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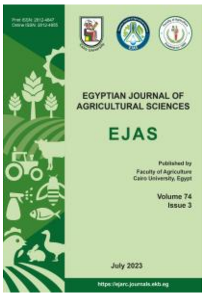

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Salinity Tolerant Indices Based on Yield Performance of Some Sugar Beet Varieties as Treated by Potassium Silicate to Mitigate Saline Soil Stress

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ABSTRACT

Salinity stress is a significant abiotic factor that limits the yield and quality of sugar beet grown in newly reclaimed saline lands. The field experiment was conducted at a private farm in Tamia (29° 17` N, 30° 53` E), Fayoum, Egypt, in 2021/2022 and 2022/2023 successive seasons. The objective of this study was to assess the usefulness of potassium silicate (K_2SiO_3) in four K-silicate foliar spray concentrations in alleviating salinity stress on five sugar beet varieties grown in saline soil. A split-plot design in a randomized complete block arrangement was used with three replications. Spraying K-silicate showed improved sugar beet varieties' tolerance to soil salinity. Increasing the concentration of the sprayed K-silicate gave higher root and sugar yield productivity. Results showed that the varieties significantly differed, where the Narmar and Afendra varieties showed superiority over the other three tested varieties, with the highest values of root and sugar yield and it is related traits in both seasons. The potassium silicate rate of 2,000 mg/L gave the highest juice quality and lowest impurities, suggesting a great potential for using potassium silicates with sugar beet to produce high roots and quality for economical sugar production under saline soil. The sugar beet varieties with less than one unit of salinity tolerance index (STI), yield stability index (YSI), and salinity susceptibility index (SSI) values were suitable for cultivation under saline soil stress and non-stress environments. These indices were more effective in identifying high-yielding varieties under saline soil stress as well as non-stress conditions.

Keywords: *Saline stress, Potassium silicate, Sugar beet, Yield traits, Tolerance indices.*

1. INTRODUCTION

Sugar beet (*Beta vulgaris*, L.) is an important sugar crop. Nowadays sugar beet is considered the first source of sugar production in Egypt and contributes to the production of sugar by about 61.2% (1.71 million tons) of the total sugar production, corresponding to 29.9% (0.835) million tons) from sugarcane, according to the Council of Sugar Crops (2022). Sugar beet is well adapted to a wide range of soil types, considered a tolerant crop to salinity, and is mainly cultivated in newly reclaimed lands. Abiotic stresses result from the intensive use of natural resources and increasing population contributing significantly to reducing crop yields below the potential maximum yields (Ashraf *et al.*, 2010). In Egypt, saline soil is a factor hindering the horizontal expansion of agriculture in new lands, which requires screening imported sugar beet varieties to select the tolerant varieties and recommend their cultivation in salinity-affected soils.

Salinity stress is a major abiotic stress, which has adverse effects on crops. Salinity stress causes a decrease in crop production due to the inhibition of the photosynthesis of plants

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by inhibiting photochemical activities and a decrease in the activities of the Calvin cycle enzyme (Yokoi *et al.,* 2002). Potassium silicate (K Si) may increase salinity tolerance capacity in the plants by improving water status, increasing photosynthetic activity, stimulating of antioxidant system by reducing salt uptake, and increasing K uptake (Franzen, 2007). Potassium silicate (K Si) is a source of highly soluble K and Si. It activates many enzymes involved in respiration and photosynthesis. The benefits of silicon amendments are well documented in plants, including enhanced productivity and tolerance to various biotic and abiotic stresses. Potassium silicate increases plant growth and yield, as Sia meliorates abiotic stresses in several ways (Farag *et al*., 2014). Potassium (K) is an essential element for plant growth, having physiological and biochemical functions. It is necessary for activating starch synthase enzymes (Fathy *et al.,* 2009). In addition to K essential role in enzyme activation, it plays roles in protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance, and stress resistance (Wang *et al*., 2013). Increasing potassium fertilizer for sugar beet caused a significant increase in growth, productivity, and root quality (Aksu and Altay, 2020). Silicon helps plants survive in conditions of water scarcity and saline soils, decreasing transpiration in cells, and reducing micronutrient and metal toxicity (Salem *et al.,* 2021). Many studies suggested the positive growth effects of potassium silicate, including increased dry mass and yield. Furthermore, potassium silicate plays a very important role in the reduction of the plant's vulnerability to biotic and abiotic environmental stress (Abd El-Hady and Bondok, 2017).

Salinity tolerance should be considered an essential breeding objective in areas where the sugar beet crop is likely to encounter stress. Saline soil stress is a major limiting factor that affects crop productivity. Varieties with high productivity in both stress and non-stress conditions are useful for breeding purposes. (Hesadi *et al.,* 2015, Sadeghian *et al.,* 2000 and Mohamdian, 2010). The evaluation of the salinity tolerance of sugar beet was accomplished using complicated indices such as the salinity sensitivity index (SSI), yield stability index (YSI), and salinity tolerance Index (SRI), which usually lasts for two years in cropland. The indices are more effective for selecting better sugar beet varieties concerning tolerance because a single index or comprehensive analysis of different traits has shortcomings in identifying saline tolerance (Wenbo *et al.*, 2023, Abu-Ellail and El-Mansoub 2020, El-Kady *et al.*, 2021 and Ghoulam *et al.,* 2002). The objectives of the present research were to evaluate the performance of five sugar beet varieties and their response to different levels of spryer application with potassium silicate on growth, yield, and quality of sugar beet in saline soil conditions, as well as to determine the efficiency of tolerance indices to identify saline-tolerant sugar beet varieties.

2. MATERIALS AND METHODS

2.1. Site and plant material

The field experiment was conducted at a private farm in Tamia (29° 17` N, 30° 53` E), El Fayoum, Egypt, in two successive growing seasons (2021/2022 and 2022/2023) to study the effect of four potassium silicate rates, *i.e.* (0 without potassium silicate as control, 500, 1,000 and 2,000 mg/L) on quality and yield traits of five multigerm sugar beet varieties (Table 1), which were obtained from Sugar Crop Research Institute, Agricultural Research Center, Giza, Egypt Contents of 20 liters of potassium silicate are shown in (Table 2). The treatments were application to plants by spraying the plants and the ground around the sugar beet plants. A split-plot design in a randomized complete block arrangement was used with three replications.

Table (1): Origin of the examined multigerm sugar beet varieties.

No.	Variety	Company	Origin
1	**Afendra-KWS**	KWS	Germany
2	**Shantala-KWS**	KWS	Germany
3	**BTS8935**	BETA SEED	UK
4	**Melodia**	KHBC	Poland
5	**Narmar**	STRUBE	Germany

Potassium silicate levels were randomly assigned to the main plot once after thinning (after thirty days from sowing), and the second dose one month later, while sugar beet varieties were distributed in the subplot. Nitrogen was applied as urea (46.5 % N) in three equal doses, one-third before the first irrigation after thinning directly and the second and third ones were applied at 65 and 85 days after planting. Further, calcium superphosphate (15.5 % P_2O_5) at a rate of 100 kg/fed. was applied during land preparation. The plot area was 10.5 m^2 (1/400 fed) containing 5 rows of 3.5 m length (60 cm between rows and 25 cm between plants). Sugar beet varieties in the first and second seasons were sown on September 25th and 30th, respectively. The plants were thinned into two plants per hill after 30 days and thinned to one plant per hill after 45 days from sowing. All other agricultural practices were conducted as recommended. Soil physical and chemical properties of the experimental site were determined according to Page (1982) as shown in **(Table 3).**

Table (2): Analysis of 20 liters of potassium silicate (W/V).

Components	Percentage
Total Potassium (K) (as silicate)	15.3%
Silicon (Si)	17.3%
Specific Gravity (SG)	1.4
pH	11.3 - 12.3
Conductivity	70 - 90
Appearance	Clear liquid

2.2. Studied traits

At harvest, a random sample of ten guarded plants was taken from the middle ridges of each plot to determine the following traits:

Root Traits: Root length/plant (cm), Root diameter/plant (cm) and Root weight/plant (Kg).

Quality analysis: Quality analysis was conducted on fresh samples of sugar beet roots at the Laboratory of El-Fayoum Sugar Factory, El-Fayoum, Egypt.

Table (3): Some physical and chemical properties of the soil before planting during two seasons.

Properties	2021/2022	2022/2023
Practical size distribution%		
Sand%	23.24	20.33
Silt%	31.63	34.02
Clay%	45.13	45.65
Textural	Silty clay	Silty clay
pH	7.03	7.34
EC (ds/m)	6.42	6.17
O.M (%)	0.97	1.32
CaCO3	1.48	2.06
Soluble cations (mq /L)		
Ca++	16.33	15.11
Mg++	8.87	7.84
Na+	14.85	13.51
K+	0.92	2.67
Soluble Anions (mq/ L)		
HCO_3-	2.68	2.57
CL-	21.40	20.23
SO4	16.89	16.33
Available macronutrients (mg/kg)		
N	31.24	18.62
P	3.28	5.48
K	1.57	1.77
Fe	3.89	4.15
Mn	1.42	2.33
Zn	0.73	1.05
Cu	0.65	0.86

- Impurities: sodium, potassium, and α-amino-nitrogen concentrations were estimated as mg/100 g beet, where sodium and potassium were determined in the digested solution using “Flame-photometer”. Alfa-Amino-N (α-Amino-N) was determined using Hydrogenation according to the method described by Cooke and Scott (1993).
- Sucrose percentage (Pol %) was determined in fresh macerated root according to the method of Le Docte (1927).
- Sugar lost to molasses percentage (SLM%) was calculated according to the equation of

Devillers (1988): SLM = 0.14 (Na + K) + 0.25 (α–amino N) + 0.50.

- Extractable sugar percentage (ES %) was calculated using the following equation of Dexter *et al.* (1967): ES% = sucrose % - SLM % - 0.6

Yield: Yield of clean roots were determined from the three guarded rows for each treatment,

- Root yield/fed (ton): Roots were carefully separated and weighed in kilograms, then converted to estimate tons per fed. (fed. = 4,200 m^2).
- Sugar yield was estimated according the following equation:

Sugar yield/fed. (ton) = root yield/fed. (ton) x extractable sugar%

2.3. Salinity tolerance indices

The same varieties were grown in clay land (non-salty), and all measurements were taken to compare with their counterparts in salty land using tolerance indexes. It was calculated for each sugar beet variety at harvest time according to the method of Fischer and Maurer (1978), Fernandez (1992) and Rosielle and Hamblin (1981) as follows:

Salinity sensitivity index (SSI)

$$SSI = \frac{1-(\frac{Ys}{Yp})}{1-(\frac{\overline{Ys}}{\overline{Yp}})}$$

Yield stability index (YSI)

$$YSI = \frac{Ys}{YP}$$

Salinity tolerance Index (SRI)

$$STI = Ys\ (\frac{Ys}{Yp})/\overline{Ys}$$

Where: Ys. (mean yield for a variety under stress environment), Yp (mean yield for a variety in a normal environment), Sugar beet variety with "SSI, YSI, and STI" values of 1.0 or more than one is susceptible to salinity, while this variety with values less than 1.0 is tolerant to salinity.

Decrease percentage of root and juice traits

It was calculated for each sugar beet variety at harvest time according to the method of Abu-Ellail *et al.* (2021) as follows: D1-D2/D1%, Where: D1 (mean yield for a variety in normal soil), D2 (mean yield for a variety in saline soil).

2.4. Statistical analysis

All obtained data were statistically analyzed according to the technique (MSTAT- c) computer software package. Using analysis of variance (ANOVA) for the split-plot design as published by Gomez and Gomez (1984). The least significant of differences (LSD) method was used to test the differences between treatment means at 5% level of probability as described by Snedecor and Cochran (1980).

3. RESULTS AND DISCUSSION

3.1. Effect of potassium silicate on root yield and related traits

Results obtained in Table (4) showed that increasing potassium silicate rates from 0 up to 2,000 (mg/L) significantly increased root length and root diameter (cm) during the 1*st* and 2*nd* seasons. The highest mean values were obtained by adding the highest application rate of potassium silicate (2,000 mg/L). On the contrary, the least mean values were obtained by growing sugar beet plants under control treatment. Meanwhile, there was a significant increase in root yield (ton/fed) of sugar beet plants as a result of increasing potassium silicate rates from zero up to 2000 mg/L. The direct effect of potassium silicate on plant growth is increasing the cell chlorophyll content, hormonal growth responses, and acceleration the respiration process, in-plant membranes, increasing substances penetration, changing dry matter production, and nutrient uptake. These results are due to the hydrophilic nature of silicon, leading to retaining more water, dilute salts, and protecting tissues against physiological stress (Salem *et al.*, 2021). Also, Ali *et al.* (2019) found that potassium silicate application led to an increase in growth parameters compared with the control, due to the effect of potassium silicate on solubilization and uptake of nutrients. Silicon deposition in roots reduces the binding sites for metals resulting in decreased uptake and

Table (4): Means of root, quality and impurities traits of five multi-germ sugar beet varieties as affected by saline soil during two 2021/2022 and 2022/2023 seasons.

Potassium silicate doses (mg/L)	2021/2022										
	RL	RD	RW	RY	SLM%	Su%	ES%	SY	N%	Na%	K%
Zero mg/L	25.9	9.87	0.89	21.15	2.05	16.13	13.48	2.85	1.76	4.35	3.61
500 mg/L	28.32	10.83	1.10	23.11	1.66	18.91	16.65	3.85	1.51	3.32	2.25
1000 mg/L	30.21	12.31	1.23	25.99	1.42	20.53	18.51	4.81	1.04	2.45	2.29
2000 mg/L	31.56	13.67	1.61	28.78	1.22	21.24	19.42	5.59	0.89	2.02	1.54
LSD at 0.5%	1.15	1.23	0.11	2.13	0.33	1.42	1.21	0.83	0.61	0.97	0.64
2022/2023											
Zero mg/L	26.71	10.83	0.96	22.32	1.95	17.35	14.80	3.44	1.70	3.61	3.69
500 mg/L	29.97	12.89	1.25	26.19	1.77	19.16	16.79	4.40	1.53	3.17	3.15
1000 mg/L	30.19	13.24	1.65	29.72	1.51	20.75	18.64	5.54	1.31	2.23	2.68
2000 mg/L	32.45	14.11	1.72	30.12	1.20	20.89	19.09	5.75	1.02	1.42	1.77
LSD at 0.5%	1.57	1.06	0.10	2.04	0.51	1.32	0.98	0.71	0.56	0.88	0.86

RL= Root length, RD =Root diameter, RW= Root weight, RY= Root yield, SLM= Sugar lost in molasses, SU= Sucrose, ES= Extractable sugar, SY= Sugar yield, N= Alpha amino nitrogen, Na= Sodium and K= Potassium

translocation of salts and toxic metals from roots to shoots. Also, silicon nutrition increases phenolic compounds in plants (Li *et al.*, 2009). Plant applications of potassium silicate revealed a significant increase in sucrose %, extractable sugar, and sugar yield (ton/fed). However, SLM% and the total N, Na, and K percentages decreased, as compared with the control in both seasons (Table 4). In general, 2,000 mg/L of potassium silicate treatment caused the best growth performance, followed by 1,500 mg/L potassium silicate treatments in both seasons. Applying potassium silicate was accompanied by an increase in the values of sucrose and refined sugar percentages compared with the control treatment. The trend of an increase in sucrose content and extractable sugar was associated with the potassium silicate rate in all applications from 1,500 to 2,000 mg/L. This result could be expected due to the decrease of impurities i.e., (K, Na, and N) in the juice. The silicon supplementation reduces the adverse impact of abiotic stresses due to the improved photosynthetic activity, enhanced K/Na selectivity ratio, and increased enzyme activity, resulting in limited sodium absorption by plants. Sugar beet is one of seven plant species classified as silicon bio-accumulators **(**Guntzer *et al.*, 2012). Ali *et al.* (2019) found that spraying sugar beet plants with K-silicate has the potential to alleviate the negative effects of stress and increase fertilizer use efficiency, and hence can save fertilizers.

3.2. Performance of sugar beet varieties

The data (Table 5) showed that there were notable variations among sugar beet cultivars in both seasons concerning root length, root diameter, weight, and root yield (ton/fed). Throughout the two seasons, varieties Narmar and Afendra-KWS had the greatest values for the majority of productive parameters. In the first season, varieties Afendra-KWS and Narmar out produced the other sugar beet varieties in terms of root yield (29.12 and 28.34 tons/fed), whereas varieties Afendra-KWS and Melodia recorded the highest values (25.13 and 27.74 tons/fed) in the second season, and the variety "Shantala-KWS" with the least root output recorded in both seasons (24.15 and 24.32 tons/fed). The variations recorded in the investigated sugar beet varieties may be due to variations in their genetic composition and responses to environmental factors. El-Kady *et al.* (2021) and Abd El-Aal *et al.* (2010) also noted variations in root characteristics and discovered highly significant variances in sugar beet root weight between varieties. The results (Table 5)

Table (5): Means of root, quality and impurities traits of five multi-germ sugar beet varieties as affected by saline soil during two 2021/2022 and 2022/2023 seasons.

Varieties	**2021/2022**										
	RL	RD	RW	RY	SLM%	Su%	ES%	SY	N%	Na%	K%
Afendra	32.21	12.76	1.15	29.12	1.35	19.91	17.96	5.23	1.26	1.86	1.95
Shantala	30.19	8.66	0.93	24.15	1.43	16.02	13.99	3.38	1.21	1.81	2.68
BTS8935	29.97	9.33	0.81	26.03	1.38	15.92	13.94	3.63	1.31	1.43	2.51
Melodia	28.56	10.44	0.76	25.72	1.49	17.61	15.52	3.99	1.51	2.12	2.22
Narmar	34.89	11.67	1.09	28.34	1.38	19.69	17.71	5.02	1.37	1.74	2.13
LSD at 0.5%	1.43	1.21	0.12	1.15	NS	0.96	0.66	0.53	NS	NS	NS
2022/2023											
Afendra	28.39	13.12	1.17	25.13	1.38	20.01	18.03	4.55	1.25	2.12	1.93
Shantala	34.17	9.42	0.99	24.32	1.68	18.52	16.24	3.95	1.95	2.5	2.48
BTS8935	27.91	11.08	0.95	23.63	1.69	17.66	15.37	3.63	1.89	2.62	2.5
Melodia	26.55	10.43	0.88	27.78	1.56	17.74	15.58	4.33	1.9	2.43	1.74
Narmar	35.68	12.87	1.13	26.65	1.53	19.18	17.05	4.54	1.72	2.29	2.02
LSD at 0.5%	1.31	1.52	0.14	1.02	NS	0.89	0.85	0.73	NS	NS	NS

RL= Root length, RD = Root diameter, RW= Root weight, RY= Root yield, SLM= Sugar lost in molasses, S= Sucrose, ES= Extractable sugar, SY= Sugar yield, N= α-amino nitrogen %, Na= Sodium and K=Potassium

demonstrated that there were significant differences between sugar beet varieties in terms of sucrose percentage, extractable sugar percentage, and sugar yield (ton/fed). However, the differences between varieties did not reach the significance level when it came to sugar lost to molasses (SLM%) and impurities like N%, Na%, and K%. It was noticed that variety "Afendra-KWS" had the least SLM% (1.35 and 1.38 % in 1*st* and 2*nd* seasons, respectively), which led to achieving the greatest values of sucrose % (19.91 % and 20.01 % in 1*st* and 2*nd* seasons, respectively), extractable sugar% (17.96 % and 18.03 % in 1st and 2nd seasons, respectively), and sugar yield (5.23 and 4.55 tons/fed in 1*st* and 2*nd* seasons, respectively). The observed differences in these properties between the tested varieties of sugar beet may be attributed to the influence of genes, which is a major factor in the structure and morphology of plants. According to research by Merwad (2015), there are notable variations in the production of sucrose and refined sugar among sugar beet cultivars when potassium silicate was applied as opposed to the control treatment. These results are in agreement with El-Kady *et al.* (2021) and Nemeata Alla *et al.* (2018) who indicated that significant differences among sugar beet varieties in impurities components, potassium, sodium, and alpha Amino-N that decreased significantly influenced by potassium silicate in both seasons.

3.3. Interaction effect between varieties and potassium silicate rates

3.3.1. Root yield and its related traits

Data in Table (6) show that the interaction between the tested sugar beet varieties and soil application of potassium silicate rates significantly affected root yield, root length, root diameter, root weight, and root yield in the two seasons. When the plants were treated with 1,500 mg/L potassium silicate, the sugar beet variety "Melodia" recorded the highest values of root length (38.36 and 38.27 cm, respectively) in both seasons. However, when the plants were treated with 2,000 mg/L potassium silicate, the variety "Melodia" registered the highest significant value of root length (39.35 and 39.52 cm, respectively) in both seasons. Plants treated with silicon were reported to show reduced negative effects of stress (Artyszak *et al.,* 2021).

Furthermore, variety "Shantala-KWS" exhibited the highest root diameter (16.66 and 17.51 cm, respectively) when treated with 1,500 and 2,000 mg/L potassium silicate, in the first season, while in the second season it recorded (15.52 and 16.86 cm, respectively). Variety (Melodia) registered the biggest root weight (1.57 and 1.69 kg) in the first season when treated with 1,500 and 2,000 mg/L potassium silicate, respectively. However, in the second season, the variety "Narmar" recorded the highest root weight (1.47 and 1.63 kg) when treated with 1,500 and 2,000 mg/L potassium silicate. According to Epstein (2009), the beneficial role of Si in alleviating stress in plants exposed to drought is mainly due to the enhancement in water relations and photosynthesis (Artyszak *et al.*, 2015), has been reported that Si treatment could alleviate salt stress damage.

Results revealed that Variety "Shantala-KWS" registered the biggest root yield (32.15 and 33.02 ton/fed) in the first season when treated with 1,500 and 2.000 mg/L potassium silicate, respectively. However, in the second season, the variety "Melodia" recorded the highest root weight (31.04 and 31.52 ton/fed) when treated with 1500 and 2000 mg/L potassium silicate. The significant interaction between tested sugar beet varieties and potassium silicate for root and quality traits in both seasons were reported by Enan *et al.* (2016), who found that the treatment with 10-liter potassium silicate /fed. recorded the highest significant root traits values. In addition, they revealed that the interaction between sugar beet varieties and potassium silicate had a significant effect on root and sugar yields in both seasons.

3.3.2 Sugar yield and Juice quality traits

Results in Tables (7 and 8) indicated that the interaction between varieties and potassium silicate levels was significantly affected in sucrose, extractable sugar percentages, sugar yield, and impurities elements (N, Na and K), in the two seasons. Variety "Melodia" plants treated with 2,000 mg/L Potassium silicate, recorded the highest values of sucrose percentage (22.35 and 21.35 %,) and extractable sugar % (20.94 and 19.60 %), and the highest sugar yield (6.65 and 6.18 ton/fed) in first and second seasons, respectively, compared with the other tested varieties. It seems that an increase in potassium silicate application in terms of amount and frequency is positively related to the content of sucrose and refined sugar in the root. Abd Allah *et al.* (2021) reported that the utilization of potassium silicate reduced the impurities in juice. Hozayn (2013) found significant differences among the tested varieties in all studied characters of sugar beet grown under newly reclaimed soil.

Results accessible in Table (7) the variety (Afendra-KWS) gave the lowest N and Na percentages with treated 2,000 mg/L potassium silicate (0.53 and 1.1 %, respectively) and (0.59 and 1.05 %), in the first and second seasons, respectively. Meanwhile, the sugar beet variety (BTS8935) recorded the highest K % (1.96 and 2.04%, respectively) in the first and the second seasons under treatment with 2000 mg/L potassium silicate. Impurities decrease was positively related to increasing potassium silicate rates. This result may be due to the effect of potassium silicate on sodium, potassium, and α-amino nitrogen percentages in beets root. Artyszak *et al.* (2015) reported that foliar application of silicon had no significant effect on sugar beet roots impurities parameters (N, P, and K) in both seasons. El-Sayed *et al.* (2019) revealed that increasing potassium silicate made up a decrease in sodium, potassium and amino nitrogen contents of sugar beet varieties up to 300 kg. ha. $^{-1}$

3.4. Salinity indices

3.4.1. Salinity susceptibility index (SSI) of sugar beet varieties

Results in Table (9) showed that two sugar beet varieties had a salinity susceptibility index (SSI) based on root and sugar yields of less than one and were relatively tolerant to salinity stress in both seasons. Root yield and its related are the most important agronomic traits in selecting varieties tolerant to saline stress. Meanwhile, saline stress reduced root and sugar yields by reducing the root weight and diameter per plant, sucrose percentage, and extractable sugar % compared results with performance under normal soil. SSI for root yield and sugar yield revealed that the varieties Afendra, and Shantala were tolerant to saline stress, which had SSI values of less than one in the first season. In the second season, varieties "Afendra" and "BTS8935"

Table (6): Interaction effect between sugar beet varieties and potassium silicate doses on productivity traits during 2021/2022 and 2022/2023 seasons.

Sugar beet varieties	**Root length**				**Root diameter**				**Root weight**				**Root yield**			
	Saline Soil				Saline Soil				Saline Soil				Saline Soil			
	Potassium silicate doses				Potassium silicate doses				Potassium silicate doses				Potassium silicate doses			
	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L
2021/ 2022																
Afendra	26.92	31.36	33.21	34.97	12.36	13.82	14.71	15.63	0.79	1.07	1.46	1.58	21.92	25.44	27.94	28.81
Shantala	28.39	33.38	36.46	37.45	13.37	15.29	16.66	17.51	0.84	1.16	1.29	1.53	22.63	28.08	32.15	33.02
BTS8935	30.92	34.06	37.09	38.08	11.31	13.46	15.34	16.16	0.91	1.05	1.23	1.44	25.16	29.23	30.02	30.89
Melodia	32.85	37.44	38.36	39.35	10.68	12.31	14.49	15.34	1.02	1.21	1.57	1.69	27.19	29.79	31.33	32.24
Narmar	26.92	31.33	33.38	34.12	12.42	13.82	14.73	15.62	0.89	1.13	1.34	1.52	21.98	25.44	27.94	28.81
LSD at 0.5%				**3.20**				**2.71**				**0.27**				**2.57**
	2022 / 2023															
Afendra	31.71	36.02	36.98	38.23	11.91	14.31	15.16	15.35	0.97	1.12	1.34	1.52	21.53	27.45	29.36	29.36
Shantala	30.13	35.26	36.43	37.74	12.23	13.52	14.01	14.34	0.91	1.07	1.31	1.44	23.01	25.82	27.35	27.82
BTS8935	30.22	34.84	35.39	36.61	10.82	14.23	15.62	16.86	0.85	1.13	1.32	1.41	22.16	27.05	28.44	28.93
Melodia	33.24	36.73	38.27	39.52	12.33	13.12	14.63	14.84	0.88	1.12	1.39	1.46	24.24	28.93	31.04	31.52
Narmar	32.09	37.71	38.19	39.43	10.71	12.36	13.25	14.43	0.95	1.24	1.47	1.63	26.05	27.54	28.55	29.01
LSD at 0.5%				**2.93**				**2.40**				**0.31**				**2.28**

Table (7): Interaction effect between sugar beet varieties and potassium silicate doses on quality traits during 2021/2022 and 2022/2023 seasons.

Sugar beet Varieties	**Sugar lost in molasses %**				**Sucrose %**				**Extractable sugar %**				**Sugar yield**			
	Saline Soil				Saline Soil				Saline Soil				Saline Soil			
	Potassium silicate doses				Potassium silicate doses				Potassium silicate doses				Potassium silicate doses			
	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L
2021/ 2022																
Afendra	2.03	1.79	1.34	1.10	15.42	18.83	21.13	22.01	12.79	16.44	19.19	20.31	2.80	4.18	5.36	5.85
Shantala	2.08	1.79	1.37	1.12	15.34	19.25	19.93	20.12	12.66	16.86	17.96	18.40	2.87	4.73	5.78	6.08
BTS8935	2.11	1.87	1.37	1.13	14.13	17.11	18.62	19.66	11.42	14.64	16.65	17.93	2.87	4.28	5.00	5.54
Melodia	1.97	1.73	1.36	1.11	16.56	18.12	20.91	22.35	13.99	15.79	18.95	20.64	3.80	4.70	5.94	6.65
Narmar	2.07	1.78	1.41	1.16	15.79	19.51	20.84	21.15	13.12	17.13	18.83	19.39	2.88	4.36	5.26	5.58
LSD at 0.5%				**NS**				**2.15**				**1.48**				**1.09**
	2022 / 2023															
Afendra	2.08	1.81	1.38	1.13	16.91	19.21	20.91	21.31	14.23	16.80	18.93	19.58	3.01	4.61	5.56	5.75
Shantala	2.11	1.78	1.38	1.14	17.56	19.83	20.15	20.68	14.85	17.45	18.17	18.94	3.88	4.51	4.97	5.27
BTS8935	2.12	1.91	1.37	1.13	16.74	18.96	19.42	20.26	14.02	16.45	17.45	18.53	3.81	4.45	4.96	5.36
Melodia	2.02	1.83	1.39	1.14	17.99	18.84	19.15	21.34	15.37	16.41	17.16	19.60	4.47	4.75	5.33	6.18
Narmar	2.09	1.84	1.43	1.19	17.43	19.91	20.21	20.95	14.74	17.47	18.18	19.16	4.68	4.81	5.19	5.56
LSD at 0.5%				**NS**				**1.19**				**1.10**				**1.03**

Table (8): Interaction effect between sugar beet varieties and potassium silicate doses on impurities traits during 2021/2022 and 2022/2023 seasons.

Sugar beet Varieties	Alpha amino nitrogen (N %)				Sodium (Na %)				Potassium (K %)			
	Saline Soil				Saline Soil				Saline Soil			
	Potassium silicate doses				Potassium silicate doses				Potassium silicate doses			
	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L	Zero mg/L	500 mg/L	1000 mg/L	2000 mg/L
2021/ 2022												
Afendra	1.68	1.40	0.64	0.53	3.46	2.40	1.23	1.1	4.49	4.31	3.64	2.22
Shantala	1.77	1.51	0.73	0.62	3.57	2.45	1.30	1.17	4.55	4.06	3.58	2.16
BTS8935	1.73	1.51	0.85	0.74	3.66	2.56	1.32	1.19	4.77	4.56	3.38	1.96
Melodia	1.72	1.37	0.68	0.57	3.09	2.11	1.26	1.13	4.34	4.24	3.64	2.22
Narmar	1.65	1.39	0.83	0.72	3.54	2.41	1.29	1.16	4.74	4.28	3.72	2.3
LSD at 0.5%				**NS**				**NS**				**NS**
	2022 / 2023											
Afendra	1.77	1.49	0.70	0.59	3.48	2.48	1.30	1.05	4.61	4.21	3.71	2.29
Shantala	1.79	1.59	0.78	0.67	3.62	2.21	1.23	1.17	4.65	4.10	3.66	2.24
BTS8935	1.73	1.57	0.83	0.72	3.66	2.55	1.28	1.15	4.83	4.70	3.46	2.04
Melodia	1.74	1.52	0.74	0.63	3.28	2.40	1.31	1.18	4.44	4.38	3.72	2.3
Narmar	1.71	1.50	0.86	0.75	3.52	2.46	1.30	1.17	4.76	4.46	3.83	2.41
LSD at 0.5%				**NS**				**NS**				**NS**

showed the most tolerance to salinity compared to normal soil. Meanwhile, the most sensitive varieties "Melodia" and "Narmar" in the first and second seasons, respectively, had a salinity susceptibility index (SSI) more than unity. The positive effect of indices on selecting the stress-tolerant sugar beet varieties was investigated by Wenbo *et al.* (2023) and Okasha and Mubarak (2018). They found that the stress tolerance capacity of sugar beet germplasms could not be evaluated by using a single indicator, as the evaluation results would be inaccurate. Multiple indicators should be used for an effective, objective, and comprehensive evaluation.

3.4.2. Decrease percentage of sugar beet varieties

Data in Table (9) showed that root yield and related traits were the most affected than sugar yield and its related traits. The decreased percentage of root and sugar yields ranged from the lowest values of 29.36 and 52.63 % for varieties"(Melodia" and "Narmar", respectively, to the highest values of 33.63 and 60.80 %, respectively, for variety "BTS8935" in the first season. While in the second season, it ranged from 28.59 and 46.23 % for variety "Shantala" to the highest values of 32.44 and 56.72 % for varieties Melodia and BTS8935, respectively. Root and sugar yields confirmed the importance of using these traits as useful selection criteria for screening the drought tolerance, and most importantly, both traits can be considered for screening sugar beet varieties at high saline stress. These results are in agreement with those found by Hesadi *et al.* (2015), Sadeghian *et al.* (2000), Mohamdian (2010) and Abu-Ellail and El-Mansoub (2020) who found that the selection of more tolerant varieties with the least SSI values may be a suitable method under stress. Under severe stress, root yield and, sugar yield, decreased to 59 % and 60 %, respectively, of the values obtained with adequate water; whereas, sugar content increased 6%. Several selection criteria have been proposed to select genotypes based on their yield in stress and non-stress environments.

Table (9): The decrease percentage and salinity susceptibility index (SSI) of root, sugar yields and their related traits of five sugar beet as affected by saline soil during two seasons 2021/2022 and 2022/2023.

Sugar beet varieties	Season 2021/2022						
	Decrease percentage D1-D2/D1%						
	Root length	Root diameter	Root weight	Root yield	Sucrose %	Extractable sugar %	Sugar yield
Afendra	37.86	17.88	97.24	31.84	22.14	20.45	55.49
Shantala	38.94	16.35	82.62	33.63	20.26	18.54	57.46
BTS8935	39.72	15.40	99.75	32.94	19.88	18.18	60.80
Melodia	34.73	15.23	70.39	29.36	22.41	20.68	52.66
Narmar	37.45	16.04	88.20	31.50	21.26	19.49	52.63
Mean	37.74	16.18	87.64	31.85	21.19	19.47	55.81
Salinity susceptibility index (SSI)							
Afendra	0.91	1.17	0.90	0.96	0.91	0.93	0.95
Shantala	0.89	1.01	0.96	0.77	1.09	1.07	0.94
BTS8935	1.06	0.84	1.08	1.15	0.95	0.93	1.00
Melodia	1.23	0.85	1.06	1.35	1.03	1.05	1.12
Narmar	0.96	1.29	1.02	0.95	1.04	1.04	1.00
Mean	1.01	1.03	1.00	1.04	1.00	1.00	1.00
Season 2022/2023							
Decrease percentage D1-D2/D1%							
Afendra	38.96	15.68	75.64	30.32	21.46	19.76	46.23
Shantala	38.40	14.54	73.22	28.59	20.80	18.06	56.72
BTS8935	37.14	17.15	81.80	29.65	20.42	18.70	50.10
Melodia	39.93	14.85	82.51	32.44	21.43	17.68	50.84
Narmar	39.77	14.74	89.83	29.71	21.07	20.29	53.31
Mean	38.84	15.39	80.60	30.14	21.04	18.90	51.44
Salinity susceptibility index (SSI)							
Afendra	1.02	1.02	1.06	0.79	0.87	0.84	0.67
Shantala	0.89	1.38	1.04	1.12	1.10	1.19	1.15
BTS8935	1.01	0.72	0.96	0.90	0.98	0.92	0.98
Melodia	1.12	1.32	0.97	0.90	1.07	1.47	1.26
Narmar	0.99	0.92	0.97	1.64	1.02	0.86	1.26
Mean	1.01	1.07	1.00	1.07	1.01	1.06	1.06

3.4.3. Yield stability index (YSI) and salinity tolerance index (STI)

Descriptive statistics of yield stability index (YSI) and salinity tolerance index (STI) are presented in Table (10). The sugar beet varieties that gave low values of YSI and STI can be considered tolerant to salinity stress. In the first season, the sugar beet varieties Afendra and Shantala exhibited the lowest YSI and STI values for most studied traits, whereas the highest values of these indices were recorded by "Melodia" followed by "BTS8935". In the second season, the sugar beet varieties "Afendra" and "BTS8935" exhibited the least YSI and STI values for most studied traits, whereas the highest values of these indices were recorded by "Melodia" followed by "Narmar". Many studies indicated that the studied tolerant indices were the most suitable parameters for screening salinity-tolerant and high-yielding varieties. These results indicated that the varieties with high YSI values usually have high differences in yield in different conditions. In general, similar ranks for the varieties were observed by STI indices, which suggested that these two indices were equal for selecting varieties under saline

Table (10): Yield stability index (YSI) and salinity tolerance index (STI) of root, sugar yields and their related traits of five sugar beet as affected by saline soil during two seasons 2021/2022 and 2022/2023.

Sugar beet varieties	Root length	Root diameter	Root weight	Root yield	Sucrose %	Extractable sugar %	Sugar yield
Season 2021/2022							
Yield stability index (YSI)							
Afendra	0.92	1.03	0.89	0.92	1.00	1.00	0.92
Shantala	0.97	1.11	0.94	0.92	0.99	0.99	0.94
BTS8935	1.06	0.94	1.02	1.06	0.91	0.89	0.94
Melodia	1.13	0.89	1.15	1.14	1.07	1.09	1.25
Narmar	0.92	1.03	1.00	0.95	1.02	1.03	0.95
Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Salinity tolerance index (STI)						
Afendra	0.68	0.77	0.37	0.67	0.67	0.60	0.40
Shantala	0.71	0.79	0.43	0.63	0.72	0.64	0.40
BTS8935	0.82	0.61	0.53	0.82	0.62	0.53	0.44
Melodia	0.91	0.58	0.58	0.92	0.76	0.70	0.65
Narmar	0.69	0.80	0.48	0.67	0.72	0.66	0.44
Mean	0.76	0.71	0.48	0.74	0.70	0.63	0.47
Season 2022/2023							
Yield stability index (YSI)							
Afendra	1.01	1.03	1.06	0.92	0.98	0.97	0.76
Shantala	0.96	1.05	1.00	0.98	1.01	1.01	0.98
BTS8935	0.96	0.93	0.93	0.95	0.97	0.96	0.96
Melodia	1.06	1.06	0.96	1.04	1.04	1.05	1.13
Narmar	1.01	0.92	1.04	1.11	1.01	1.01	1.18
Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Salinity tolerance index (STI)						
Afendra	0.80	0.75	0.57	0.64	0.74	0.67	0.35
Shantala	0.74	0.84	0.52	0.77	0.82	0.79	0.68
BTS8935	0.76	0.57	0.45	0.69	0.76	0.68	0.61
Melodia	0.86	0.84	0.47	0.76	0.83	0.86	0.81
Narmar	0.81	0.64	0.51	0.95	0.79	0.70	0.85
Mean	0.79	0.73	0.50	0.76	0.79	0.74	0.66

stress. According to the results in Tables 9 and 10, these indices were able to identify the superior varieties under saline stress. SSI, YSI, and STI were correlated with yield under stress conditions, compared with indices (decrease percentage), suggesting that these constructions are suitable for screening salinity-tolerant and high-yielding treatments under saline soil conditions. These results are in harmony with those obtained by Farshadfar *et al.* (2012), Okasha and Mubarak (2018) who indicated that varieties with high STI, and YSI values were suitable for cultivation under non-stress environments also, indicate that STI and YSI, indices were more effective in identifying high-yielding genotypes under stress as well as non-stress conditions.

Conclusion

The results concluded that potassium silicate application enhances sugar beet varieties to give high juice quality and root yield traits through improved saline soil tolerance. The treated with a potassium silicate rate of 2,000 mg/L gave the highest juice quality and lowest impurities. It could be suggested that there is a great potential for potassium silicates in sugar beet to produce high roots and quality for economical sugar production under saline soil. Results showed that sugar beet varieties with less than a unit of STI, YSI, and SSI values were suitable for cultivation under saline soil stress and non-stress environments. These indices were more effective in identifying high-yielding varieties under saline soil stress as well as non-stress conditions.

Authors' contributions

All authors contributed in conceptualization, methodology, software, validation, formal analysis investigation, resources, data curtain, writing the original draft preparation, writing, review, editing, supervision and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Competing interests

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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مؤشرات تحمل الملوحة بناءاً على أداء إنتاجية بعض أصناف بنجر السكر المعاملة بسليكات البوتاسيوم لتخفيف إجهاد التربة المالحة

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ملخص

يعتبر الإجهاد الملحي عاملاً غير حيوي خطير يحد من إنتاجية ونوعية بنجر السكر المزروع في الأراضي المالحة المستصلحة حديثًا. أجريت التجربة الحقلية في مزرعة خاصة في طامية (29° 17` شمالاً، 30° 53` شرقاً) الفيوم، مصر، في موسمين متتاليين (2022/2021 و2023/2022) لتقييم تأثير سيليكات البوتاسيوم (K_2SiO_3) في أربعة تراكيزات من الرش الورقي لتخفيف إجهاد الملوحة في خمسة أصناف من بنجر السكر المزروعة في تربة مالحة. تم استخدام تصميم القطع المنشقة بترتيب القطاعات العشوائية الكاملة بثلاثة مكررات. أظهر رش سيليكات البوتاسيوم تحسناً في تحمل أصناف بنجر السكر للملوحة بصفة عامة. زيادة تركيز الرش بسيليكات البوتاسيوم أعطى إنتاجية عالية للجذور والسكر. أظهرت النتائج أن الأصناف اختلفت فيما بينها معنوياً حيث أظهر الصنفان "نارمار" و"أفندرا" تفوقاً على الأصناف الخمسة الأخرى المختبرة وسجلا أعلى قيم لمحصول الجذور والسكر والصفات المرتبطة في كلا الموسمين. أعطت المعاملة بسليكات البوتاسيوم بمعدل 2,000 ملغم/لتر أعلى جودة للعصير وأقل نسبة شوائب. يقترح أن هناك إمكانات كبيرة لسليكات البوتاسيوم في بنجر السكر لإنتاج محصول جذور ذات جودة عالية ولإنتاج السكر اقتصادياً تحت ظروف التربة المالحة. أظهرت النتائج أن أصناف بنجر السكر ذات قيم أقل من وحدة من مؤشر تحمل الملوحة (STI) ، ومؤشر ثبات الغلة (YSI) ، ومؤشر الحساسية للملوحة (SSI) كانت مناسبة للزراعة تحت إجهاد التربة المالحة والبيئات الطبيعية. وكانت هذه المؤشرات أكثر فعالية في تحديد الأصناف عالية الإنتاجية تحت إجهاد التربة المالحة وكذلك في ظروف عدم الإجهاد.

المجلة المصرية للعلوم الزراعية المجلد (74) العدد الثالث (يوليو 2023):61-75.