RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
56 (2) 739-750, 2024
http://doi.org/10.54910/sabrao2024.56.2.25
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

SILICON AS STIMULANT TO MITIGATE WATER STRESS IN SUGAR BEET PRODUCTIVITY AND QUALITY UNDER DEFICIT IRRIGATED CONDITIONS IN EGYPT

D.M. ABO-BASHA*, H.H. ABDEL-KADER, S.A.A. ELSAYED, and F.A. HELLAL

Department of Plant Nutrition, National Research Centre, Dokki, Cairo, Egypt
*Corresponding author's email: dr.doaa_nrc@yahoo.com
Email addresses of co-authors: hananhaggaga@gmail.com, elsayed.saied1993@yahoo.com, hellalaf@yahoo.com

SUMMARY

Egypt suffers from limited water resources, which threatens food security and reduces the chances of horizontal expansion by reclaiming new desert lands. Therefore, it was necessary to achieve this target for the productivity and quality of crops under harsh conditions. Field experiments proceeded at the Nubaria research station under sandy soil conditions to evaluate the effects of different silicon sources (silica gel, algae rich in silicon, and potassium silicate) on sugar beet yield and quality under different irrigation regimes (100%, 75%, and 50%) of water requirement (WR) during the growing seasons of 2020 and 2021. Results showed that potassium silicate was most effective for increasing chlorophyll content and growth parameters compared with other sources under water stress conditions. Also, improved nutrient contents in the root and shoot of sugar beet gave the highest values on N (0.58%, 2.54%), P (0.132%, 0.318%), K (0.42%, 1.05%), Fe (67.18, 83.28 ppm), and Zn (11.29, 12.73 ppm) content, respectively, when applied with K_2SiO_3 compared with deficit irrigation conditions. Stimulating rich-Si remains the most effective for enhancing the growth, quality, and yield of sugar beet grown under deficit irrigation regimes, which makes plants more resistant to weather conditions and water stress.

Keywords: Silicon sources, sugar beet, yield, sugar quality, water stress

Key findings: The application of stimulate rich-Si has been found to alleviate the harmful effects of water stress on sugar beet crops. Among the different sources of silicon, the application of stimulates rich-Si K_2SiO_3 and algae containing Si is the most effective in enhancing sugar beet yield by reducing water stress effects and improving growth, quality, and sugar yield under deficit irrigation conditions.

Communicating Editor: Prof. Dr. Clara R. Azzam

Manuscript received: October 9, 2023; Accepted: December 5, 2023.

Citation: Abo-Basha DM, Abdel-Kader HH, Elsayed SAA, Hellal FA (2024). Silicon as stimulant to mitigate water stress in sugar beet productivity and quality under deficit irrigated conditions in Egypt. *SABRAO J. Breed. Genet.* 56(2): 739-750. http://doi.org/10.54910/sabrao2024.56.2.25.

INTRODUCTION

Drought stress is a primary abiotic stress, limiting global crop production and putting food security at higher risk. It is becoming more prevalent and severe in many locations due to reduced rainfall and higher evaporation owing to global climate change (Diatta *et al.,* 2020). Sugar beet (*Beta vulgaris L.*) serves as the second source of sugar production in Egypt and many countries worldwide. The Egyptian government promotes sugar beet by encouraging producers to expand the area under sugar beet cultivation to enhance sugar output and close the gap between sugar production and consumption. Sugar beet is a crop that is valuable in Egypt for several reasons. Sugar beet is the only economically cultivated crop species in a wide range of temperate regions that stores sucrose (Galal *et al*., 2022).

Nonetheless, sugar beet production in tropical and subtropical areas is expanding quickly and becoming a significant part of the sugar industry (Abou-Elwafa *et al*., 2020). Nofal *et al.* (2014) reported that under newly reclaimed soils, enhancement of sugar beet production is achievable through using balanced fertilization management. Focusing efforts on irrigation, El-Sarag (2009) revealed that maximizing sugar beet production can happen through optimizing irrigation intervals. On the other hand, the management of agricultural practices in a good way leads to improved physiological performance, as reflected in improved productivity and quality (Gaballah *et al*., 2020). Water stress negatively impacted most yield metrics and nutritional content of the studied barley cultivars. At the same time, applying K Silicate increased yield components and grain yield of barley significantly with or without water stress (Hellal *et al*., 2020 b).

Silicon (SiO_2) is a recent problem in fertilization techniques. Similarly, silicon application is a novel idea for sugar beet fertilization (Artyszak *et al*., 2015). Silicon is crucial, lessening the plant's susceptibility to biotic and abiotic environmental stress. Increased tolerance to water stress is one of silicon's most significant positive impacts on plant development (Sacała, 2009). According to Cai *et al*. (2009), this element strengthens the plants' resilience to pests and diseases. The sugar beet is one of seven plant species that fall under the category of silicon bio-accumulators (Guntzer *et al*., 2012).

However, there is a shortage of research on the efficacy of this type of fertilization; therefore, it is necessary to determine the ideal amount and timing of silicon administration. By preserving leaf water potential, stomatal conductance, leaves' erectness, photosynthetic activity, and the structure of xylem vessels during the rising transpiration ratio, giving silicon to plants helps them tolerate excessive drought (Hattori *et al*., 2005). The study assessed how irrigation water levels influenced sugar beet roots’ output and technical quality when applied with stimulates rich-Si as soil and foliar fertilizer.

MATERIALS AND METHODS

Field experiments

A field experiment transpired during the winter of 2020 and 2021 to study the effect of applied silicon treatments from different sources on sugar beet productivity and quality under water-stress conditions in areas of Egypt at the Experimental Research Farm of the National Research Center (latitude 30.87 N, longitude 31.17 E, and mean elevation at 21 masl) to probe the effect of three silicon treatments’ application from different sources (silica gel as a soil conditioner, algae (*Spirulina platensis*) rich in silicon, and potassium silicate fertilizer (K_2SiO_3) on sugar beet (*Beta vulgaris*) Etch-poly cultivar, the most productive and superior quality cultivar under water-stress conditions.

Experimental location features

The experimental region showed features of an arid location, with chilly winters and scorching, dry summers. The experimental site's soil falls under the sandy soil category. Soil chemical and nutritional characteristics were 7.81 and 8.07 pH; 1.02 and 0.96 EC dS m^{-1}; 2.44 and

2.61 available N (mg/100 g soil); 0.66 and 0.63 available P (mg/100 g soil); 16.81 and 15.96 available K (mg/100 g soil); 6.32 and 6.15 available Fe mg kg^{-1}; 3.14 and 3.10 available Mn mg kg^{-1}; 2.25 and 2.39 available Zn mg kg^{-1}; and 0.41 and 0.39 available Cu mg kg^{-1}, in the first and second seasons, respectively. The chemical analyses followed the method by Cottenie *et al*. (1982).

Experiment description and statistical design

The experiments included 12 treatments resulting from the combinations of three irrigation regimes (100%, 75%, and 50% from the irrigation requirements) as the main plots and four bio-stimulant treatments (control, silica gel [24 kg ha^{-1}], algae [*Spirulina platensis*] rich in silicon [2 gm l^{-1}], and potassium silicate [2 gm l^{-1}] as the subplots on sugar beet (*Beta vulgaris*) Etch-poly cv. The experimental design was a split plot with three replications. The experimental area consisted of 36 plots. The subplot area was 12 m^2 (3 m × 4 m).

Field treatments

Sugar beet seeds' planting (October 20) on hills was 20 cm apart. Before planting, phosphorus application at a rate of 72 kg P_2O_5 ha^{-1} was in the form of calcium superphosphate (15.5% P_2O_5). Adding the nitrogen fertilizer had the recommended rate of 192 kg N ha^{-1} in the form of urea (46% N) in two equal doses, applying the first fertilization after thinning (25 days after planting) and the second at 55 days after planting. Potassium sulfate (48% K_2O), a potassium fertilizer administered at a rate of 57.6 kg K_2O ha^{-1}, occurred 40 days after planting. The other cultivation practices, i.e., controlling weeds and insects, continued on the typical sugar beet field following the standard recommendations. Foliar application treatments in both seasons, 45 and 60 days after planting, had a rate of 2 g l^{-1} from Algae and K_2SiO_3. Silica gel as a soil application had a rate of 24.0 kg ha^{-1}. Silica gel contains 467 g kg^{-1} total Si and 58 g kg^{-1} soluble Si. Potassium Silicate as K_2SiO_3 contains 2.5 SiO_2: 1 K_2O. The commercial algae extract used as a foliar application contains 100% solubility and a pH of 7.9 and includes 16%–18% silicon (34.3%–38.5% SiO_2), 42.0%–51.0% organic matter, 1.0%–2.8% nitrogen, 1.0%–4.5% phosphorus (P_2O_5), 7%–16% potassium (K_2O), and 1.6%–7.5% amino acids. Producing the blue algae *Spirulina platensis* ensued at the Algal Biotechnology Unit, National Research Centre.

Irrigation treatments

Three drip irrigation regimes, applied as a percentage of the crop evapotranspiration (ETc), employed computations according to Allen *et al.* (1998), as follows:

$$\mathbf{ETc = ETo \times Kc}$$

Where: Kc = crop coefficient, ETc is the crop water needs (mm day^{-1}), and ETo is the reference evapotranspiration (mm day^{-1}). ETo calculations used the technique of Allen *et al.* (1998), as follows:

$$\mathbf{ETo = Epan \times Kp}$$

Where: Epan is the evaporation from class A and Kp is the pan coefficient.

The plants in all plots incurred irrigation at 10-day intervals with different amounts of water. Irrigation water quantities approximation used the following equation:

$$\mathbf{IWA = \frac{A \times ETc \times Ii}{Ea \times 1000}}$$

Where: A = plot size (m^2), ETc is the reference evapotranspiration (mm day^{-1}), IWA is the irrigation water application (m3), Ii is the irrigation intervals (day), and Ea is the application efficiency (%). An irrigation water application (IWA) controller was a 50 mm-diameter plastic pipe (spiles). Each plot had a single spile to transport water. The pumped volume of water via a plastic pipe attained identification using Israelsen and Hansen (1962).

$$Q = CA\sqrt{2gh}\,10^{-3}$$

Where: Q is the discharge of irrigation water (l sec^{-1}), C is the coefficient of discharge, A is the cross-section area of the irrigation pipe (cm^2), g is gravity acceleration (cm sec^{-2}), and h is the average of the influential head of water (cm). The amounts of irrigation water are available in Table 1, 4000, 3000, and 2000 m^3 ha^{-1} to cover 100%, 75%, and 50% of irrigation needs, respectively. Irrigation treatments begin after complete germination (15 days after planting).

Chlorophyll content

According to Minolta (1989), using the Minolta-SPAD Chlorophyll Meter (Minolta Camera Co., Osaka, Japan) helped measure the greenery present in a plant.

Growth characteristics

The following measurements happened at harvesting (April 25): fresh root weight (kg), root length and diameter (cm), and leaf area index (LAI) = unit leaf area per plant (cm^2)/plant ground area (cm^2).

Nutritional status

Plant sample collection from each experimental plot ensued at harvesting time. Washing samples of dry matter (shoot or root) using distilled water, then proceeding to dry at 70 °C and preparing for analysis of macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn), according to Cottenie *et al.* (1982).

Juice quality traits and impurities content

A digital refractometer assessed the percentage of total soluble solids (TSS). According to Carruthers and Oldfield (1960), the sucrose percentage (S%) calculation used a Sacharometer on a lead acetate extract of freshly macerated roots. Using the approach of Silin and Silina (2011) computed the juice purity percentage (JP%) by dividing the sucrose (%) total soluble solids. Operating the Flame photometer and the technique outlined by Brown and Lilland (1964) obtained the amounts of sodium (Na) and potassium (K) (meq $100g^{-1}$ beet) in the digested solution. Also, the α- Amino N quantification utilized the double beam filter photometry using the blue number method (Sheikh, 1997). The following equation calculated impurities: Impurities (%) equal to 0.094 (α amino-N) + 0.343 (Na+ K).

Table 1. Water requirement for drip irrigated sugar beet grown on sandy soil at Nubaria, Behira Governorate.

Month	Sept.		Oct.		Nov.		Dec.		Jun	Total
Period	15-30		1-30		1-30		1-31		1-15	
ETo mm day^{-1}	5.9		6.4		7		6.2		5.4	
No. of day	20	10	25	10	22	12	26		15	140
Kc		0.53		0.88		1.09		0.72		
Kr		0.7		0.85	0.91	0.95	1.00			
Etc/loc. mm day^{-1}	2.19	2.374	4.787	5.236	6.943	6.42	4.464	3.888		
Ks	1.15	(87%)								
Eu	1.11	(90%)								
Lr	10%									
Lrg mm day^{-1}	3.075	3.333	6.722	7.352	9.749	9.015	6.268	5.462		
Lrg L day^{-1} $plant^{-1}$	0.769	0.833	1.681	1.838	2.437	2.254	1.567	1.366		
Lrg L $season^{-1}$ $plant^{-1}$	18.304	8.502	45.301	28.38	78.18	42.54	45.907	31.392		300
Lrg L m^3 $season^{-1}$ $plant^{-1}$	295.7	236.0	673.2	398.8	949.9	473.89	614.84	355.39		
(I_1)	531.74		1071.95		1423.79		970.23		4000 m3 fed^{-1}	

ETo= reference evapotranspiration, Kc= crop coefficient, Kr= reduction factor for the influence of ground cover, Ks= a coefficient for the water storge efficiency of the soil, Eu= application uniformity, Lr = leaching requirements, I_1 = 100% of water requirements.

The formula used to calculate the recoverable sugar percentage (RS%) was RS% = (S%-0.29) - (0.343[Na+K] + 0.094 [ɑ amino-N]). According to Harvey and Dutton (1993), the formula for calculating the proportion of sucrose lost to molasses (SLM%) is SLM% = 0.343 (K+ Na) + 0.094 (ɑ amino-N)-0.31.

Root and Sugar Yield Parameters

Estimating the root yield (ton ha^{-1}), collecting plants continued from each subplot's four central ridges. The following equation helped compute the white sugar yield (ton ha^{-1}):

WSY = recoverable sugar percentage (RS%) × 100 x root yield (ton ha^{-1}).

Technological quality

Sugar loss in molasses percentage (SM): = (0.14 [Na + K] + 0.25 [ɑ -amino N] + 0.50) (Devillers, 1988); Extractable sugar percentage (EX): = (Sucrose % - [SM] + 0.60), and Extractability percentage (EXB: = ([EX] / Sucrose % × 100) (Dexter *et al.,* 1967).

Statistical analysis

Snedecor and Cochran's (1981) method helped calculate the data gathered for two seasons. The least significant difference (LSD) test of Duncan (1955) provided a comparison of treatment means at a 5% level of significance, according to Gomez and Gomez (1984).

RESULTS

Growth parameters

The data presented in Table 2 indicated that the chlorophyll content of sugar beet plants gained significant effects from the different studied water treatments. In general, the chlorophyll content of sugar beet leaves in control treatments was higher at 100% WR than the other water regimes (43.43). For decreasing water application to 75% and 50% WR, the reduced chlorophyll content in sugar beet plants was 41.23 and 36.63. Significant physiological and biochemical effects of silica were visible in the structure of photosynthetic pigments and in the metabolism of proteins and carbohydrates. Therefore, data revealed that achieving the maximum plant height and leaf area was at 100% water requirement combined with foliar application of Si under all examined irrigation water treatments, with the lowest one observed at 50% WR (water stress). Increasing water stress caused a decrease in plant height and total leaf area, with the minimum values attained in the control treatments. Applying algal extract and K_2SiO_3 combined with 100% WR gave the highest plant height (75.67 and 74.33 cm, respectively), whereas the recorded lowest values occurred in the control treatment (62.0 cm). Under water stress (50% WR), foliar application of algal extract increased the total leaf area (963) and the leaf area index (12), followed by K_2SiO_3 (873) and (10.92), and the lowest values manifested in the control's total leaf area (572) and leaf area index (7.15).

Yield parameters

The presented results showed that water stress negatively affected sugar beet yield parameters. The data in Table 3 illustrates the effect of Si-rich materials on the fresh and dry root, shoot weight, and root yield under different irrigation water requirement treatments (100%, 75%, and 50% WR). The findings indicated that increasing water stress was the main reason for a decreasing root and shoot fresh and dry weight and root yield of the sugar beet crop.

The highest values of root fresh weight (2157 g) and shoot fresh weight (926.7 g), root yield (59.95 ton ha^{-1}) and biological yield (111.98 ton ha^{-1}) appeared with applying 100% WR combined with foliar application of K_2SiO_3, while the lowest values (894 g and 469.3 g for plant root and shoot fresh weight, the root yield and total yield at 47.28 ton ha^{-1} and 76.1 ton ha^{-1}, respectively) emerged at the control treatment under water stress treatment (50% WR). At water stress treatment, the application of silica source improved the root and shoot fresh weight, especially when applying the

Table 2. Growth parameters as affected by rich-Si stimulates under irrigation water levels. (Data average of two seasons).

Water requirements	Si-Treatments	Chlorophyll (SPAD)	Plant length (cm)	Total Leaf Area (cm)	Leaf area index (LAI)
100%	Control	43.43	62.00	859.4	10.74
	Silica gel	49.53	67.67	1128.3	14.10
	Algae	58.53	75.67	1462.9	18.29
	K_2SiO_3	62.53	74.33	1456.3	18.20
75%	Control	41.23	53.67	656.0	8.20
	Silica gel	44.20	64.33	876.9	10.96
	Algae	52.77	66.00	1104.3	13.80
	K_2SiO_3	56.87	68.67	1001.5	12.52
50%	Control	36.04	46.80	572.0	7.15
	Silica gel	38.63	56.10	764.6	9.56
	Algae	46.12	57.55	962.9	12.04
	K_2SiO_3	49.70	59.88	873.3	10.92
LSD (0.05)	Water req.	4.71	4.81	32.5	3.41
	Si-Treat.	3.89	3.45	21.6	2.42
	Interaction	7.06	6.78	44.4	4.79

Table 3. Yield parameters as affected by rich-Si stimulates under irrigation water levels. (Data average of two seasons).

Water requirements	Si- Treatments	Fresh weight (g)		Dry weight (g)		Root yield (ton ha^{-1})	Biological yield (ton ha^{-1})
		Root	Shoot	Root	Shoot		
100%	Control	1311	643.1	136.7	59.13	54.96	85.63
	Silica gel	1625	746.7	152.9	72.78	58.51	97.03
	Algae	1910	893.0	164.0	78.38	59.52	109.08
	K_2SiO_3	2157	926.7	192.6	88.67	59.95	111.98
75%	Control	1140	598.7	105.7	40.10	48.91	79.13
	Silica gel	1315	680.1	125.7	60.03	53.66	88.61
	Algae	1693	755.2	141.5	70.75	58.13	97.44
	K_2SiO_3	1643	754.3	171.0	76.32	59.21	98.09
50%	Control	894	469.3	82.87	31.44	47.16	76.01
	Silica gel	1031	533.2	98.54	47.07	48.36	79.70
	Algae	1328	592.1	110.90	55.47	52.90	87.65
	K_2SiO_3	1288	591.3	134.04	59.83	53.66	91.70
LSD (0.05)	Water req.	13.62	6.25	3.14	1.18	0.886	1.260
	Si-Treat.	10.65	4.21	2.54	1.26	0.497	0.984
	Interaction	19.93	8.59	4.66	2.00	1.135	1.842

algae extract (1328 and 591.3 g), followed by K_2SiO_3 (1288 and 591.3 g), and the lowest values registered for the control treatment.

The presented data in Table 3 indicated that deficit irrigation decreased the root yield by 6.05 ton ha^{-1} (11.0%) and 7.8 ton ha^{-1} (14.0%) on the control treatment under 75% and 50% WR compared with irrigation by 100% WR. At the same time, foliar application of potassium silicate increased root yields by 23.86%, 39.40%, and 23.30%, compared with the control treatment under each irrigation water regime (100%, 75%, and 50%), respectively.

The results showed the same trend with root length and root diameters of sugar beet plants with irrigation water treatments (Figure 1). Application of K_2SiO_3 and algae extracts gave the highest increased percentage of root length and diameters. The control treatments provided the lowest values under deficit irrigation water treatments. These outcomes might refer to silica, which builds up in the stem epidermis cell wall and helps to create stronger stems.

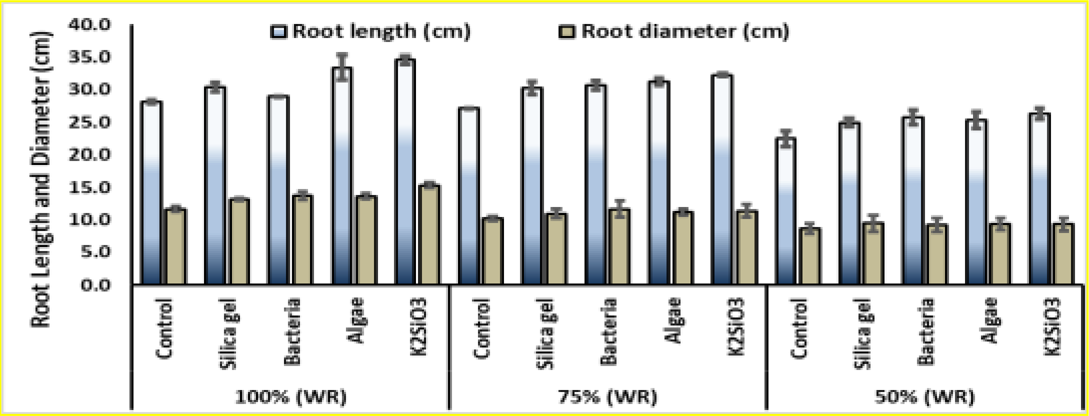

Figure 1. Effect of Si treatments and irrigation levels on sugar beet root length and diameters.

Macronutrient contents

Nutrient content in the root and shoot of sugar beet significantly improved when applied with silicon-rich materials under sufficient and deficit irrigation conditions. Table 4 shows the effect of foliar application of Si-rich materials on nitrogen (N), phosphorus (P), and potassium (K) in roots and shoots of sugar beet under irrigation water treatments (100%, 75%, and 50% WR). The results of control treatments showed that the highest values of nitrogen were 1.19% and 3.66%, phosphorus were 0.18% and 0.44%, and potassium were 0.60% and 1.44%, observed, respectively, in root and shoot of sugar beet at 100% WR, followed by 75% WR combined with the K_2SiO_3 treatment. But the lowest one occurred at the control treatment under water stress treatment of 50% WR, recording 0.40% and 2.07% for N content, 0.119% and 0.164% for P content, and 0.31% and 0.73% for K content, on fresh roots and shoots, respectively.

Increasing water stress correlated with decreasing macronutrient contents in the root and shoot of the sugar beet crop, and the minimum values were evident in control with 50% WR treatment. Under water stress treatment, the application of K_2SiO_3 was superior, followed by the algae extract, and the lowest values of N, P, and K occurred at the silica gel and control treatment. Regardless of the irrigation water treatments, application of K_2SiO_3 gave the most significant values of N, P, and K contents in the root (0.85%, 0.159%, and 0.52%) and in the shoot (3.15%, 0.385%, and 1.28%), followed by algae extract treatment, with the lowest one coming from the control.

Micronutrient contents

The data in Table 5 demonstrates how foliar application of K_2SiO_3 and algae-rich silicon affects Fe, Zn, and Mn content in root and shoot of sugar beets under different irrigation water treatments (100%, 75%, and 50% WR). The outcomes revealed that values of Fe, Mn, and Zn decreased with increasing water stress, while the opposite was true by increasing irrigation water level up to 100% of WR. The K_2SiO_3 and algae-rich silicon treatments under 100% WR were superior, and the lowest values were evident at the control treatment under a water stress regime (50% WR). The highest values of Fe (116.9 and 131.5 ppm), Mn (33.3 and 42.8 ppm), and Zn (17.3 and 20.5 ppm) in root and shoot, respectively, were prominent with the application of K_2SiO_3 at 100% WR, while the control treatment showed the lowest values at 50% WR for Fe (44.79 and 74.27 ppm), for Mn (15.65 and 20.41 ppm), and for Zn (8.85 and 10.03 ppm) in roots and shoots, respectively. The impact of irrigation treatments on the contents of micronutrients indicated that application of 100% and 75% WR gave the most significant values, and the lowest values came under the deficit irrigation treatment (50% W).

Table 4. Macronutrient contents as affected by rich-Si stimulates under irrigation water levels. (Data average of two seasons).

Water requirements	Si- Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
		Root	Shoot	Root	Shoot	Root	Shoot
100%	Control	0.91	2.83	0.158	0.327	0.48	1.17
	Silica gel	1.04	3.25	0.168	0.398	0.54	1.32
	Algae	1.04	3.55	0.173	0.401	0.57	1.45
	K_2SiO_3	1.19	3.66	0.177	0.436	0.60	1.44
75%	Control	0.51	2.64	0.151	0.209	0.40	0.93
	Silica gel	0.64	2.93	0.161	0.231	0.51	1.18
	Algae	0.65	3.23	0.167	0.310	0.53	1.32
	K_2SiO_3	0.75	3.24	0.169	0.406	0.54	1.35
50%	Control	0.40	2.07	0.119	0.164	0.31	0.73
	Silica gel	0.50	2.29	0.127	0.181	0.40	0.92
	Algae	0.51	2.53	0.131	0.243	0.41	1.04
	K_2SiO_3	0.58	2.54	0.132	0.318	0.42	1.05
LSD (0.05)	Water req.	0.055	0.112	0.046	0.030	0.032	0.073
	Si-Treat.	0.043	0.097	0.033	0.027	0.026	0.142
	Interaction	0.081	0.171	0.064	0.046	0.048	0.177

Table 5. Micronutrient contents as affected by rich-Si stimulates under irrigation water levels. (Data average of two seasons).

Water requirements	Si- Treatments	Iron (mg kg^{-1})		Manganese (mg kg^{-1})		Zinc (mg kg^{-1})	
		Root	Shoot	Root	Shoot	Root	Shoot
100%	Control	74.65	113.04	28.8	36.04	13.32	17.21
	Silica gel	89.83	119.73	29.7	38.00	14.59	18.78
	Algae	104.56	126.80	31.3	41.39	16.34	19.91
	K_2SiO_3	116.98	131.52	33.3	42.84	17.23	20.48
75%	Control	57.13	94.73	20.0	26.03	11.29	12.79
	Silica gel	61.96	94.63	21.1	27.28	12.40	14.21
	Algae	80.44	103.58	23.7	30.50	13.58	15.64
	K_2SiO_3	85.68	106.23	24.5	31.16	14.40	16.24
50%	Control	44.79	74.27	15.65	20.41	8.85	10.03
	Silica gel	48.57	74.19	16.51	21.39	9.72	11.14
	Algae	63.06	81.20	18.56	23.91	10.65	12.26
	K_2SiO_3	67.18	83.28	19.23	24.43	11.29	12.73
LSD (0.05)	Water req.	4.32	6.24	1.054	0.698	0.124	0.023
	Si-Treat.	3.65	5.13	1.068	0.547	0.099	0.226
	Interaction	6.55	9.33	1.742	1.022	0.183	0.205

Sugar quality measures

The data in Table 6 presents the effect of silicon sources on sugar quality composition under different irrigation water treatments (100%, 75%, and 50% WR). The obtained data revealed that the minimum values of sucrose, TSS, purity, Na, K, and ɑ amino N emerged at the control under the studied water stress treatment (50% WR). At the same time, the highest values of sucrose (18.8%), TSS (21.8%), purity (86.1%). As well as, Na, K and ɑ amino N (1.19, 2.22 and 0.97 meq/100g f.w) surfaced after the foliar spray of K_2SiO_3 under irrigation water at 100% WR. Regardless of irrigation water treatments, the data indicated that foliar spray of algae extract and K_2SiO_3 scored the most significant sucrose, TSS, purity, Na, K, and ɑ amino N values. The smallest values logically arose at control treatments.

Table 6. Sugar quality affected by rich-Si stimulates under irrigation water levels, (Data average of two seasons).

Water requirements	Si- Treatment	Sucrose	TSS	Purity	Sodium	Potassium	α- amino N
			(%)		(meq/100g fresh weight root)		
100%	Control	16.34	24.67	66.28	1.57	3.12	2.74
	Silica gel	17.75	23.77	74.70	1.17	2.74	1.99
	Algae	17.15	22.26	77.09	1.24	2.47	1.77
	K_2SiO_3	18.79	21.83	86.12	1.19	2.22	0.97
75%	Control	14.23	26.17	54.37	1.76	3.49	3.07
	Silica gel	14.95	25.57	58.49	1.31	3.07	2.23
	Algae	14.91	24.07	61.98	1.39	2.77	1.99
	K_2SiO_3	15.91	21.06	75.57	1.34	2.49	1.08
50%	Control	11.16	20.52	54.37	1.86	3.32	4.26
	Silica gel	11.72	20.05	58.48	1.60	3.14	3.85
	Algae	11.69	18.87	61.96	1.47	3.04	3.50
	K_2SiO_3	12.47	16.51	75.54	1.45	2.86	2.14
LSD (0.05)	Water req.	0.231	0.714	0.487	0.065	0.023	0.012
	Si-Treat.	0.411	0.652	0.332	0.045	0.039	0.021
	Interaction	0.527	1.121	0.672	0.091	0.051	0.026

Table 7. Sugar technology affected by rich-Si stimulates of sugar beet under irrigation water levels, (Data average of two seasons).

Water requirements	Si- Treatment	SM (%)	EX (%)	EXB (%)	RS (%)	QI (%)	RSY (ton ha^{-1})
100%	Control	3.62	14.35	87.77	13.75	84.10	7.344
	Silica gel	2.77	15.58	87.79	14.98	84.41	8.760
	Algae	3.47	14.28	83.27	13.68	79.77	8.136
	K_2SiO_3	2.60	15.77	83.93	15.17	80.73	9.096
75%	Control	2.16	12.67	89.01	12.07	84.79	5.904
	Silica gel	1.94	13.62	91.05	13.02	87.04	6.984
	Algae	1.93	13.58	91.07	12.98	87.04	7.536
	K_2SiO_3	1.99	14.52	91.29	13.92	87.51	8.232
50%	Control	1.70	9.93	90.79	11.51	83.09	6.168
	Silica gel	1.52	10.68	92.87	12.55	85.30	7.344
	Algae	1.51	10.65	92.89	11.46	85.30	6.816
	K_2SiO_3	1.56	11.39	93.11	12.71	85.76	7.608
LSD (0.05)	Water req.	0.231	0.714	0.487	0.065	0.012	0.023
	Si-Treat.	0.411	0.652	0.332	0.045	0.021	0.039
	Interaction	0.527	1.121	0.672	0.091	0.026	0.051

Sugar technological measures

Results presented in Table 7 imply the effect of silicon sources' application on sugar technological measures under different irrigation water treatments (100%, 75%, and 50% WR). The acquired data revealed that the minimum values of the sugar loss in molasses percentage (SM), Extractable sugar percentage (EX), Extractability percentage (EXB), Recoverable sugar percentage (RS), Recoverable sugar yield (RSY), and Quality index (QI) resulted in the control under the studied water stress treatment (50% WR). Meanwhile, the highest values of EX (15.77), EXB (83.9), RS (15.2), RSY (3.79), and QI (80.7) appeared after foliar application of K_2SiO_3 with the irrigation water level at 100% WR. The lowest values of sugar technological characteristics were noticeable under control treatments for all three irrigation water regimes. Under the deficit irrigation (50% WR), foliar application of K_2SiO_3 escaped the stress and produced the highest values of the SM

(1.56), EX (11.4), EXB (93.11), RS (12.7), RSY (3.17), and QI (85.8). Regardless of irrigation water treatments, the findings signified the foliar application of K_2SiO_3 scored with the highest values of EX, EXB, RS, and RSY; however, the lowest values attained were from the control treatments.

DISCUSSION

Foliar application of stimulates rich-Si improved the chlorophyll content of sugar beet leaves, especially with increasing water stress up to 50% water requirement (WR). These increments may be due to the role of silica in enhancing photosynthesis under water stress conditions, as found by Hafez *et al*. (2014). Silicon is essential for plant development, photosynthetic rate, and nutrient intake. Enhanced cell structure, plant architecture, strength, and leaf quality positively impacted plant growth characteristics and stress tolerance (Rizwan *et al.,* 2015). When applied under water stress, K-silicate improved shoot fresh weight, shoot length, leaf area, and leaf length (Abdul-Qadir *et al*., 2017).

Grain and straw yield metrics, which have greater values than when not applying Nano Silica under water stress, showed favorable impacts from Nano Silica. The best concentration of Nano Silica application to barley plants under drought stress is 100 ppm. These plants exhibited the highest yield and biochemical characteristic values. Results showed that applying Nano Silica can increase the yield of barley seeds in dry regions and could be a beneficial foliar fertilizer (Hellal *et al*., 2020a; Nemeata-Alla and Helmy, 2022). Potassium silicate may enhance characteristics linked to yield, seed quality and yield, and nutrient (N, P, and K) absorption (Gomaa *et al*., 2021). Compared to woody anatomy with delicate stems, the bark stem reacts more to sticky anatomy with a higher stem hardness, according to Melo *et al.* (2015). Plant tissue becomes harder when exposed to Si.

Water stress reduces plant development by interfering with several physiological and biochemical functions, including respiration, photosynthesis, food metabolism, and the production of secondary metabolites (Jaleel *et al.,* 2009; Bastaubayeva *et al*., 2023; Gusev *et al*., 2023). Arkadiusz (2018) found that spraying the growth medium with 100 to 300 ppm of potassium silicate strongly influenced the plant at the 4-leaf stage and beneficially affected the plant at other stages. Growth parameters, yield components, and nutrient content enhancement were successful by foliar spraying pea plants with potassium silicate at a rate of 228 ppm (Ismail *et al.,* 2017).

Iron, zinc, and manganese uptake by shoots and roots significantly increased when applying K_2SiO_3 and algae-rich silicon under deficit irrigation treatments. Plants have a silica gel layer, or phytolith, with a complex composition like rock (Smis *et al.*, 2014). Si preserves the cells' shape by enhancing the structural integrity of cell walls during cell elongation and division (Sivanesan and Park, 2014).

Essential plant nutrients, including nitrogen (N), phosphorus (P), and, to a lesser degree, potassium (K), and some secondary nutrients and micronutrients, are the prime determinants influencing crop yields and water usage efficiency. Food security in the world's arid regions is just as vital internationally if crops receive the proper nutrition, especially when using chemical fertilizers (Roy *et al.,* 2006).

The lowest values of sugar quality measures occurred after applying the control treatment under water stress (50% WR). The beneficial effect of foliar application of Si-rich materials improved the sugar quality measures of sugar beet under stressed irrigation water conditions. These results are in line with those obtained by Okasha and Mubarak (2018). Nofal *et al*. (2014) substantiated that potassium fertilization improved the amount and quality of sugar in sugar beet roots; the potassium additions improved the sucrose content, purity, TSS, yield of extractable sugar, and recoverable sugar. In this context, Abo Shady *et al*. (2009) found there was no discernible change in the proportion of Na, K, sucrose, recoverable sugar, and amino nitrogen.

CONCLUSIONS

The beneficial roles of silicon in combating water stresses have numerous reports. The alleviative effects of silicon under water stress conditions emerged with the application of the stimulate rich-Si for sugar beet crops. The application of stimulates rich-Si K_2SiO_3 and algae containing Si remains the most effective for enhancing sugar beet yield through alleviating the water stress effects and improving the growth, quality, and sugar yield under deficit irrigation water.

ACKNOWLEDGMENTS

Authors extend sincere thanks to all staff at the Research and Production Station in El-Nubira for their assistance during carrying out of this investigation.

REFERENCES

Abdul-Qadir A, Alikhan S, Ahmed R, Masood S, Irshad M, Kaleem F, Kumar S, Shahzad M (2017). Exogenous Ca_2SiO_4 enrichment reduces the leaf apoplastic Na + and increases the growth of okra (Abelmoschus esculentus L.) under salt stress. *Sci. Hort*. 214: 1-8.

Abo Shady KA, El-Said MN, Ibrahim MFM (2009). Effect of bacterial bio-fertilization and N levels on yield and quality of sugar beet (variety IoIa). *J. Agric Sci. Mansoura Univ.* 34(12): 10815-10823.

Abou-Elwafa SF, Amin AEEA, Eujayl I (2020). Genetic diversity of sugar beet under heat stress and deficit irrigation. *Agron. J.* 112(5): 3579-3590.

Allen LHJR, Valle RR, Jones JW, Jones PH (1998). Soybean leaf water potential responses to carbon dioxide and drought. *Agron. J.* 90:375-383.

Arkadiusz A (2018). Effect of silicon fertilization on crop yield quantity and quality-A Literature Review in *Europ. J. Plants* 7(54): 1-17.

Artyszak A, Gozdowski D, Kucińska K (2015). The effect of calcium and silicon foliar fertilization in sugar beet. *Sugar Tech.* 1. doi:10.1007/s12355-015-0371-4.

Bastaubayeva SO, Amangaliev BM, Zhussupbekov EK, Tabynbayeva LK, Batyrbek M, Raiymbekova AT, Memon S, Memon SA (2023). Irrigation and mineral fertilizer effects on physical properties of light chestnut soil used in the cultivation of sugar beet (*Beta vulgaris* L.). *SABRAO J. Breed. Genet*. 55(1): 202-210. http://doi.org/10.54910/sabrao2023.55.1.19.

Brown JD, Lilland O (1964). Rapid determination of potassium and sodium in plant material and soil extracts by flam photometry. *J. Am. Soc. Hortic. Sci.* 48, 341-346.

Cai K, Gao D, Chen J, Luo S (2009). Probing the mechanisms of silicon – mediated pathogen resistance. *Plant Signal Behav.* 4:1-3.

Carruthers A, Oldfield JET (1960). Methods for the assessment of beet quality. In the book: The Technological Value of the Sugar Beet. pp. 224-248. doi:10.1016/B978-1-4832-2907-2.50024-4.

Cottenie A, Verlo M, Kjekens L, Camerlynch RA (1982). Chemical analysis of plant and soil. Laboratory of Analytical Agro Chemistry. *State Univ of Gent*. 4, pp. 280-284.

Devillers P (1988). Prevision du sucre melasse. Sucrerie francases. 129, 190-200. (C.F The Sugar Beet Crop book. 1st Edition published by Chapman and Hall, Univ. Press, Cambridge, UK.

Dexter ST, Frankes MG, Snyder FW (1967). A rapid and practical method of determining of extractable white sugar as may be applied to the evaluation of agronomic practices and grower deliveries in the sugar beet industry. *J Am. Soc. Sugar Beet Technol*. 14: 433-454.

Diatta AA, Fike JH, Battaglia ML, Galbraith J, Baig MB (2020). Effects of biochar on soil fertility and crop productivity in arid regions: A review. *Arab. J. Geosci*. 13:595.

Duncan DB (1955). Multiple range and multiple F test. *Biometrics,* 11: 1-42.

El-Sarag EI (2009). Maximizing sugar beet yield, quality and water use efficiency using some agricultural practices under North Sinai Conditions. *Bull. Fac. Agric. Cairo Univ*. 60:255-167.

Gaballah MS, Mansour HA, Nofal OA (2020). Balanced fertilization of major crops in Egypt: A review. *Plant Arch*. 20:2453-2458.

Galal AA, El-Noury MI, Essa ME, Abdelhafez AA, Abou-Elwafa SF (2022). Response of sugar beet varieties to plant geometrical distribution. *Egy. Sugar J.* 18: 1-15.

Gomaa MA, Kandil EE, El-Dein AAMZ, Abou-Donia MEM, Ali HM, Abdelsalam NR (2021). Increase maize productivity and water use efficiency through application of potassium silicate under water stress. *Sci. Rep.* 11, 224.

Gomez KA, Gomez AA (1984). Statistical Procedures for Agriculture Research. 2nd Ed., John Wiley and Sons, New York, 180.

Guntzer F, Keller C, Meunier JD (2012). Benefits of plant silicon for crops: A review. *Agron. Sustain. Dev.* 32:201- 213.

Gusev VN, Bastaubayeva ShO, Tabynbayeva LK, Zhusupbekov EK, Musagodzhaev NT (2023). Mineral fertilizers impact on sugar beet productivity in Southeast Kazakhstan. *SABRAO J. Breed. Genet*. 55(5): 1803-1811. http://doi.org/10.54910/sabrao2023.55.5.31.

Hafez YM, Mourad Y, Mansour RM, Abdelaal KhAA (2014). Impact of non-traditional compounds and fungicides on physiological and biochemical characters of barely infected with *Blumeria graminis* f. sp hordei under field conditions, *Egy. J. of Bio. Pest Control*. 24(1):445-453.

Harvey GW, Dutton JV (1993). Root quality and processing. In: The Sugar Beet Crop Science into Practice. D.A. Cook and Scott (Eds.), pp. 571-617.

Hattori T, Inanaga S, Araki H (2005). Application of silicon enhanced drought tolerance in *Sorghum bicolor*. *Physiol. Plant*. 123(4): 459-466.

Hellal F, Ahmad KhA, El-Sayed S, El-Azab K (2020a). Mitigating the negative effect of water stress on barley by nano silica application. *Plant Arch*. Vol. 20, supplement 1, 2020 pp. 3224-3231.

Hellal F, El-Sayed S, Abdel Hady M (2020b). Barley responses to potassium fertilization under water stress condition. *Plant Arch.* Vol. 20, supplement 1, 2020 pp. 3140-3147.

Ismail EEM, Galal RM, Mahseb MEJ (2017). Effect of some potassium sources on productivity and quality of pea under conditions of saline soil plant production, *Mans. Univ*. 8 (12):1323-1328.

Israelsen W, Hansen VE (1962). Irrigation Principles and Practices. 3rd Ed. New York, London.

Jaleel CA, Manivannan P, Wahid A, Farooq M, Somasundaram R, Panneerselvam R (2009). Drought stress in plants: A review on morphological characteristics and pigments composition. Int. *J. Agric. Biol*. 11: 100-105.

Melo BA, Moraes JC, Carvalho LV (2015). Resistance induction in chrysanthemum due to silicon application in the management of whitefly *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae). *Revi. de Cien. Agroambientais.* 13: 1-8.

Minolta A (1989). Chlorophyll meter SPAD-502. Instruction manual. Minolta Co., Ltd., Radiometric Instruments Operations, Osaka, Japan.

Nemeata Alla HEA, Helmy SAM (2022). Response of sugar beet to sandy soil amended by zeolite and potassium sulfate fertilization. *SABRAO J. Breed. Genet*. 54(2): 447-457. http://doi.org/10.54910/sabrao2022.54.2.20.

Nofal OA, El Eila HI, El-Sayed SAA (2014). Balanced potassium and boron fertilization management for maximizing yield and quality of some sugar beet varieties. *Inter. J. of Academic Res.* 6: 229-234.

Okasha SA, Mubarak MH (2018). Genotype x environment interaction and stability analysis for root yield and quality traits in sugar beet (*Beta vulgaris* L.). *Egy. J. Plant Breeding*. 22(3), 469-486.

Rizwan M, Ali S, Ibrahim M, Farid M, Bharwana MA, Etal SA (2015). Mechanisms of silicon-mediated alleviation of drought and salt stress in plants: A review. *Environ. Sci. Pollut. Res.* 22: 15416-15431.

Roy RN, Finck A, Blair GJ, Tandon HLS (2006). Plant nutrition for food security: A guide for integrated nutrient management. *FAO Fert. & Plant Nutrition Bulletin.* 16.

Sacała E (2009). Role of silicon in plant resistance to water stress. *J. Elem.* 14:619-630.

Sheikh AR (1997). Laboratorial Methods and their Application to Control Food and Sugar Industries Process. Mersa Publication, Tehran, Iran.

Silin PM, Silina NP (2011). Chemistry control in sugar technology. *Food Tech. Pub.* USSRP. 167.

Sivanesan I, Park SW (2014). The role of silicon in plant tissue culture. *Front. in Plant Sci*, 5: 1-4.

Smis A, Murguzur FJA, Struyf E, Soininen EM, Jusdado JGH, Meire P, Brathen KA (2014). Determination of plant silicon content with near infrared reflectance spectroscopy. *Front. in Plant Sci.* 5: 1-9.

Snedecor GW, Cochran WG (1981). Statistical Methods, 7th Ed. The Iowa State University Press, Ames, Iowa, USA.