water (%)	Plant Heigh t (cm)	No. of leave / plant	Leaf area (cm^2)	Leaf relative water cont. (%)
0%	Water	99.67	47.78	29.63	68.78	93.73	45.67	28.58	70.88
	Potassium Silicate	107.2	59.00	33.27	71.31	100.4	56.50	33.36	78.84
Mean		103.43	53.39	31.45	70.05	97.06	51.08	30.97	74.68
25%	Water	85.60	41.33	26.85	66.18	87.70	39.67	27.68	68.48
	Potassium Silicate	97.80	45.00	28.01	69.69	92.80	43.50	28.51	71.20
Mean		91.7	43.16	27.43	67.49	90.25	41.58	28.09	69.78
50%	Water	70.30	35.00	21.87	60.15	68.20	37.00	26.44	62.40
	Potassium Silicate	83.40	41.00	26.72	67.74	87.30	39.33	27.32	66.17
Mean		76.85	38.00	24.29	63.95	77.75	38.16	26.88	64.28
Mean	Water	85.19	41.37	26.12	65.03	83.21	40.78	27.57	67.25
	Potassium Silicate	96.13	48.33	29.33	69.58	93.50	46.44	29.73	72.07
L.S.D. at 0.05 level									
Drought (A)		*4.48*	*5.13*	*1.609*	*6.1*	*3.44*	*2.84*	*1.22*	*7.44*
Stimulants (B)		*4.58*	*2.61*	*1.458*	*3.95*	*3.86*	*3.66*	*2.14*	*4.55*
A x B		*7.93*	*4.52*	*2.525*	*7.74*	*6.69*	*6.34*	*3.72*	*8.09*

Data in Table (4) appeared that the reducing irrigation level from full irrigation (100 % of plants irrigation requirements /fed.) to 50 % of irrigation requirements /fed. decreased the leaf dry matter, and Leaf Chlorophyll A, and B of tomato plants in both growing seasons. Results also revealed that the above-mentioned leaf dry matter, and Leaf Chlorophyll A, and B affected by foliar application of potassium silicate spraying. In this regard, potassium silicate significantly increased leaf dry matter, and leaf chlorophyll A, and B compared with untreated plants in both growing seasons. Concerning the interaction between potassium silicate and different drought levels, the results indicated that the foliar spraying potassium silicate with irrigation deficit conditions (75% and 50 % of irrigation requirements /fed.) was gave the lowest values of all leaf dry matter, and leaf chlorophyll A, and B as compared with the untreated plants and highest values were by potassium silicate at irrigation zero drought levels (100%) in both seasons.

Table 4
Effect of potassium silicate spray application on leaf dry matter and chlorophyll content of tomato plants grown under three drought levels, after 60 days transplanting seasons 2019 and 2020

Treatments		Leaf dry matter %		Leaf Chlorophyll A (mg/g FW)		Leaf Chlorophyll B (mg/g FW)	
Drought level	Stimulants						
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
0%	Water	20.90	18.14	18.70	19.70	41.06	36.62
	Potassium Silicate	21.39	21.73	27.3	18.69	40.823	35.38
Mean		*21.14*	*19.93*	*23.00*	*19.19*	*40.94*	*36*
25%	Water	18.28	17.93	16.80	16.17	36.27	31.39
	Potassium Silicate	20.34	20.8	23.403	25.17	44.253	37.84
Mean		*19.31*	*19.36*	*20.10*	*20.67*	*40.26*	*34.61*
50%	Water	17.81	17.86	19.22	8.69	32.43	15.3
	Potassium Silicate	20.60	20.4	18.46	16.38	35.15	31.07
Mean		*19.21*	*19.13*	*18.84*	*12.53*	*33.79*	*23.18*
Water		19.01	17.98	18.24	14.85	36.59	27.78
Potassium Silicate		20.78	20.98	23.05	20.08	40.08	34.76
L.S.D. at 0.05 level							
Drought (A)		*0.98*	*0.612*	*2.72*	*7.58*	*7.66*	*6.44*
Stimulants (B)		*1.07*	*0.67*	*4.37*	*4.27*	*6.28*	*8.73*
A x B		*1.86*	*1.177*	*7.58*	*7.40*	*10.88*	*15.12*

Plant components

As shown in Tables 5 and 6 obviously indicated that reducing irrigation level significantly or non-significantly increased non- enzymatic anti-oxidants (Proline, total indoles, total phenols, total free amino acids, and total carbohydrate) in tomato plants in both seasons. Regarding the spraying of potassium silicate significantly increased Proline, Total Indoles, Total phenols, Total free amino acids, and Total Carbohydrate in tomato plants compared with the water-sprayed plants in both seasons. Under irrigation (50 % of plants irrigation requirements /fed.), potassium silicate spraying significantly increased Proline, Total Indoles, Total phenols, Total free amino acids, and Total Carbohydrate in tomato plants compared with the water-sprayed plants in both seasons.

Table 5
Effect of potassium silicate application on some non- enzymatic anti-oxidants of tomato plants grown under three drought levels, after 60 days transplanting (2019 season)

Treatments		Proline (mg/100)	Total Indols (mg/100g)	Total phenols (%)	Total free amino acids (mg/100g)	Total Carbo Hydrate (%)
Drought level	Stimulants					
0%	Water	38.26	0.19	1.19	0.28	37.26
	Potassium Silicate	40.94	0.20	1.20	0.42	40.97

Mean		39.60	0.20	1.20	0.35	39.12
25%	Water	40.30	0.24	1.24	0.34	39.30
	Potassium Silicate	42.04	0.30	1.30	0.57	41.04
Mean		41.17	0.27	1.27	0.45	40.17
50%	Water	41.47	0.26	1.26	0.39	39.94
	Potassium Silicate	44.62	0.53	1.53	0.58	43.62
Mean		43.04	0.39	1.39	0.48	41.78
Water		40.00	0.23	1.22	1.19	38.83
Potassium Silicate		42.53	0.34	1.34	1.29	41.88
L.S.D. at 0.05 level						
Drought (A)		1.34	0.04	0.17	0.03	4.05
Stimulants (B)		2.07	0.07	0.14	0.08	2.1
A x B		3.06	0.08	0.18	1.1	5.04

Table 6
Effect of potassium silicate application on some non- enzymatic anti-oxidants of tomato plants grown under three drought levels, after 60 days transplanting (2020 season)

Treatments		Proline (mg/100g)	Total Indols (mg/100g)	Total phenols (%)	Total free amino acids (mg/100g)	Total Carbo Hydrate (%)
Drought level	Stimulants					
0%	Water	41.20	0.18	1.18	0.33	40.20
	Potassium Silicate	42.19	0.26	1.26	0.41	41.99
Mean		41.70	0.22	1.22	0.37	41.10
25%	Water	42.63	0.21	1.19	0.40	41.19
	Potassium Silicate	43.82	0.30	1.27	0.46	42.63
Mean		43.22	0.26	1.23	0.43	41.01
50%	Water	42.88	0.21	1.22	0.42	41.63
	Potassium Silicate	46.31	0.33	1.35	0.55	45.31
Mean		44.60	0.27	1.29	0.48	43.47
Water		42.23	0.2	1.19	0.33	41.01
Potassium Silicate (5 ml/1 l)		44.10	0.29	1.29	0.52	43.37
L.S.D. at 0.05 level						
Drought (A)		2.27	0.06	0.06	0.05	4.06
Stimulants (B)		1.81	0.09	0.12	0.06	5.86
A x B		5.96	0.18	0.11	0.19	6.01

Data in Table (7) clearly demonstrated that reducing drought level increased peroxidase (PO), polyphenol oxidase (PPO), and catalase in tomato plants in both seasons. Regarding the spraying of potassium silicate significantly increased peroxidase (PO), polyphenol oxidase (PPO), and catalase in tomato plants compared with the water-sprayed plants in both seasons. Under irrigation (50% of plants irrigation requirements /fed.), potassium silicate spraying significantly increased peroxidase (PO), polyphenol oxidase (PPO), and catalase in tomato plants compared with the water-sprayed plants in both seasons.

Table 7
Effect of potassium silicate application on some non- enzymatic anti-oxidants of tomato plants grown under three drought levels, after 60 days transplanting, seasons of 2019 and 2020

Treatments		PO $(X10^{-3})$ (Peroxidase) Δ240		Polyphenol oxidase PPO $(X10^{-3})$ Δ240		Catalase Δ240	
Drought	Stimulants						
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
0%	Water	1002.00	1149.00	34.17	31.63	212.30	239.40
	Potassium Silicate	1654.00	1707.00	47.83	38.00	323.10	403.30
Mean		1328.00	1428.00	41.00	34.82	267.70	321.40
25%	Water	1143.00	1269.00	37.67	49.20	231.50	300.20
	Potassium Silicate	1734.00	1765.00	51.73	63.50	391.50	516.80
Mean		1439.00	1517.00	44.70	56.35	311.50	408.50
50%	Water	1525.00	1584.00	45.17	59.17	304.30	320.30
	Potassium Silicate	2218.00	1889.00	62.30	69.00	484.40	525.50
Mean		1872.00	1737.00	53.73	64.08	394.30	422.90
Water		1223.31	1334.07	39	46.67	249.37	286.66
Potassium Silicate (5 ml/1 l)		1868.56	1787.31	53.96	56.83	399.67	481.87
L.S.D. at 0.05 level							
Drought (A)		357.6	287.6	11.54	5.466	66.64	167.4
Stimulants (B)		132.2	399.8	19.16	6.803	92.13	142.8
A x B		0.19	0.78	0.02	0.01	0.37	0.35

Tomato yield and water use efficiency

Data registered in Table (8) exhibited that there were significant differences in the early yield, total yield of tomato plants and water use efficiency (WUE) under the three irrigation schedule regimes treatments. The maximum early yield, total yield was recorded by using the full irrigation (100 % of plants irrigation requirements /fed.) followed by the moderate irrigation regime (75 % of irrigation requirements /fed.) then the severe water stress regime (50 % of irrigation requirements / fed.). The decrement in all studied early yield, and yield of tomato plants significantly gained with increasing water stress levels from 75 % to 50 % of water irrigation /fed. The largest reduction in early yield, and yield of tomato plants were observed under severe water stress (50 % of irrigation requirements /fed.) during the two seasons of this study. On the other hand, water use efficiency (WUE) was increased up to 75 of irrigation requirements, then it was decreased with the further decrease in the applied irrigation water (50 % of irrigation requirements /fed.). These results were true in both seasons.

As for foliar spraying with foliar spray of Potassium Silicate results declared that the Potassium Silicate application, created significant enhancement effects on early yield, yield and water use efficiency of tomato plants. The previous result is true during the both seasons. The interaction between using the full irrigation (100 % of plants irrigation requirements /fed.) followed by the moderate irrigation regime (75 % of irrigation requirements /fed.) then the severe water stress regime (50 % of irrigation requirements / fed.) and foliar application of Potassium Silicate had significant effect on early yield, and yield of tomato plants. The highest values of early yield, and yield of tomato plants were obtained when tomato plants irrigated at full irrigation (100 % of plants irrigation requirements /fed.) followed by the moderate irrigation regime (75 % of irrigation requirements /fed.) and foliar spraying with Potassium Silicate. Potassium Silicate application improved water use efficiency (WUE). This was true inside each irrigation level. Moreover, such effect was more pronounced at 50% deficit water.

Table 8
Effect of potassium silicate application on tomato yield and water use efficiency (WUE) under three drought levels, seasons of 2019 and 2020

Treatments		Early yield (Ton/fed		Total (Ton/Fed)		Water use efficiency (kg/m^3)	
Drought level	Stimulants	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
0%	Water	9.07	10.56	28.82	33.93	7.23	8.63
	Potassium Silicate	12.57	12.78	37.30	38.46	9.37	9.77
Mean		10.82	11.67	33.065	36.20	8.3	9.2
25%	Water	7.53	8.00	24.02	27.49	8.05	9.37
	Potassium Silicate	8.90	9.70	28.04	31.57	9.40	10.76
Mean		8.219	8.856	2.034	31.84	8.73	10.07
50%	Water	3.79	3.74	12.44	12.65	6.25	6.47
	Potassium Silicate	6.61	7.08	22.32	22.23	11.20	11.37
New Mean		5.20	5.41	17.38	17.44	8.73	8.92
Water		6.80	7.63	21.76	24.69	7.18	8.16
Potassium Silicate		9.36	9.85	29.22	30.76	9.99	10.63
L.S.D. at 0.05 level							
Drought (A)		0.65	0.95	1.54	2.03	NS	1.1
Stimulants (B)		1.17	0.79	2.73	2.41	1.2	1.5
A x B		2,03	1.37	4.73	3.70	1.9	1.8

Physical characters of tomato fruit

Results in Tables 9 and 10 revealed that there are no significant differences in the physical fruit characters of tomato fruits, i.e., average fruit weight, firmness, polar diameter, equatorial diameter, and fruit shape index under the three irrigation schedule regimes treatments. As for foliar spraying with foliar spray of Potassium Silicate, results in the same Tables sharply cleared that the foliar application of Potassium Silicate, created significant ascending effects on average fruit weight, firmness, polar diameter, equatorial diameter, and fruit shape index of tomato. The previous result is true during the both seasons. The interaction between irrigation at different drought levels and Potassium silicate foliar application, it was found that potassium silicate foliar application at full irrigation (100 % of plants irrigation requirements /fed.) had significant effect of average fruit weight, firmness, polar diameter, equatorial diameter, and fruit shape index of tomato. Where the highest values of physical fruit characters of tomato plants were obtained when tomato plants irrigated (100 %) followed by the moderate irrigation regime (75 % of irrigation requirements /fed.) with potassium silicate foliar application.

Table 9
Effect of Effect of exogenous spray application of potassium silicate some on physical fruit characters of tomato plants grown under three drought levels (2019 season)

Treatments		Average fruit weight (g)	Firmness (Kg/cm2)	Polar diameter(mm)	Equatorial diameter (mm)	Fruit shape index
Drought level	Stimulants					
0%	Water	96.41	1.33	53.07	88.45	0.60
	Potassium Silicate	128.89	2.17	49.70	90.03	0.55
Mean		112.65	1.75	51.38	89.24	0,575
25%	Water	88.45	1.58	47.67	72.04	0.66
	Potassium Silicate	130.35	2.91	49.67	89.28	0.56
Mean		109.4	2.24	48.67	80.66	0.61
50%	Water	102.78	1.57	47.70	75.24	0.63
	Potassium Silicate	127.77	2.50	51.50	89.63	0.57
Mean		115.275	2.03	49.6	82.43	0.6
Water		95.88	1.49	49.48	78.58	0.63
Potassium Silicate		129.00	2.53	50.29	89.65	0.56
L.S.D. at 0.05 level						
Drought (A)		ns	ns	ns	ns	ns
Stimulants (B)		4.47	0.44	1.93	2.92	0.03
A x B		7.747	ns	3.34	5.05	0.05

Table 10
Effect of potassium silicate application on some physical characters of tomato fruit under three drought levels (2020 season)

Treatments		Average fruit weight (g)	Firmness (Kg/cm2)	Polar diameter (mm)	Equatorial diameter (mm)	Fruit shape index
Drought level	Stimulants					
0%	Water	104.20	1.47	45.10	72.11	0.63
	Potassium Silicate	125.81	2.11	55.40	92.29	0.60
Mean		115.00	1.79	50.25	82.2	0.61

25%	Water	99.12	1.61	46.80	75.50	0.62
	Potassium Silicate	129.18	2.33	53.20	89.51	0.59
Mean		114.15	1.97	50.00	82.50	0.60
50%	Water	106.24	1.73	50.00	78.12	0.64
	Potassium Silicate	118.97	2.32	60.60	89.79	0.67
Mean		112.60	2.02	55.3	83.95	0.65
Water		103.19	1.60	47.30	75.24	0.63
Potassium Silicate		124.66	2.25	56.40	90.53	0.62
L.S.D. at 0.05 level						
Drought (A)		ns	ns	ns	ns	ns
Stimulants (B)		5.89	0.14	2.26	3.26	0.03
A x B		ns	0.24	ns	ns	ns

Data in Table (11) revealed that the chemical fruit characters parameters significantly increased by potassium silicate application compared with the untreated plants (water) in two seasons. Reducing irrigation level to (50 % of irrigation requirements /fed.) increased the chemical fruit characters parameters, i.e., TSS, V.C, total Lycopene, and Carotenoids of tomato plants in two seasons. Concerning the interaction between potassium silicate and drought levels, it was noticed that the potassium silicate foliar application under full irrigation (100 %) gave the highest values of all chemical fruit characters parameters, i.e., TSS, V.C, total Lycopene, and Carotenoids of tomato plants compared with other in both seasons.

Table 11
Effect of of potassium silicate application on some tomato nutritional contents of tomato plants grown under three drought levels, after 60 days transplanting, seasons of 2019 and 2020

Treatments		TSS (%)		V.C (mg/100g FW)		Total Carotenoids mg 100 g−1 fresh weight)		Lycopene mg 100 g−1 fresh weight)	
Drought level	Stimulants	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
0%	Water	4.50	4.25	17.27	15.24	43.71	35.21	4.18	3.18
	Potassium Silicate	4.25	4.25	18.87	18.87	51.14	48.00	4.91	4.27
Mean		4.37	4.25	18.07	17.05	47.15	41.60	4.54	3.73
25%	Water	4.53	4.63	19.94	19.94	47.36	39.57	3.84	3.92
	Potassium Silicate	5.50	5.83	21.94	21.94	53.07	51.09	5.903	4.59
Mean		5.01	5.23	20.94	20.94	50.21	45.33	4.87	4.25
50%	Water	4.60	4.25	20.99	21.06	41.49	42.38	4.29	4.43
	Potassium Silicate	6.25	6.25	25.26	26.64	60.29	52.79	6.583	5.38
Mean		5.42	5.25	23.12	23.85	50.89	47.58	5.43	4.90
Water		4.54	4.38	19.4	18.75	44.19	39.05	4.11	3.84
Potassium Silicate		5.33	5.44	22.02	22.48	54.84a	50.63	5.80	4.75
L.S.D. at 0.05 level									

Drought (A)	0.46	0.48	1.62	1.15	9.42	13.66	1.45	0.91
Stimulants (B)	0.26	0.36	0.94	0.77	8.37	11.56	0.98	1.66
A x B	0.46	0.62	1.63	1.34	14.50	20.03	1.71	2.89

Discussion

Tomato is sensitive to water stress at all growth stages and it is more sensitive to drought stress at flowering growth stage (Sibomana et al., 2013). Reduced plant growth under abiotic stress is considered to be a negative symptom of stress [Aliche, et al., 2000; Luitel, et al., 2015] due to the reduced growth of new leaves that is associated with limited cell elongation and cell division of stem. Cell growth is inhibited mainly because of the interruption of the water flow from the xylem to the elongating cells and the changes in the physicochemical properties of the cell walls which become more rigid, whereas cell division impairment results mainly from the decreased photosynthesis and carbohydrates availability for cell mitosis and photosynthetic capacity. Drought large reduction in leaf dry matter %, and had a significant negative impact on leaf chlorophyll a and b contents. Similar results were found by Abd El-Mageed et al. (2018) who noticed that chlorophylls and carotenoids in cucumber leaves were not affected with 80%, of crop evapotranspiration, but reduced significantly under 60%, of crop evapotranspiration, which may be attributed to leaf senescence under drought stress.

Deficit irrigation had a negative effect of the relative water content, being the worse at 50% deficit irrigation water. This finding was noted earlier in some crop plants (Abd El-Mageed et al., 2016; 2018). We noticed that drought significantly induced production high concentrations of enzymatic (Catalase, Polyphenol oxidase, and Peroxidase) and Osmoprotectant compounds (Carbohydrate, total free amino acids, total phenols, total In-dole and proline) of tomato. Albert (2019) reported that plant survival under water deficit depends on the development of an efficient antioxidant system, with enzymatic and non-enzymatic components and Osmoprotectant compounds. Enzymatic components are mainly superoxide dismutases (SOD), catalases (CAT), peroxidases and ascorbate peroxidases (APX), glutathione peroxidase (GPX), peroxide dismutases, polyphenol oxidases, laccases, anthocyanidin reductase ,anthocyanidin synthase, mono–dehydroascorbate reductases (MDAR), dehydroascorbate reductases (DHAR) and glutathione reductases (GR). Non-enzymatic plant antioxidants are mainly amino acid (such as cysteine, glutathione), ascorbic acid, pigments and polyphenols, such as carotenoids and anthocyanins. Osmoprotectant compounds are non-toxic highly soluble molecules, with low molecular weight. They include proteins and amino-acids (e.g. proline), quaternary amines (e.g. glycine-betaine and alanine–betaine), polyols and sugars (e.g. mannitol, sorbitol, and sucrose), organic acids (e.g .malic and citric acids), hydrophilic proteins (e.g. heat shock proteins) and ions (e.g. calcium, potassium, and chloride ions).

With respect the effect of drought stress on the root contents of non- enzymatic anti-oxidants, drought caused a significantly increased in non- enzymatic anti-oxidants (Carbohydrate, total free amino acids, total phenols, total Indole and proline) content. Proline is one of the important compatible solutes that accumulates under stress conditions and has been considered to play a substantive role in osmotic adjustment (Nayyar and Walia, 2003). Abd El-Mageed et al. (2018) found that maximum free proline concentration in cucumber leaves is correlated with 80%, of crop evapotranspiration (a moderate stress status). This result may be attributed to the increase in protein breakdown and/or the conversion of some amino acids such as ornithin ,arginine and glutamic acid to proline.

The higher water use efficiency, under 75% water deficit, in the present work, was earlier noticed by Abd El-Mageed et at. (2016) who reported that the WUE increased under water stress. Du et al. (2017) declared that this result may be explained by the fact that the water accumulation in the fruit causes the dilution of fruit ingredients). The reduced fruit size and low dilution resulting from decreased water levels in fruits must have resulted in accumulation of assimilates, consequently water deficit caused improvement in the quality parameters (Nangare et al., 2016). Spraying tomato plants with potassium silicate resulted in a significant increase in in the all studied vegetative growth characters (plant height, No. of leaves/plant and leaf area) of tomato plants as compared with the control treatment (spraying plants with water). Moreover, vegetative growth characters were higher in Si-treated plants even at moderate (25%) drought stress .In this regard, using potassium silicate caused a remarkable improvement in the vegetative growth to be similar to that produced in the control plants at 100% irrigation level. (Table 3).

Enhancing the vegetative growth characteristics, and Leaf relative water content (%) (Table 3) by Si foliar applications was related to improving chlorophyll (Table 4), non-enzymatic (Table 5 and 6) and enzymatic antioxidants (Table 7). The present results confirm these findings of Alam et al. (2021) and Salim et al. (2021) who recorded better results for growth parameters (plant height, number of leaf plant^{-1}, and shoot dry matter) of cantaloupe, and squash, respectively, with the exogenous application of Si-based Furthermore, the results of many researchers proved that the fresh and dry mass of leaves, stems and roots of were markedly declined against limited water irrigation as compared to normal irrigation, while the negative effects of limited water supply on biomass were positively mitigated and enhanced with application of Si. These results were noticed on potato (Abd El-Gawad et al., 2017), tomato (Abd Elwawed, 2018) and sugarcane plants (Verma et al., 2020).

Increasing the vegetative growth characteristics of plant (such as plant height and number of leaves) for plants subjected to the irrigation water deficit at the levels at 25 % and 50% could probably be attributed to the mechanism for silicon-mediated tolerance of water stress by its beneficial effects on the physiological aspects include maintaining nutrient balance, decreasing water loss from leaves, promoting photosynthetic rate photosynthetic rate and improve plant resistance to water deficiency (Chen et al. 2018) and regulating the levels of endogenous plant hormones (Zhu and Gong, 2014). Also, the result confirmed the important function of silicate in enhancing rigidity, strengthening and elasticity of cell wall (Hanafy et al., 2008). Furthermore, these increments the vegetative growth characteristics of the plant may be due to the role of potassium in plant nutrition and enhancing the translocation of assimilates and protein synthesis (Abd El-Gawad et al., 2017).

We observed a significant positive effect of potassium silicate application on leaf dry matter % and leaf content of Chlorophyll A and B. This effect was more pronounced in the water-deprived plants (Table 4). As the results of our study, some reports pointed out about a beneficial effect of Si addition under water shortage, on the cultivars of tomato (Silva et al., 2012 and Abd Elwahed, 2018) and cowpea (Silva et al., 2019) through increasing the chlorophyll a content with Si addition. Similarly, Zahedi et al. (2020) reported that plants treated with SiO_2 preserved more of their photosynthetic pigments compared with control plants at Moderate (60%) FC .The positive influences of Si are possibly due to the multiple effects of Si, such as the amelioration of plant water content and photosynthetic activity, and the reduction in oxidative stress [Zhu and Gong, 2014].

Foliar application of potassium silicate significantly induced production high concentrations of enzymatic (Catalase, Polyphenol oxidase and Peroxidase) and non- enzymatic anti-oxidants (Carbohydrate, total free amino acids, total phenols, total Indole and proline) in tomato plants grown under 25 and 50% drought levels. It has been widely reported that Si supply decreases the oxidative damage through enhancing the antioxidant enzyme (SOD, APX, CAT and POD) activities under drought stress in tomato (Shi et al. 2014), cowpea (Silva et al., 2019), strawberry (Zahedi et al., 2020), sugarcane (Verma, et al., 2021) and squash (Salim et al., 2021) plants, and the contents of non-enzymatic antioxidants in plants (Zhu and Gong, 2014). Nonenzymatic antioxidants include glutathione, ascorbic acid, nonprotein amino acids, and phenolic compounds (Hasanuzzaman, et al., 2020). Similarly, Zahedi et al. (2020) reported that plants treated with SiO_2 preserved presented higher levels of key osmolytes such as carbohydrate and proline with control plants at Moderate (60%) FC. Recently, Salim et al. (2021) recorded significant increases in the concentrations of stress indicators (total free amino acids and proline) in squash plants grown under drought conditions (50% of water holding capacity (WHC) compared to the control plants (80% WHC).

The treatment of potassium silicate caused significant increase in early and total yield of tomato plants at the 0-drought level as well as improvements in the yield and average fruit weight and at 25% drought levels, where the yield at this level was similar to that when tomato plant obtained the optimum irrigation condition. Higher yield at moderate drought stress with Si application might be attributed to the stimulation effect of potassium silicate on increasing plant growth (Table 3), chlorophyll formation (Table. 4) the leading to move the photosynthetic production to give higher Average fruit weight and hence increasing yield aspects. Similar results were obtained by Alam et al. (2021) on cantaloupe under moderate drought stress. In addition, foliar spray with potassium silicate increased growth, yield and quality on potato (El-Saady., 2017), tomato (Al-Shmmari et al., 2020), cowpea (Silva et al., 2019), strawberries (Zahedi et al., 2020), Jerusalem artichoke (Abo El-Fadel and Shama, 2020), and squash (Salim et al., 2021) grown under water stress conditions.

Foliar application of potassium silicate significantly increased water uses efficiency (WUE) within each irrigation level. The higher water use efficiency, under 75% water deficit, in the present work, was earlier noticed by Verma et at. (2020) who reported that the silicon application mitigated the drought stress by improving relative Leaf Water Content. Silicon may regulate the balance water level absorption and the water loss through the leaf surface. The present results are on line with several researches who recorded increase in vitamin C, TSS% and firmness in tomato (Islam et al. , 2018 and Al-Shmmari et al., 2020) grapevine fruits (Bassiony et al., 2018) due to silicon treatments under mild drought stress. Zahedi et al. (2020) reported that plants treated with SiO_2 under moderate and severe drought condition strawberry fruits obtained from plants treated with silicon contained higher levels of anthocyanin, total phenol, vitamin C, and DPPH compared to water spraying. The present study proved that the combination of irrigation after depletion of 75%of available soil water and foliar application of 4000 ppm potassium silicate is considered the most favorable treatment ,where the mild drought stress gave a high yield as un-stressed plants with ought showing any obvious harmful stress on the plants.

References

A.O.A.C. (1990). Official methods of analysis of association of official analytical chemists, 15th Ed. Published by A.O.A.C. 2200 Wilson Bouleverard Arlington Virginia 22201 USA.

Abd El-Mageed, T.A.; Semida, W.M.; Mohamed, G.F. and Rady, M.M. (2016). Combined effect of foliar-applied salicylic acid and deficit irrigation on physiological–anatomical responses, and yield of squash plants under saline soil. South African Journal of Botany 106: 8–16

Abd El-Mageed, T.A.; Semida, W.M.; Taha, R.S. and Rady, M.M. (2018). Effect of summer-fall deficit irrigation on morpho-physiological, anatomical responses, fruit yield and water use efficiency of cucumber under salt affected soil. Scientia Horticulturae 237:148–155

Abd Elwahed, A. H. M. (2018). Response of tomato plant to foliar application of potassium silicate under different irrigation water levels. J. Biol. Chem. Environ. Sci., 13(1), 59-78

Abd-El-Kareem, F.; Elshahawy, I.E. and Abd-Elgawad, M.M. (2019). Effectiveness of silicon and silicate salts for controlling black rot and induced pathogenesis-related protein of strawberry plants. Bulletin of the National Research Centre, 43:91

Abo El-Fadel, N. and Shama, M.A. (2020). Foliar Application of Glycine Betaine and Potassium Silicate and Its Effect on Growth Performance of Jerusalem Artichoke Grown on Calcareous Soil Under Water Stress Conditions. J. Adv. Agric. Res. (Fac. Agric. Saba Basha). 25 (1)14-36.

Albert, E. (2017). Genetic and genomic determinants of response to water deficit in tomato (Solanum lycopersicum) and impaSWct on fruit quality. Ph.D. Thesis, Agricultural sciences. Université d'Avignon, 422pp.

Aliche, E.B.; Prusova-Bourke, A.; Ruiz-Sanchez, M.; Oortwijn, M.; Gerkema, E.; Van As, H.; Visser, R.G. and van der Linden, C.G. (2020). Morphological and Physiological Responses of the Potato Stem Transport Tissues to Dehydration Stress. Planta, 251, 1–15.

Al-Shammari, A.M.; Abood, M.A. and Hamd, G.H. (2020). Improvement in production, fruit quality and water use efficiency of three tomato cultivars by foliar application of Tecamin flower under water deficit conditions. Journal of Central European Agriculture, 21(2), 379-385

Arnon, D.I., (1949). Copper enzymes in isolated chloroplasts. Polyphenol-oxidase in Beta vulgaris L. Plant Physiology 24, 1–5.

Bassiony,S.S.; Zaghloul, A.E. and Abd El-Aziz, M.H. (2018). Effect of irrigation levels with foliar spray of silicon, calcium and amino acids on "Thompson seedless" grapevines. i. yield and fruit quality J. Product. & Dev., 23(3): 429-452.

Chellappa, L. R., & Doraikannan, S. (2022). Assessment and comparison of the antimicrobital activity and antioxidant potential of commercially available probiotic infused green tea, slim tea and green coffee. International Journal of Health Sciences, 6(S1), 2487–2498. https://doi.org/10.53730/ijhs.v6nS1.5315

Chen, D.; Wang, S.; Yin, L. and Deng, X. (2018) How does silicon mediate plant water uptake and loss under water deficiency? Front Plant Sci 9:281. https://doi.org/10.3389/fpls.2018.00281

DaCosta, M. and Huang, B.R. (2006). Osmotic adjustment associated with variation in bent grass tolerance to drought stress. J Am Soc Horti Sci 2006; 131: 338-344.

DaCosta, M. and Huang, B.R. (2006). Osmotic adjustment associated with variation in bent grass tolerance to drought stress. J Am Soc Horti Sci 2006; 131: 338-344.

Debona, D.; Rodrigues, F. A. and Datnoff, L. E. (2017). Silicon's role in abiotic and biotic plant stresses. Annual Review of Phytopathology, 55, 85–107.

Degif, A.B. and Woltering, E. (2015). Ethylene, 1-MCP and the antitranspirants effect of active compound-film forming blend. Malaysian Journal of Medical and Biological Research, 2 (3): 256-261. doi: 10.18034/mjmbr

Du, T.; Kang, S.; Zhang, J. and Davies, W.J. (2015). Deficit irrigation and sustainable water -resource strategies in agriculture for China's food security. J. Exp. Bot. 66,2253–2269.

Egilla , J.N.; Davies, F.T. and Drew, M.C.(2001).. Effect of potassium on drought resistance of Hibiscus rosa-sinensis cv. Leprechaun: Plant growth, leaf macro- and micronutrient content and root longevity. Plant Soil 2001, 229, 213–224.

El-Saady, W.A. (2017). Effect of irrigation water level and potassium silicate foliar application rate on drip irrigated-potato growth, yield and quality. Current Science International, 6 (4): 940-954.

FAO (2020) food loss analysis tomato value chain in Egypt. http://www.fao.org/3/ca5885en/CA5885EN.pdf (Accessed Oct 2020).

FAOSTAT (2020). FAO Statistical Database (FAOSTAT). Available at: http://www.fao.org/faostat/en/#data/QC (Accessed Oct 2020).

FAOSTAT (2021). http://www.fao.org/faostat/en/#data/QC (accessed on 13.02.2021).

Farag, A. A., Abdrabbo, M. A. A. and Ahmed, M. S. M. (2014). GIS Tool for Distribution Reference Evapotranspiration under Climate Change in Egypt International Journal of Plant & Soil Science 3(6): 575-588, 2014; Article no. IJPSS.2014.6.005.

Foolad, M. R.; Zhang, L. P. and Subbiah, P. (2003). Genetics of drought tolerance during seed germination in tomatoes: Inheritance and QTL mapping. Genome, 46, 536–545.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedures for agricultural research, John Wiley and Sons, Inc., New York, 680 pp.

Halford, N.G. (2009). New insights on the effects of heat stress on crops. J. Exp. Bot. 2009, 60, 4215–4216.

Hanafy, A. H.; Harb, E.M.; Higazy, M. A. and Morgan, S. H. (2008) .Effect of silicon and boron foliar applications on wheat plants grown under saline soil conditions. International J. Agric. Res., 3: 1-26.

Hasanuzzaman, M.; Bhuyan, M.H. B.; Zulfiqar, F.; Raza, A.; Mohsin, S.M.; Mahmud, J.A.; Fujita, M. and Fotopoulos, V. (2020). Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator .Antioxidants, 9, 68

Hassan, A.A. (1988). Tomato. 1st ed., Published by Arab House for Publishing and Distribution, Cairo, Egypt (in Arabic).

Hayat, S.; Ali, B.; Hasan, S.A. and Ahmad, A. (2007). Brussino steroid enhanced the level of antioxidants under cadmium stress in Brassica juncea. Environmental and Experimental Botany 60, 33–4

Islam, M. Z.; Mele, M. A.; Choi, K. Y. and Kang, H. M. (2018). The effect of silicon and boron foliar application on the quality and shelf life of cherry tomatoes. Zemdirbyste Agric. 105, 159–164.

Jensen, M.E. (1983). Design and operation of farm irrigation systems. ASAE, Michigan, USA, p. 827.

Larsen, S. (1962). On the biogenesis of some indole compounds. Physiol. Plant, 15:552-565.

Luitel, B.P.; Khatri, B.B.; Choudhary, D.; Paudel, B.P.; Jung-Sook, S.; Hur, O.-S.; Baek, H.J.; Cheol, K.H. and Yul, R.K. (2015). Growth and Yield Characters of Potato Genotypes Grown in Drought and Irrigated Conditions of Nepal. Int. J. Appl. Sci. Biotechnol., 3, 513–-519.

Marin, J.A.; Andreu, P.; Carrasco, A. and Arbeloa, A. (2010). Determination of proline concentration, an abiotic stress marker, in root exudates of excised root cultures of fruit tree rootstocks under salt stress. Revue des Régions Arides – Numéro spécial – 24 (2/2010) Actes du 3ème Meeting International ''Aridoculture et Cultures Oasisennes : Gestion et Valorisation des Ressources et Applications Biotechnologiques dans les Agrosystèmes Arides et Sahariens''Jerba (Tunisie) 15-16-17/12/2009..https://core.ac.uk

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants, 3rd ed.; Academic Press: London, UK 2012; pp. 178-189.

Miller, G. L. (1959). Use of dinitrossalicylic acid reagent for determination of reducing sugars. Anal Chem., 31: 426-428

Mir, R.A.; Bhat, B.A.; Yousuf, H.; Islam, S.T.;Raza, A.; Rizvi, M.A.; Charagh, S.; Albaqami ,M.; Sofi, P.A. and Zargar, S.M. (2022). Multidimensional role of silicon to activate resilient plant growth and to mitigate abiotic stress. Front. Plant Sci. 13:819658.

Miyao, G.; Goodell, P.B.; Davis, R.M.; Hembree, K.J.; Natwick, E.T.; Ploeg, A.; Aegerter, B.J.; Lanini, W.T.; Stapleton, J.J.; Stoddard, C.S.; Subbarao, K.V.; Trumble, J.T. and Zalom F.G. (2020). Revised continuously. UC IPM Pest Management Guidelines: Tomato. UC ANR Publication 3470. Oakland, CA. available at: https://www2.ipm. ucanr.edu/agriculture/tomato/ (Accessed Oct 2020).

Muneer, S., and Jeong, B. R. (2015). Proteomic analysis of salt-stress responsive proteins in roots of tomato (Lycopersicon esculentum L.) plants towards silicon efficiency. Plant Growth Regul. 77, 133–146. doi: 10.1007/s10725-015-0045-y

Nagata, M. and Yamashita, I. (1992). Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. J. Japan. Soc. Food Sci. Technol., 39: 925-928.

Nayyar, H. and Walia, D.P. (2003). Water stress induced proline accumulation in contrasting wheat genotypes as affected by calcium and abscisic acid. Boil. Plant, 46: 275-279.

Nobel, P.S. (2009). Physicochemical and Environmental Plant Physiology. 4th Edition, Academic Press, Inc., San Diego, CA., USA 604 pp.

Partama, I. B. G., Yadnya, T. G. B., Trisnadewi, A. A. A. S., & Sukada, I. K. (2018). Increasing nutrition value of fermented rice hull through biofermentation of lactobacillus complex bacteria supplemented. International Journal of Life Sciences, 2(2), 73–82. https://doi.org/10.29332/ijls.v2n2.179

Sadasivam, S. and Manickam, A. (1996). Biochemical Methods. Second Ed. New Age Int. Pvt. Ltd. Pub. and T.N. Agricul. Univ. Coimbatore: 108-110.

Sadler, G.; Davis, J. and Dezman, D. (1990). Rapid extraction of lycopene and B-carotene from reconstituted tomato paste and pink grapefruit homogeneates. J. Food Sci., 55: 1460-1461.

Salim, B.B.M.; Abou El-Yazied, A.; Salama, Y.A.M.; Raza, A. and Osman, H.S. (2021). Impact of silicon foliar application in enhancing antioxidants, growth, flowering and yield of squash plants under deficit irrigation condition. Annals of Agricultural Sciences 66:176–183

Shani, E.; Salehin, M.; Zhang, Y.; Sanchez, S.E.; Doherty, C.; Wang, R.; Mangado, C.C.; Song, L.; Tal, I. and Pisanty, O. (2017). Plant stress tolerance requires auxin-sensitive Aux/IAA transcriptional repressors. Curr. Biol. 2017, 27, 437–444.

Sharma, S.K. and Maguer, M. (1996). Lycopene in tomatoes and tomato pulp fractions. Ital. J. Food. Sci. 2: 107-113.

Shi, Y.; Zhang, Y.; Han, W. H.; Feng, R.; Hu, Y .H.; Guo, J. and Gong, H. J. (2016) . Silicon enhances water stress tolerance by improving root hydraulic conductance in Solanum lycopersicum L. Frontiers in Plant Science, 7, 196

Shi, Y.; Zhang, Y.; Yao, H.; Wu, J.; Sun, H. and Gong, H. (2014). Silicon improves seed germination and alleviates oxidative stress of bud seedlings in tomato under water deficit stress. Plant Physiol Biochem 78:27–36

Sibomana, I.C.; Aguyoh, J.N. and Opiyo, A.M. (2013) .Water stress affects growth and yield of tomato (Lycopersicon esculentum M.) Plants. G.J.B.B., 2(4):461-466.

Silva, D.C.; Melo, A.S.; Melo, Y.L.; Andrade, W.L.; Lima, L.M. and Santo, A.R. (2017). Silicon foliar application attenuates the effects of water suppression on cowpea cultivars. Ciência e Agrotecnologia, 43: e023019

Silva, O.N.; Lobato, A.K.S.; Ávila, F.W.; Costa, R.C.L.; Oliveira Neto, C.F.; Santos Filho, B.G.; Martins Filho, A.P.; Lemos, R.P ;.Pinho, J.M.; Medeiros, M.B.C.L.; Cardoso, M.S., and Andrade, I.P. (2012). Silicon-induced increase in chlorophyll is modulated by the leaf water potential in two water-deficient tomato cultivars. Plant Soil Environ., 58, 481–486

Singh, V. K.; Singh, A. K.; Singh, P. P. and Kumar, A. (2018). Interaction of plant growth promoting bacteria with tomato under abiotic stress: a review. Agric. Ecosyst. Environ. 267, 129–140. doi: 10.1016/j.agee.2018.08.020

Skirycz, A.; De Bodt, S.; Obata, T.; De Clercq, I.; Claeys, H.; De Rycke, R.; Andriankaja, M.; Van Aken, O.; Van Breusegem, F. and Fernie, A.R. (2010). Developmental stage specificity and the role of mitochondrial metabolism in the response of Arabidopsis leaves to prolonged mild osmotic stress. Plant Physiol 152: 226–244.

Song, L.; Huang, S.C.; Wise, A.; Castanon, R.; Nery, J.R.; Chen, H.; Watanabe, M.; Thomas, J.; Bar-Joseph, Z. and Ecker, J.R. (2016). A transcription factor hierarchy defines an environmental stress response network. Science 2016, 354.

Subbarao, K.V.; Trumble J.T. and Zalom F.G. (2020). Revised continuously. UC IPM Pest Management Guidelines: Tomato. UC ANR Publication 3470. Oakland, CA. available at: https://www2.ipm. ucanr.edu/agriculture/tomato/ (Accessed Oct 2020).

Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2021). Health and treatment of diabetes mellitus. *International Journal of Health Sciences*, *5*(1), i-v. https://doi.org/10.53730/ijhs.v5n1.2864

Tareen, M.J.; Abbasi, N.A. and Hafiz, I.A. (2012). Effect of oxalic acid treatments on storage life of peach fruit Cv. "Flordaking". Pak. J. Bot., 44: 207-310.

Troll, W. and Lindsley, J. (1995). A photometric method for defermination of praline J. Biol Chem. 215: 655 – 660.

Verma, K.K.; Anas, M.; Chen, Z.; Rajput.; Malviya, M.K.; Verma, L.; Singh, R.K.; Singh, K.; Song, X. and Li, R. (2020). Silicon supply improves leaf gas exchange, antioxidant defense system and growth in Saccharum officinarum responsive to water limitation. Plants, 9, 1032. http://www.mdpi.com/journal/plants

Verma, K.K.; Song, X.; Tian, D.; Singh, M.; Verma, C.L.; Rajput ,V.D.; Singh, R.K.; Sharma, A.; Singh, P.; Malviya, M.K.; and Li, R. (2021). Investigation of defensive role of silicon during drought stress induced by irrigation capacity in sugarcane: physiological and biochemical characteristics. ACS Omega XXXX, XXX, XXX−XXX. http://pubs.acs.org/journal/acsodf

Wang, M.; Zheng, Q.; Shen, Q. and Guo, S. (2013). The critical role of potassium in plant stress response. Int. Int. J. Mol. Sci. 14, 7370–7390.

Wang, Y.; Cai, S.; Yin, L.; Shi, K.; Xia, X.; Zhou, Y.; Yu, J. and Zhou, J. (2015). Tomato HsfA1a plays a critical role in plant drought tolerance by activating ATG genes and inducing autophagy. Autophagy, 11, 2033–2047.

Wang, Y.; Zhou, J. and Yu, J. (2017) . The critical role of autophagy in plant responses to abiotic stresses. Frontiers of Agricultural Science and Engineering, 4, 28–36.

Yemm, E.W. and Cocking, E.C. (1955) The Determination of Amino-acids with Ninhydrin. Analyst. 80: 209-214

Zahedi, S.M.; Moharrami, F.; Sarikhani, S. and Padervand, M. (2020). Selenium and silica nanostructure-based recovery of strawberry plants subjected to drought stress. Scientific Reports, 10:17672. https://doi.org/10.1038/s41598-020-74273-9

Zhang, H.; Xiong, Y.; Huang, G.; Xu, X. and Huang, Q. (2017). Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. Agric. Water Manag. 179 ,205–214.

Zhu, Y. and Gong, H. (2014). Beneficial effects of silicon on salt and drought tolerance in plants. Agron. Sustain. Dev., 34, 455–472.