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Effect of silicon dioxide application and potassium levels on morphophysiological properties and storable seed yield of hybrid super sweet maize (Zea mays L. 'Elika') under drought stress

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Abstract: In this experiment, we investigated the effects of drought combined with exogenous silicon (Si) and potassium application on super sweet corn growth and development. Drought stress caused decreases in the stem diameter, leaf area, cob length, cob diameter, 100 seed weight, seed number, cob yield, biologic yield, and relative water content (RWC), but proline content and catalase activity were higher under drought stress conditions. The results of a two-year experiment showed that potassium sulfate application and foliar application significantly increased RWC in drought stress conditions, and the highest increase was related to treatment with potassium sulfate in an amount of 25 kg/ha. Under normal irrigation conditions, with 25 kg of potassium sulfate per ha and Si foliar application, the maximum cob diameter (5.85 cm) was observed. Si application did not significantly affect proline content under normal irrigation conditions but increased proline content under drought stress. The highest proline content (10.77 mmol/g fresh weight) was recorded in the Si application using 25 kg of potassium sulfate per ha under drought stress conditions. Also, applying potassium sulfate with silicone foliar spraying had no significant effect on biologic yield under normal irrigation conditions. However, under drought stress treatments, biologic yield increased by applying 15 and 25 kg/ha of potassium sulfate and Si foliar spraying. In summary, applying potassium sulfate and exogenous Si can enhance the antioxidant system of the plant, promote the RWC, thus improving biologic and cob yield, and enhance the drought resistance of super sweet corn.

Keywords: abiotic stress; mineral nutrition; weather condition; climatic condition

Super sweet corn (*Zea mays* L. var. Saccharata) is one of the important and strategic crops, not only due to the short growing season for summer planting (Mokhtarpour et al. 2008) but also for the accumulation of higher quantities of sugars and the soluble polysaccharides in the grain of the endosperm (Paykarestan et al. 2019).

Agricultural production is influenced by various abiotic stresses, such as drought (Swain and Routt 2017). In arid regions, drought stress is one of the most important challenges to the summer planting crops such as sweet corn (Ahmadi et al. 2013). Therefore, due to the limited water resources in agriculture, adopting any strategy to conserve water is very important. One of these strategies is irrigation cut-off with the least yield reduction.

Therefore, technologies that depreciate the effects of water stress in sweet corn should be assessed. One

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of the strategies to increase the survival and performance of plants in situations of water stress is the management of mineral nutrition (Marschner 2012).

Elemental silicon (Si), after oxygen, is the second most abundant element in the earth's crust, which is mainly composed of silicates. Si is not considered essential for plant growth and development; however, increasing evidence in the literature shows that this metalloid is beneficial to plants, especially under stress conditions (Luyckx et al. 2017). Applying silicon enhances crop plants' tolerance against abiotic and biotic stresses (Swain and Rout 2017).

In this sense, there is clear evidence that applying Si fertilisers in crops shows positive effects against the damage caused by drought (Sacala 2009). It has been shown that under these circumstances, Si exerts a protective role for the chloroplast, as well as an improvement in the concentration of pigments related to the absorption of light, resulting in an increase in photosynthetic activity (Jesús 2018). The application of Si fertiliser is a rather common agricultural practice in many countries and regions, but in Iran, it is not common (Yan et al. 2018).

On the other hand, potassium (K) is an essential mineral nutrient for plants, which holds the key for many physiological processes in different crop species, like photosynthesis, protein synthesis, regulation of plant stomata, activation of plant enzymes and osmoregulation (Xu et al. 2021). The application of potassium to plants can increase the ability of plants to tolerate drought stress (Aksu and Altay 2020). Potassium application also alleviated drought susceptibility of all maize hybrids (Ul-Allah et al. 2020). In this case, Xu et al. (2021) reported that K reduces the deleterious effects of drought stress on plants because K application could alleviate drought stress on the growth and development of plants by regulating the morphology and secretion of roots and soil ecosystems.

Koay and Lum (2021) observed that drought treatment at the flowering stage of super sweet corn caused to decrease in the first cob height from the soil surface, cob length, 100 seed weight and seed number per cob, but plants managed to alleviate the drought stress effect by applying a recommended rate of 60 kg/ha potassium fertiliser to the corn plants.

In Iran, some corn production areas are exposed to the threat of low growth and yield reduction by drought conditions. Based on the above review, little is reported in the literature about the interaction effects of drought and potassium and silica for super sweet corn production. Hence, this study was carried out to determine the effects of potassium and silica fertiliser rates to achieve higher growth and yield of super sweet corn under drought stress.

MATERIAL AND METHODS

Site description. This study consisted of two field experiments conducted during and 2020 at the experimental field of Khorasan Razavi Agricultural and Natural Resources Research Center in Mashhad, Iran (36°2'N, 59°06'E, 1 050 m a.s.l.). The study location is characterised by a semi-arid climate with an annual average precipitation of 23 mm and annual maximum and minimum temperatures of 39 °C and 1 °C, respectively. The soil texture of the study site was Fine-Loamy over sandy-Skeletal mixed (Calcareous) mesic xeric torriortents, soil and pH, and electrical conductivity (EC) was 7.8 and 2.32 dS/m, respectively.

Field preparation and planting. The experiment field was disked and ploughed before planting to incorporate residue and to form a seedbed each year in March. Before planting, the field was fallow in both years. Two weeks before planting, soil and water samples were taken to determine the physical and chemical properties. A composite soil sample was collected at 0–30 cm depth. After air drying, the soil was passed through a 2 mm sieve to allow the measurement of a set of common soil characteristics (soil texture, pH, electrical conductivity, organic carbon content, total nitrogen, available phosphorus and available potassium) (Guo 2009) (Table 1). The experimental design was a split-plot factorial in a randomised complete block with three replications. The irrigation was conducted at two levels routine irrigation (100% crop water requirement, irrigation

Table 1. Some physicochemical characteristics of the study area's soil

Sampling depth (cm)	T.N.V (%)	EC (dS/m)	pH	Clay	Silt	Sand	OC	N total	P	K	Fe	Mn	Zn	Cu
									(mg/kg)					
0–30	20.7	2.32	7.8	7	48	45	0.75	0.067	10	175	3.52	11.2	0.74	0.78

EC – electrical conductivity; OC – organic carbon

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after 40% depletion of available soil moisture) and 50% crop water requirement (drought stress, irrigation after 80% depletion of available soil moisture) in the main plots. Soil moisture content was gravimetrically determined in soil samples taken from consecutive depths of 15 cm down to a depth of 60 cm. Soil samples were collected just before each irrigation, 48 h after, and at harvest time. Irrigation water was applied when the moisture content reached the desired available soil moisture in each treatment.

Subplots consisted of a factorial combination of three potassium sulfate (0, 15 and 20 kg/ha) and two foliar Si applications, including 0 and 5 000 ppm in the form of monosilicic acid (H_4SiO_4) (0.5% surfactant-containing solution). The foliar application was applied with a pressurised backpack sprayer (12 L capacity) calibrated to deliver 1 000 L/ha of spray solution. Drought stress was applied after six leaves. Elika, a medium maturing cultivar of super sweet corn, was used in this experiment. The origin of this cultivar was Brazil. Before seeding, according to the soil analysis results, 85 kg/ha urea, 100 kg/ha potassium sulfate and 150 kg/ha superphosphate were broadcasted and incorporated into the soil. The 85 and 80 kg/ha urea was applied at the 4-leaf stage and tassel emergence, respectively. Super sweet seeds were disinfected with a fungicide prior to planting and sown on 22 June 2019 and 20 June 2020 in five rows at 75 cm intervals (row length: 4 m, row distance: 75 cm and plant distance: 17 cm). A 3 m alley was kept between all main plots to eliminate all influence of lateral water movement. In sampling, 50 cm from the side of the plots was removed as a marginal effect. Physiological parameters were measured by selecting specified leaves from five plants per plot under fair weather conditions. To evaluate yield components also, at the maturity stage, whole plants are harvested.

Agronomic measurements. Data were collected on maturity in September 2019 and 2020 for 1 000-grain weight, biological yield and cob yield. The 1 000 seeds were counted using a seed counter and weighed on an electric balance. Two central rows of each replication were harvested and oven dried at 70 °C until constant weight or the biological yield. All cobs of the same two rows were threshed to measure cob yield.

Physiological measurements. Chlorophyll readings (soil plant analysis development (SPAD) value) were taken with a hand-held dual-wavelength meter (SPAD-502, Minolta, Tokyo, Japan). For each plot, the 30 youngest fully expanded leaves were used when the plants were at the tassel emergence stage.

All the leaves of three plants at the tassel emergence stage were removed, and the leaf numbers per shoot were recorded. Leaf size was determined by scanning the leaf area as a LI3100 area meter (Li-Cor, Lincoln, USA). Leaf size was calculated as the average of the three repetitions.

To measure the relative water content (RWC), free proline content and activity of catalase enzyme, three young and developed leaves of each plot were sampled at noon in cob the formation stage (50 days after emergence, relativetive water content of the leaf samples was calculated using the equation:

$$RWC\% = (FW - DW/TW - DW) \times 100$$

Where: FW – fresh weight of the sample leaf; TW – turgid weight; DW – weight after oven drying (Cornic 1994).

The free proline content was extracted from 0.5 g leaf samples in 3% (*w*/*v*) aqueous sulfosalicylic acid and estimated using ninhydrin reagent according to the method described by Bates et al. (1973). The absorbance of fraction with toluene aspired from the liquid phase was read at 520 nm. Proline concentration was determined using a calibration curve and expressed as μmol/g FW (fresh weight).

For calculating the catalase enzyme activity (CAT), a 0.2 g frozen sample was extracted in 3 mL of 25 mol/L sodium phosphate buffer (pH 6.8). The resultant homogenate was centrifuged at 15 000 rpm at 4 °C for 15 min, and the supernatant was used for measuring CAT activity. The decomposition of hydrogen peroxide was measured through absorption reduction at λ = 240 nm (Cakmak 2008).

Statistical analysis. Data collected on growth and yield parameters were analysed statistically using Fischer's analysis of variance technique by SAS statistical analysis software v9.1 package (SAS Institute, Cary, USA). The year effect was found non-significant, and therefore the average of two years was used to present data. The least significant difference (*LSD*) test was used to compare treatment means, applying a P threshold of 0.05 to declare significance. To investigate the degree of association between cob and biologic yield and morpho-physiologic traits, the Pearson correlation coefficient ($P < 0.05$) was calculated.

RESULTS AND DISCUSSION

The results showed that some of the agronomic and physiological parameters of super sweet corn were significantly affected by climatic conditions in two years (Table 2). Improved agronomic traits

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Table 2. Summary of combined analysis of variance for morpho-physiological characteristics of super sweet corn under irrigation levels, potassium sulfate application and silica foliar spraying during 2019 and 2020

SOV	*df*	Mean square						
		plant height	stem diameter	leaf area	SPAD value	cob length	cob diameter	1 000 seed weight
Year	1	69.3^{ns}	21.5^{ns}	74 977 350^{ns}	29.0^{ns}	21.6*	0.89*	2 390*
Year × rep	6	83.7	6.0	1 566 092 915	24.9	3.3	0.11	210
Irrigation	1	158.6^{ns}	26.4*	507 190 115 300**	11.4^{ns}	37.7**	4.86**	2 520**
Year × irrigation	1	0.9^{ns}	4.8^{ns}	1 177 494^{ns}	0.9^{ns}	0.5^{ns}	0.01^{ns}	20^{ns}
Error I	6	89.7	2.4	1 615 503 482	15.9	0.2	0.3	80
Potassium sulfate	2	297.7**	6.8**	33 143 666 490*	0.1^{ns}	11.8**	1.88**	420**
Silica	1	237.5**	3.8**	3 701 756 171^{ns}	0.4^{ns}	3.7**	1.56**	1 830**
Year × potassium sulfate	2	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	10^{ns}
Year × silica	1	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	11^{ns}
Irrigation × potassium sulfate	2	28.3^{ns}	0.1^{ns}	3 154 181 567^{ns}	25.6**	0.1^{ns}	0.01^{ns}	10^{ns}
Irrigation × silica	1	32.9^{ns}	0.1^{ns}	3 058 009 504^{ns}	12.9**	0.9*	0.18**	130**
Potassium sulfate × silica	2	35.6*	0.2^{ns}	3 146 558 015^{ns}	0.1^{ns}	0.3^{ns}	0.01^{ns}	70**
Year × irrigation × potassium sulfate	2	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	10^{ns}
Year × irrigation × silica	1	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.03^{ns}	10^{ns}
Year × potassium sulfate × silica	2	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	10^{ns}
Irrigation × potassium sulfate × silica	2	3.0^{ns}	0.2^{ns}	3 200 224 730^{ns}	0.6^{ns}	0.03^{ns}	0.19**	10^{ns}
Year × irrigation × potassium sulfate × silica	2	0.1^{ns}	0.1^{ns}	1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	10^{ns}
Error II	60	9.1	0.1	1 626 188 123	0.5	0.09	0.02	40
Coefficient of variation (%)		1.9	2.3	15.5	1.6	1.4	2.8	0.2

SOV	*df*	mean square					
		seed number	cob yield	biologic yield	RWC	proline content	catalase activity
Year	1	4 739.7^{ns}	53.9*	65.3*	77.76^{ns}	7.26*	13.74*
Year × rep	6	8 659.9	4.3	5.8	19.02	0.79	0.71
Irrigation	1	161 319.4**	2 011.4**	186.4**	2 310.84**	1 173.20**	110.68**
Year × irrigation	1	121.7^{ns}	3.8^{ns}	1.5^{ns}	11.76^{ns}	2.94^{ns}	4.71^{ns}
Error I	6	1 930.8	25.4	3.7	39.72	1.01	2.14
Potassium sulfate	2	34 650.6**	75.0**	29.0**	36.20**	3.14**	1.24**
Silica	1	28 216.2**	80.4**	9.0**	54.90**	6.82**	1.63**
Year × potassium sulfate	2	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	0.01^{ns}
Year × silica	1	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	0.10^{ns}
Irrigation × potassium sulfate	2	726.8^{ns}	4.1^{ns}	0.6^{ns}	12.89**	3.64**	1.40**
Irrigation × silica	1	135.7^{ns}	14.3*	0.7^{ns}	16.83**	11.20**	2.01**
Potassium sulfate × silica	2	143.1^{ns}	3.5^{ns}	0.1^{ns}	0.64^{ns}	0.23**	0.10*
Year × irrigation × potassium sulfate	2	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.02^{ns}	0.01^{ns}	0.0^{ns}
Year × irrigation × silica	1	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	0.01^{ns}	0.01^{ns}
Year × potassium sulfate × silica	2	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.03^{ns}	0.01^{ns}	0.01^{ns}
Irrigation × potassium sulfate × silica	2	80.2^{ns}	7.8^{ns}	1.5*	0.20^{ns}	0.30**	0.09^{ns}
Year × irrigation × potassium sulfate × silica	2	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.01^{ns}	0.01^{ns}	0.01^{ns}
Error II	60	256.5	3.2	0.48	0.76	0.04	0.022
Coefficient of variation (%)		2.4	7.9	6.9	1.2	3.4	8.6

ns – non-significant, $^{**}P < 0.01$; $^{*}P < 0.05$; SPAD – soil plant analysis development; RWC – relative water content

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such as cob length, cob diameter, 100 seed weight, seed and biologic yield and catalase activity were obtained in the first year (Table 3). In contrast, the average proline content was higher in the second year compared to the first year (Table 3). Drought stress caused to decrease the stem diameter, leaf area (LA), cob length, cob diameter, 100 seed weight, seed number, cob yield, biologic yield and RWC, but proline content and catalase activity were higher under drought stress conditions (Table 3). Drought stress significantly decreased the LA. It appears that water shortages affect cell growth and division by decreasing cell turgor; hence, it decreases leaf area in plants (Singh et al. 2016). The results of the physiological assessment of super sweet corn treated by potassium sulfate and silica in drought stress conditions for a 2-year experiment have been shown in Table 4. Results of two years experiment showed that the potassium sulfate application and foliar applied Si significantly increased relative water content in drought stress conditions and the highest increase was related to treatment by potassium sulfate in the amount of 25 kg/ha (Table 4). There was no significant effect of potassium sulfate and Si on proline content and catalase activity in control conditions in experiments, against proline content and catalase activity affected significantly by potassium sulfate application and foliar application of Si in drought stress conditions, especially in potassium sulfate application amount of 25 kg/ha treatment (Table 4). Sattar et al. (2021) demonstrated that foliar application of Si had a significant effect on antioxidant defense mechanism and proline, which showed that application of Si ameliorated the effects of terminal drought stress mainly by regulating antioxidant defence mechanism, and production of proline. Interaction of drought and potassium sulfate application led to the highest proline accumulation so the most increase was related to 25 kg/ha potassium sulfate application from 2.43 to 10.05 μmol/g FW (Table 4). Cob length and diameter, 100 seed weight and cob yield in the plants grown in drought conditions were considerably lower than in control plants in the two years experiments. Foliar application of Si noticeably raised yield components such as cob length and diameter, 100 seed weight and cob yield in both non stress and drought stress conditions (Table 4). Lower 1 000 seed weight resulting from drought stress may be due to lower uptake of water and nutrients by the plant and so decreases in the synthesis and transfer of photosynthates and

Table 3. The main effects of potassium sulfate application and silica foliar spraying on the morpho-physiological characteristics of super sweet corn under drought stress conditions during 2019 and 2020

Catalase activity (μmol/min mg protein)	Proline content (mmol/g FW)	RWC (%)	Biologic yield (t/ha)	Cob yield (t/ha)	Seed number	1-000 seed weight (g)	Cob diameter (mm)	Cob length (cm)	SPAD value	Leaf area	Stem diameter (mm)	Plant height (cm)	
Year													
2.09^{a}	5.64^{b}	75.8^{a}	10.87^{a}	23.3^{a}	673^{a}	80.35^{a}	5.33^{a}	21.7^{a}	43.2^{a}	35 779^{a}	15.62^{a}	154.6^{a}	2019
1.33^{b}	6.19^{a}	74.0^{a}	9.22^{b}	21.8^{b}	659^{a}	70.35^{b}	5.13^{b}	20.8^{b}	44.3^{a}	34 012^{a}	14.47^{a}	152.9^{a}	2020
Irrigation													
0.64^{b}	2.42^{b}	79.8^{a}	11.44^{a}	27.2^{a}	707.5^{a}	80.37^{a}	5.45^{a}	21.91^{a}	44.10^{a}	42 164^{a}	15.57^{a}	155.0^{a}	well-watered
2.79^{a}	9.41^{a}	70.08^{b}	8.65^{b}	18.0^{b}	625.6^{b}	70.34^{b}	5.00^{b}	20.65^{b}	43.40^{a}	27 627^{rb}	14.52^{b}	152.4^{a}	drought
Potassium sulfate													
1.50^{c}	5.59^{c}	73.8^{c}	9.13^{c}	21.03^{c}	632.5^{rc}	70.46^{c}	4.98^{c}	20.64^{c}	43.80^{a}	27 843^{b}	14.58^{c}	150.46^{c}	0
1.76^{b}	5.95^{b}	75.1^{b}	9.98^{b}	22.73^{b}	668.9^{b}	70.91^{b}	5.25^{b}	21.35^{b}	43.76^{a}	30 281^{b}	15.03^{b}	154.41^{b}	15
1.89^{a}	6.21^{a}	75.9^{a}	11.03^{a}	24.09^{a}	698.2^{a}	80.19^{a}	5.46^{a}	21.85^{a}	43.70^{a}	46 563^{a}	15.50^{a}	156.46^{a}	25
Silica													
1.58^{b}	5.65^{b}	74.2^{b}	9.74^{b}	21.70^{b}	649.4^{b}	70.42^{b}	5.10^{b}	21.0^{b}	43.8^{a}	28 686	14.84^{b}	152.2^{b}	no
1.84^{a}	6.18^{a}	75.7^{a}	10.35^{a}	23.53^{a}	683.7^{a}	80.29^{a}	5.36^{a}	21.4^{a}	43.6^{a}	41 105	15.24^{a}	155.3^{a}	spray

Based on the *LSD* (least significant difference) test, means shown by the same letters are not significantly different at a 5% level. SPAD – soil plant analysis development; RWC – relative water content

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Table 4. The interaction between drought stress and potassium sulfate application and drought stress and silica foliar spraying on several biochemical and agronomic characteristics of super sweet corn during 2019 and 2020

	Well-watered	Drought	Well-watered	Drought	Well-watered	Drought	Well-watered	Drought
	SPAD value		RWC (%)		proline content (mmol/g FW)		catalase activity (µmol/min mg protein)	
Potassium sulfate								
0	43.17^{c}	44.42^{a}	79.46^{b}	68.28^{c}	2.38^{a}	8.75^{c}	0.65^{a}	2.35^{c}
15	44.22^{b}	43.17^{b}	79.90^{a}	70.30^{b}	2.45^{a}	9.45^{b}	0.64^{a}	2.87^{b}
25	44.90^{a}	42.62^{c}	80.32^{a}	71.66^{a}	2.43^{a}	10.05^{a}	0.63^{a}	3.15^{a}
Silica								
No application	43.80^{b}	43.84^{a}	79.55^{b}	68.90^{b}	2.50^{a}	8.80^{b}	0.65^{a}	2.51^{b}
Spraying	44.40^{a}	42.97^{b}	80.23^{a}	71.25^{a}	2.45^{a}	10.02^{a}	0.63^{a}	3.06^{a}
	Cob diameter (cm)		1 000 seed weight (g)		Cob yield (t/ha)		Cob length (cm)	
Silica								
No application	5.28^{b}	4.92^{b}	70.81^{b}	70.02^{b}	25.89^{b}	17.51^{b}	21.61^{b}	20.55^{b}
Spraying	5.63^{a}	5.09^{a}	80.92^{a}	70.66^{a}	28.50^{a}	18.57^{a}	22.20^{a}	20.75^{a}

Based on the least significant difference (*LSD*) test, means shown by the same letters are not significantly different at a 5 % level. SPAD – soil plant analysis development; RWC – relative water content; FW – fresh weight

assimilates to seeds; in this situation, the plant can compensate for the shortage of assimilates even by retransferring nutrient resources and seeds become lighter (Aghdam et al. 2019). Under drought conditions, Si foliar application increased 1 000 seed weight (Table 4). The increasing trend of 1000 seed weight as affected by Si application is due to the positive effects of Si on assimilating transfer, photosynthetic enzymes activity, chlorophyll formation, and plant growth improvement (Li et al. 2022). In line with our findings, the positive effect of Si application on 1 000-seed weight has been reported maise (*Zea mays* L.) (Li et al. 2022).

As can be seen in Figure 1, Si application increased plant height in potassium sulfate application levels. Maximum (156.9 cm) plant height was obtained using 25 kg/ha potassium sulfate and Si foliar ap-

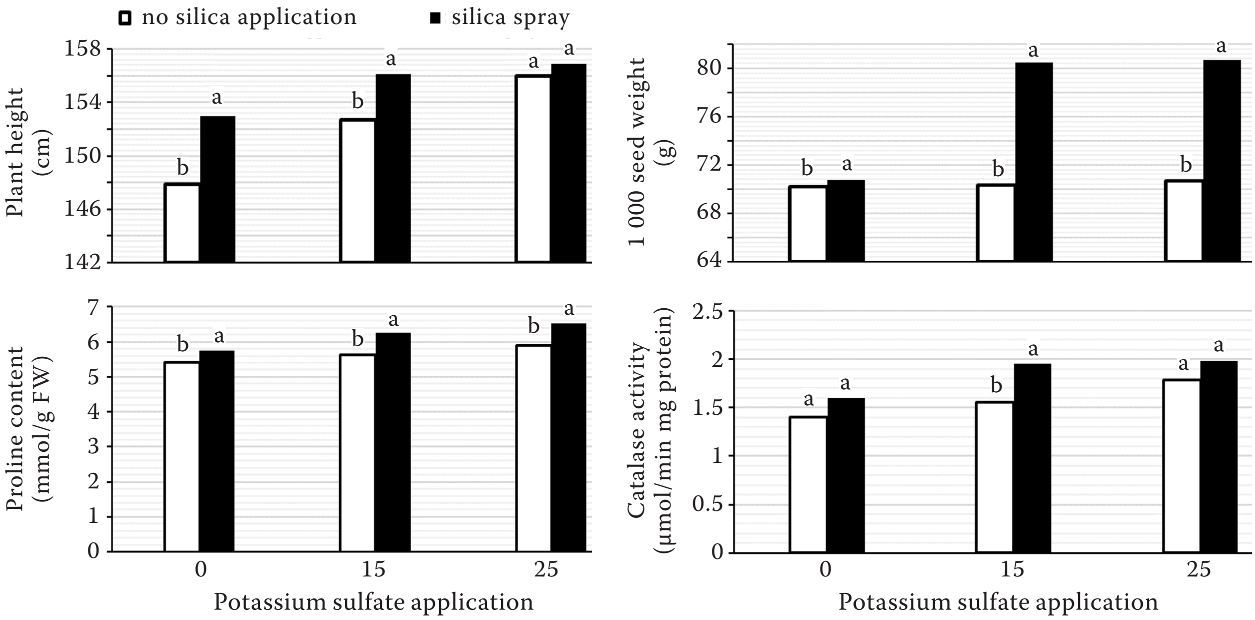

Figure 1. The interaction between potassium sulfate application and silica foliar spraying on several morphologic and biochemical characteristics of super sweet corn during 2019 and 2020. FW – fresh weight

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plication (Figure 1). Under applying 15 and 25 kg/ha potassium sulfate, foliar spraying Si increased 1 000 seed weight by 14.9% and 12.7%, respectively but in non-applying potassium sulfate, mentioned increase rate by Si foliar spraying is less than applying 15 and 25 kg/ha potassium sulfate (Figure 1).

Meanwhile, individual and combined potassium sulfate and Si applications increased the proline content. Still, this increase was more significant with foliar application of at the application of 15 and 25 kg/ha potassium sulfate, compared to non-applying potassium sulfate (Figure 1). Maximum (6.52 mmol/g FW) and minimum (5.42 mmol/g FW) proline content was recorded with Si foliar spraying and applying 25 kg/ha potassium sulfate and without Si and potassium sulfate application, respectively (Figure 1). In addition, only with the application of 15 kg/ha potassium sulfate, silicone foliar application significantly increased catalase activity. Still, with 25 kg/ha and whitout potassium sulfate application, the activity of the antioxidant enzyme did not change significantly with silicon foliar application (Figure 1).

It seems that drought stress decreased cob diameter in all treatments (Table 5). A maximum (5.85 cm) cob diameter was observed under normal irrigation conditions with applying 25 kg/ha potassium sulfate and Si foliar application, and a minimum (4.58 cm) one was obtained without potassium sulfate and Si application under drought stress conditions (Table 5).

Applying potassium sulfate with silicone foliar spraying did not significantly affect normal irrigation conditions. However, under drought stress treatments, biologic yield increased by applying 15 and 25 kg/ha potassium sulfate and Si foliar spraying (Table 5). Results of the mean comparison of biologic yield affected by potassium sulfate and Si application and drought stress indicated that silicone foliar application at potassium sulfate consumption levels increased biologic yield in drought stress; the maximum biologic yield was 9.82 t/ha with applying 25 kg/ha potassium sulfate in Si foliar spraying, respectively; minimum biologic yield (7.35 t/ha) was obtained in without potassium sulfate and Si application (Table 5).

As can be seen in Table 5, the interaction between drought stress and potassium sulfate and Si application on proline content demonstrated that drought stress increased proline content by 10.15 and 10.77 mmol/g FW for Si foliar application under application of 15 and 25 kg/ha potassium sulfate, respectively (Table 5).

Mean comparison of proline content as affected by irrigation, potassium sulfate, and Si application clarified that Si application had not a significant effect on proline content under normal irrigation conditions but increased proline content under drought stress and Si foliar application; generally, the highest proline content (10.77 mmol/g FW) was recorded in Si application by using 25 kg/ha potassium sulfate under drought stress condition (Table 5).

Positive correlations between RWC and yield components included 1 000 seed weight and seed number (Table 6), indicating that the value increase of one variable is associated with an increase in the other. Moreover, positive relationships were found between some compelling characteristics of cob yield, such as cob length, diameter and RWC. Also, proline content and catalase activity had strength and positive correlations with RWC. This same behaviour was also observed in the means of cob yield, biologic yield and proline (Table 6).

Table 5. The interaction between drought stress, potassium sulfate application and silica foliar spraying on cob diameter, biological yield and proline content of super sweet corn during 2019 and 2020

Potassium sulfate application	Silica application	Well-watered	Drought	Well-watered	Drought	Well-watered	Drought
		cob diameter (cm)		biologic yield (t/ha)		proline content (mmol/g FW)	
0	no application	5.11^{a}	4.58^{b}	10.47^{a}	7.35^{b}	2.50^{a}	8.35^{b}
	spraying	5.31^{a}	4.90^{a}	10.25^{a}	8.47^{a}	2.37^{a}	9.15^{a}
15	no application	5.21^{b}	5.05^{a}	11.10^{a}	8.20^{b}	2.50^{a}	8.75^{b}
	spraying	5.71^{a}	5.04^{a}	11.77^{a}	8.85^{a}	2.40^{a}	10.15^{a}
25	no application	5.53^{b}	5.13^{b}	12.10^{a}	9.25^{b}	2.50^{a}	9.32^{b}
	spraying	5.85^{a}	5.32^{a}	12.97^{a}	9.82^{a}	2.27^{b}	10.77^{a}

Based on the *LSD* (least significant difference) test, means shown by the same letters are not significantly different at a 5 % level. FW – fresh weight

Table 6. Pearson correlation coefficient between 13 traits of super sweet corn during 2019 and 2020

	Plant height	Stem diameter	Leaf area	SPAD value	Cob length	Cob diameter	1 000 seed weight	Seed number	Cob yield	Biologic yield	RWC	Proline content	Catalase activity
Plant height	1	0.37^{ns}	0.11^{ns}	-0.09^{ns}	0.61^{**}	0.61^{**}	0.67^{**}	0.59^{**}	0.47^{ns}	0.51^{*}	0.53^{*}	-0.21^{ns}	0.05^{ns}
Stem diameter		1	0.21^{ns}	0.31^{ns}	0.77^{**}	0.51^{*}	0.62^{**}	0.42^{ns}	0.55^{*}	0.61^{**}	0.54^{*}	0.43^{ns}	-0.13^{ns}
Leaf area			1	0.26^{ns}	0.22^{ns}	0.26^{ns}	0.21^{ns}	0.25^{ns}	0.06^{ns}	0.23^{ns}	0.17^{ns}	0.19^{ns}	-0.13^{ns}
SPAD value				1	0.12^{ns}	-0.01^{ns}	-0.04^{ns}	0.05^{ns}	0.03^{ns}	0.02^{ns}	-0.02^{ns}	0.22^{ns}	-0.41^{ns}
Cob length					1	0.77^{**}	0.87^{**}	0.77^{**}	0.67^{**}	0.76^{**}	0.75^{**}	0.57^{*}	-0.22^{ns}
Cob diameter						1	0.78^{**}	0.81^{**}	0.72^{**}	0.80^{**}	0.71^{**}	0.54^{*}	-0.29^{ns}
1000 seed weight							1	0.75^{**}	0.67^{**}	0.74^{**}	0.74^{**}	0.50^{*}	-0.12^{ns}
Seed number								1	0.69^{**}	0.83^{**}	0.77^{**}	0.65^{**}	-0.44^{ns}
Cob yield									1	0.72^{**}	0.88^{**}	0.81^{**}	0.60^{**}
Biologic yield										1	0.75^{**}	0.65^{**}	-0.34^{ns}
RWC											1	0.83^{**}	0.54^{*}
Proline content												1	0.83^{**}
Catalase activity													1

ns – non-significant, $^{**}P < 0.01$; $^{*}P < 0.05$; SPAD – soil plant analysis development; RWC – relative water content

Pearson correlation analysis showed that some sociological traits such as RWC, were one of the main factors affecting cob and biological yield. A positive relationship between them was observed (Table 6).

Exposed to drought-stressed conditions, individual application of potassium sulfate and Si further aggrandised antioxidant enzyme activity, increased RWC, and proline accumulation. In contrast, Si foliar spraying significantly improved cob length and diameter, 1 000 seed weight and cob yield. On the other, adding exogenous Si and potassium sulfate increased the cob diameter and biomass production and proline contents online under drought stress. In summary, applying potassium sulfate and exogenous Si can enhance the antioxidant system of the plant, promote the RWC, thus improving biologic and cob yield, and enhance the drought resistance of super sweet corn.

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