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The Role of Nano-Silica in Reducing the Negative Impact of Different Shocks on Cucumber Plant Growth

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ABSTRACT

The current research aims to determine whether salinity in irrigation water, frost, drought, and heat damage to cucumbers may be reduced or avoided by using manufactured nano-silica (NaSiPs) particles. After soaking the seeds for 3 hours in a nano-silica suspension, seedlings with a length of 15 cm in the greenhouse were sprayed with various NaSiPs concentrations (0, 100, 200, and 400 mg L^{-1}). When the plant reached 30 cm in length, the various shock treatments were applied. At harvest, some vegetative parameters were determined as well as chemical analysis of plants (root, leaves , and fruits). The results confirmed that NaSiPs were effective in reducing the negative effects of various shocks on plant biometrics, chlorophyll, and fruit yield. The findings revealed that there were no significant effects of the two-way interaction between shock treatments and nano-silica rates on the plant biometrics, chlorophyll, and fruit yield. The concentrations of sodium and potassium in roots, leaves, and fruits, as well as silicon and proline in roots and leaves, were found to have the same effects. Except for Na and K in fruits and leaves, all parameters studied increased with increasing nano-silica rates, with the exception of fruit sodium and leaf potassium concentration. The shocks had the following order: control > salinity > frost > dryness > heat. SiNP400 treatment of plants reduced the negative effects of various shocks.

Keywords: Cucumber, Shocks, Nanosilica, silicon, proline

INTRODUCTION

A recent review by Barlow *et al*., (2015) on the effect of temperature extremes, frost and heat, in wheat (*Triticum aestivum* L.) revealed that frost caused sterility and abortion of formed grains, whereas excessive heat caused grain number reduction and decreased duration of the grain-filling period. Analysis by Meehl *et al*., (2007) revealed that daily minimum temperatures will increase more rapidly than daily maximum temperatures, leading to an increase in daily mean temperatures and agreater likelihood of extreme events, which could have a negative impact on grain yield. If these temperature changes are expected to occur over the next 30 years, understanding the potential impacts on plant growth and development will aid in the development of adaptation strategies to mitigate these impacts.

Temperature is a major factor influencing plant development. Plant productivity will be impacted by the warmer temperatures expected as a result of climate change. Pollination is one of the most sensitive phonological stages to temperature extremes across all species, and temperature extremes would have a significant impact on production during this developmental stage. At this developmental stage, there are few adaptation strategies available to cope with temperature extremes other than selecting plants that shed pollen during the cooler periods of the day or are indeterminate so flowering occurs over a longer period of the growing season.

Warm temperatures accelerated phonological development in controlled environment studies, but had no effect on leaf area or vegetative biomass when compared to normal temperatures. Warmer temperatures had the greatest impact during the reproductive stage of development, and grain yield in maize was reduced by up to 90% compared to a normal temperature regime in all cases. Temperature effects are exacerbated by water deficits and excess soil water, demonstrating that understanding the interaction of temperature and water will be required to develop more effective adaptation strategies to mitigate the impacts of higher temperature extreme events associated with climate change.

The world's arid and semi-arid regions, such as the Kingdom of Saudi Arabia, have a severe scarcity of arable water sources. As a result, groundwater is regarded as the primary source of irrigation water in the Kingdom of Saudi Arabia (DeNicola *et al*., 2015).Vegetables are grown in greenhouses with a cooling system and an irrigation system that is powered electricity due to the high temperature. The cooling system and the irrigation water pumping system both fail due to electrical faults. As a result, farmers resort to other sources of irrigation water with poor quality specifications, resulting in salinity shock when highly saline water is applied for a short period of time (Ministry of environment, water , agriculture, 2019).

Shock is a negative event that occurs unexpectedly and lasts for a short period of time, leaving behind negative effects that can be minor or fatal to plant . Shock stress is defined as a significant change in the optimum conditions for plant growth that result in changes in plant metabolism (Lobato *et al*., 2007). High winds, low or high temperatures, soil salinity, drought or flooding

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can all have an impact on crop production (Shahbaz and Ashraf, 2013). Plant production is affected by increased salinity stress due to changes in physiological and biochemical processes (Singh, 2014).

Salinity stress impairs plant cells by causing cellular dysfunction, ionic toxicity, and an increases in reactive oxygen species (ROS) (Nounjan *et al*., 2012; Yıldız and Terzi, 2013), which lowersagricultural output. Excess salts in the root zone of plant cause a number of other issues related to plant nutrition, or enzymes activity, water and nutrients uptake, and the interaction of morphological, physiological and biochemical processes (Akbarimoghaddam *et al*., 2011).Excessive Na^+ accumulation in cell walls can quickly cause osmotic stress and cell death (Munns and Tester, 2008). The ion imbalance and ion toxicity were attributed to the replacement of K^+ with Na^+ ions (Zhu, 2002). Plants' ability to maintain high levels of K is the most important feature of their salt tolerance mechanism (Chen *et al*., 2007). The effect of salinity on plant development is determined by the intensity of stress, the time of occurrence, the time of stress exposure, and the stage of plant growth (Çiçek *et al*., 2018). Abiotic stresses are a major constraints to crop production and food security around the worldwide. The situation has gotten worse as a result of the drastic and rapid changes in the global climate. Heat and drought are undoubtedly the two most significant stresses affecting crop growth and productivity (Fahad *et al*., 2017).

Plants resist these unsuitable environmental conditions by modifying ion accumulation producing osmoregulators such as proline to assist the plant in completing its life cycle (Kolupaev *et al*., 2016). Proline modifies the osmotic property of the plant against the risks of salinity and drought stresses and other shocks. Proline alters the plant's osmotic properties, making it more resistant to salinity, drought, and other stresses When plants are stressed by salinity or drought, proline accumulates more than other amino acids (Heidari *et al*., 2011). As salinity stress increases, plants produce more proline in their interior tissues. Additionally, plants tolerate salt stresses by reducing the absorption and translocation of Na^+ and Cl^- in leaves, which results in an increase in the K+/Na+ ratio.(Alsaeedi *et al*., 2018). K^+ acts as a catalyst in many enzymes and cannot be replaced by Na^+ to perform the same function. . Because of its association with RNA, particularly in ribosomes, high K+ concentrations are required to induce protein synthesis.(Zhu, 2002). Despite the widespread distribution of Si in soil, the available amounts for plant uptake are significantly low ; plants primarily absorb Si in the form of silicic acid.

Silicon is important in protecting the plant from various biotic and abiotic stresses, such as diseases, pets, drought, salinity and heavy metals toxicity as well as restoring the plant's nutritional balance.(Alsaeedi *et al*., 2018; Pilon *et al*., 2013).Silicon is an essential component of cell walls that makes them more rigid (He *et al*., 2013). Silicon also plays an important role in corn photosynthesis, increasing the content of photosynthetic pigments, photosynthesis rate, stomatal conductance, and decreasing transpiration rate (Kaya *et al*., 2006). Exogenous Si in the form of silica nanoparticles (NaSiPs), increased cucumber yield and other growth parameters under salinity by altering nutrient uptake. Cucumber grown under salinity stress was treated with NaSiPs, which increased the contents of N, K, and Si in all the plant tissues (Alsaeedi *et al*., 2019). Cucumber roots with high K^+ content tolerated salinity and water deficit stresses by maintaining ion homeostasis, regulating osmotic balance, and controlling stomatal opening (Alsaeedi *et al*., 2019).

Global food security is being threatened by rapid population growth and drastic climate change.(Lesk *et al*., 2016). Droughts have a significant impact on crop yields due to their negative effects on plant growth, physiology, and reproduction (Yordanov *et al*., 2000; Barnabas *et al*., 2008). A recent study analysed data from studies published between 1980 to 2015 to report global yield reductions of up to 21 and 40% in wheat (Triticum aestivum L.) and maize (Zea mays L.) due to drought. (Daryanto *et al*., 2016).

A combination of drought and heat shock on tobacco (Nicotiana tabacum) plants resulted in stomatal closure, photosynthesis suppression, increased respiration, increased leaf temperature, and yield reduction.(Rizhsky *et al*., 2002).

Cucumber (Cucumis sativus L.) is one of the main greenhouses vegetables crops widely grown in the Kingdom of Saudi Arabia. The total greenhouse area for cucumber production in 2018 was 2,420 hectares produced 43,717 tons (Ministry of environment, water, agricultural, 2018).

The current study's objective was to examine how NaSiPs helped cucumber plants exposed to brief salinity, frost, heat, and drought shocks in greenhouse environments. . Additionally, the K+/Na+ ratio and the amounts of Na, K, Si, and proline in various plant sections were examined.

MATERIALS AND METHODS

In this experiment, a split plot in randomized complete block design with three replications was used, with shock treatments (without and with four shocks of drought (D), frost (F), heat (H) and salinity (S)) occupying the main plots and sub main plots containing four concentrations of Nano-silica (zero(N0), 100 (N1), 200 (N2), and 300 (N3) ppm) occupying the sub main plots. The seeds (Cucumis sativus) Beit Alpha variety F1 species were pre-soaked in each Nano-silica concentration for 3 hours before the experiment.

1- The seeds were grown in plastic pots filled with potting soil and watered to saturation level. Nano-silica treatments were sprayed on all plants once the seedlings' growth was complete and their length reached 15 cm. After the plants reached a length of 30 cm, shock treatments were administered to all experimental units (12 units per shock treatment) as follows: In drought stress shock (D), the irrigation system was turned off for 48 h before plants were irrigated with normal irrigation water.
2- Plants from shock treatments (F) were transferred to incubate room at -4°C for 48 h before being returned to the same location in the greenhouse.
3- Heat treatments were performed on 12 experimental units by transferring the plants to an incubated room set to 48 °C for 48 hours, after which the plants were returned to their original location in the greenhouse.
4- In the case of saline stress, the plants were irrigated with 3500 ppm saline water for 48 hours using drippers at a rate of 4 liters per hour for 15 minutes every day in a drip irrigation system. Then the plants were irrigated with normal well irrigation water after that.

The remaining experimental units (C) were left as controls treatment (12 plot units) and where irrigated at the same rate with normal well irrigation water (total soluble salt = 768 ppm) of green house.

Preparation of Nano-silica concentration:

The amorphous hydrophilic nano-silica manufactured at AEROSIL Company was used as a source of nano-silica. The physical specifications of the nano-silica used are as follows: Specific surface area 270 – 330 m^2 g^{-1} and pH 3.7 - 4.5, loss when drying ≤ 1.5%, density 50 g L^{-1} (0.05 g cm^{-3}) and containing SiO_2 greater than 99.8%. Various concentrations were used to study from the nano silica suspension: (0 (N0), 100 ((N1, 200 (N2), 300 (N3) mg kg^{-1} soil) by mixing a specific nano-silica weight with distilled water directly into 50 gallon plastic drums (gallons = 4.54 liters). The Potground H poting soil was used as growth media produced by German company Klasman Delman

The soil preparation for planting:

The greenhouse soil was prepared before planting the seedlings by plowing, leveling, disposal of plant residues and sterilization. The drip irrigation network was implemented to irrigate the cucumber crop. The polyethylene irrigation pipes were used where the distance between the sub-lines is 50 cm with a length of 25m. The main irrigation line was connected with a dynamo of 1 horse capacity in order to maintain water pressure in the sub-lines with a diameter of 16 mm. Irrigation points were installed at a distance of 50 cm between the drippers with drain rate 4 l h^{-1}.

The experiment performs:

The seeds were pre-soaked in each nano-silica concentration for 3 hours. The pots were watered until they reached saturation and after that, one seed per pot was sown. When the growth is complete and its length becomes 15 cm, nano-silica sprinkler treatments were applied and applied on paper to all plants. When the seedling's length became 15 cm, the nano-silica was sprayed on all plants according to the treatments. The shock treatments were then applied to 12 experimental units/shock containing 60 plants (5 plants for every experimentally unit). The chemical properties of the used soil were 5.5 $dScm^{-1}$, 7.91, 28.2 $mmol^{-1}$, 8.53 $mmol^{-1}$, 5.7 $mmol^{-1}$, 8.9 $mmol^{-1}$, 6.6 $mmol^{-1}$, 22.12 $mmol^{-1}$, 1.11 $mmol^{-1}$ and 10.96 ppm for EC, Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+ and Si, respectively. After applying the shocks treatments, all experimentally units were irrigated with artesian well normal water has EC at 1.02 dS m^{-1} and pH 6.52.

Yield and yield component:

Plant height, chlorophyll, and fourth leaf area were recorded after 15, 21, and 28 days from treatments application, respectively. The main values of three recording of plant height were used in this study. Chlorophyll was measured by using chlorophyll meter model MIN LTA SPAD-502 and leaf area meter model LI-3000A for leaf area. The mean fruit yield of the middle three plants from every experimentally unit was recorded from the eighth to the thirteenth week from seedling planting and calculation of the fruit yield per one plant.

Preparation plant sample for measuring of elements:

At the end of the fruit harvest period, the 4th leaf and root of plant were collected, cleaned from dust with brush and then washed with 0.1M HCl and following that the samples were rinsed off three times by using deionized water. After that the samples were air dried for 48 hours. The samples were dried for two days at 65 ºC in a oven and then grinded and sifted in mesh sieve No. 60, after which the samples were kept in plastic bags until the content of the elements was estimated. The measuring of elements in cucumber fruits were ten fruits from every plant inside the experimentally units (three plants) and the same for fourth leaf.

Determination of Na^+, and K^+ content:

A 500 mg of dried plant sample was transferred into 50 mL volumetric flask with 5 mL concentrated sulfuric acid (H_2SO_4, 95-97%, Sigma-Aldrich, USA) on hotplate at approximately 270° C for 2 hours. Then, A 3 mL H_2O_2 was added until the digest became clear (Cottenie, 1980). After digestion, deionized water was added to bring the final volume to 50 mL. The Na^+ and K^+ contents were determined in the liquid sample by Atomic Absorption and Emission Spectrometry (model Shimadzu-AA7000, Japan).

Determination of silicon content in plant and fruits:

The Si content in the root and 4th leaf of cucumber plants was measured according to Frantz *et al*., (2008). Briefly, 5 mL of NaOH solution (1 g NaOH/mL H_2O) was added to 100 mg of powdered dried plant sample placed into polyethylene tube and shaken to mix thoroughly. The capped tube was then placed in an autoclave and heated for 30 min, then allowed to cool to room temperature. After cooling, 2 mL H_2O_2 was added to each tube and reheated in the autoclave for an additional 30 min. After cooling, 43 mL distilled water was added to each tube. After additional cooling, 0.1 mL of the digested plant material mixture was added to 10 mL distilled water. A 0.25 mL of 6M HCl was added along with an ammonium molybdate solution (0.5 mL, 10 g/100 mL at pH of 7.0), shaken and allowed to stand for up to 10 min. Tartaric acid (0.5 mL, 20 g/100 mL) was added, shaken, and allowed to sit for an additional 3 min. Sodium bisulfate (0.7 mL, 12.5 g/100 mL) was added and mixed. The blue color that developed was measured between 10 and 30 min at 650 nm. Finally, the absorbance was compared to a standard calibration curve of known Si concentrations (0-50 ppm) prepared with soluble Si combined with the reagents as described previously.

Proline detection in plant:

Proline determined according the method of Bates *et al*., (1973). In the tube with cap, 1 mg of fresh plant material was putted and mixed in 20 ml of 40% methanol and then the tube was closed with a cap to prevent evaporation in a water bath for 60 minutes at 85°C. Cool the tube. For developing the color, filtered the mixture through Whatman's No. 2 filter paper. 1 ml of filtrate was mixed with 2 ml of glacial acetic acid and 2 ml acid-ninhydrin in a test tube. The mixture was placed in a water bath for 1 hr at 100°C. The reaction mixture was extracted with 4 ml toluene and the chromophore containing toluene was aspirated, cooled to room temperature, and the absorbance was measured at 520 nm with Spectrometer. Appropriated proline standards were included for calculation of proline in the samples.

Statistical analysis:

Dependent variables were checked for normality and homoscedasticity and transformed as necessary. Data analysis was performed using Microsoft Excel 2010 and the SAS computer program. The analysis of variance one-way ANOVA was applied to evaluate the differences among treatments. Separation of means was performed by LSD test as described by Snedecor and Cochran (2014). The data were presented as mean ± standard deviation (n= 10).

RESULTS AND DISSECTION

The main effect and ANOVA of shocks treatments (C, D, F, H, and S) and nano-silica concentrations on the plant height, chrolphll, leaf area, and yield/plant were shown in Table 1. The data show that shock treatments have a significant effect on plant height and yield, whereas nano-silica and treatment interaction have a significant effect on plant height, chlorophyll, leaf area, and yield.Plant biometrics, chlorohyll and fruit yield

Plant height

Table 1 demonstrated that shock and nano-silica dose treatments resulted in significant differences in plant height.. In terms of shock treatment, the plant height ranged from 89.07 cm when exposed to heat shock to 106.23 cm with the control treatment, witha significant difference between them. For different shocks of salinity, frost, drought, and heat, plant height decreased by 11.49, 14.28, 19.34, and 25.78%, respectively, Compared to the control treatment. Plant height was lower in shocked plants than in control plants. Plant height in general, significantly increased significantly when the NaSiPs concentration was increased from 0 to 400 mg L^{-1}.

Table 1. The main effect of different stress (S: Salinity, D: Drought, F: Frost, and H:Heat) in comparison control (C: without stress), nanosilica doses (NaSi0, (0 ppm); NaSi100, (100 ppm); NaSi200, (200 ppm); NaSi400, (400 ppm)) and anova values of cucumber plant

Treat	Plant height, cm	Chlorophyll, SAPD	Leaf area, cm^2	Yield/ plant,g
		Shock		
C	120.02a	24.79	150.36	3062.6a
S	106.23ab	24.61	142.94	2950.9ab
F	102.88ab	24.57	141.64	2880.4abc
D	96.81b	24.47	133.86	2668.8cb
H	89.07b	24.31	130.93	2575.3c
LSD0.05	20.24	-	-	241.17
		Nano-silica dose		
NaSi0	89.91c	21.93c	126.50b	2246.7d
NaSi100	98.42bc	24.16b	131.36b	2686.6c
NaSi200	107.63ab	25.21b	143.77ab	2997.6b
NaSi400	116.05a	26.91a	158.14a	3379.5a
LSD0.05	16.62	1.08	22.41	284.87
		ANOVA		
Shock	*	NS	NS	***
Nano-silica dose	*	****	*	****
Stress*Nano-silica dose	NS	NS	NS	NS
CV%	21.64	5.87	21.47	13.51

^{S}: The least significant difference at a probability of 0.05
^{S}CV% coefficient of the variance%

The plant height increased by approximately 29.07% over the control treatment. Under all shock treatments. The tallest plants were those treated with NaSiPs at a rate of 400 mg L^{-1}. Similarly, at the same frost shock treatment the plant height of control plants increased from 96.25 to 127.92 cm at 400 NaSiPs concentration, with percentage increase of 33.60% over the control plants (NaSi0 and non-shocked). This result indicates that the application of the high dose of NaSiPs prevented damage to the plant height of the cucumber plants that were subjected to shocks (Fig 1a).

Leaf area

The results revealed that the effect of shock treatments on the leaf area of cucumber plants was non-significant. In comparison, we find that the shocks had the following effects in the following order: control > salinity > frost > dryness > heating.

The respective percentages of decreases compared to the control were 4.95, 5.80, 10.97, and 12.92% (Table 1). The leaf area increased significantly as the nano-silica rate increased. Higher NaSiPs rate resulted in higher values (Table 1). However, the obtained results can be explained by the fact that the use of nano-silica improved the health of the plant's growth media.

The obtained results can be explained by the fact that the application of nano-silica improved the plant's growth media, making it more healthy for plant growth. The nano-silica can improve the physical properties of the soil, which affects its properties (Alsaeedi *et al*., 2019, 2021).

At all NaSiPs treatments, shocked cucumber plants had significantly less leaf area than non-shocked control plants. . The leaf area of control and shocked plants differed significantly after NaSiPs application. In terms of salinity shock, the addition of nano-silica does not protect against the negative effect of salinity shock when comparison to control plant treatment. In comparison to other nano-silica doses, SiNP400 produces the highest values in the leaf area (fig. 1C). Plant production is affected by increased salinity stress due to changes in physiological and biochemical processes (Singh, 2014).

Chlorophyll

There were no significant differences in the effects of various shocks treatments on the relative chlorophyll content (SAPD) in leaves. The chlorophyll value of plants exposed to no-shock (control) was greater than that of the other shock treatments. The chlorophyll values after shocks were in the following order: Salinity (24.61) > frost (24.57) > drought (24.47(and heat (24.31). Plant chlorophyll levels in shocked plants were lower than in control plants. For the different shocks of salinity, frost, drought, and heat, the decrease in chlorophyll was approximately 0.73, 0.89, 1.29, and 1.94%, respectively, compared to the control treatment. Compared to control plants, shocked plants had decreased chlorophyll levels. The amount of chlorophyll dramatically increased when the addition of NaSiPs rates increased from 0 to 400 mg L^{-1}.. Under all shock treatments, the plants treated with NaSiPs at the rate of 400 mg L^{-1} had greater chlorophyl values. The plant chlorophyll of control plants increased at the same drought shock treatment from 24.26 to 28.07 SPAD at SiNP400 concentration, an increase of 15.70% over the control plants (NaSi0 and non-shocked). This indicates that the application of a high dose of NaSiPs prevented the the chlorophyll of the cucumber plants that were subjected to shocks from being damaged (Fig 1b).

Yield/plant

Table 1 showed that there were significant differences in the means of yield/plant under the shock treatments. Cucumber yield was lower in shocked plants than in control plants. The yield values under shocks were in the following order: Salinity (2950.9g) > frost (2880.4g) > drought (2668.8g) > heat (2575.3g). For the different shocks of salinity, frost, drought, and heat, the yield

decreased by about 3.65, 5.95, 12.85, and 15.91%, respectively, compared to the control treatment. Heat shock more damaging than salinity shock.

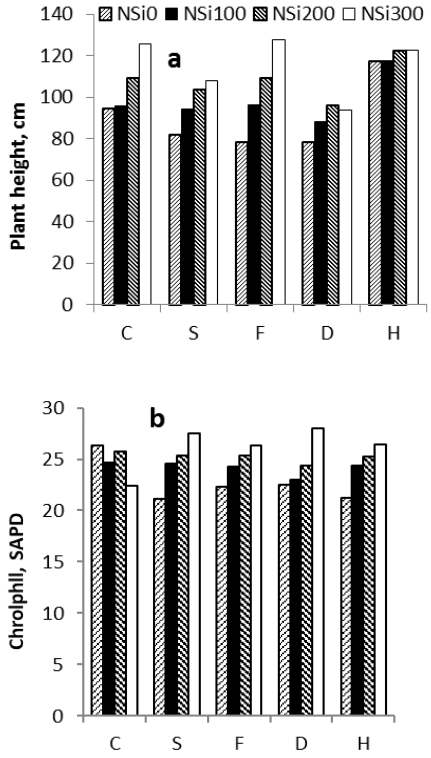

Fig. 1. The interaction effect between different stress (C (without stress), D (drought stress), F (Frost), H (Heat), and S (Salinity)) and nanosilica doses (NaSiP0, (0 ppm); NaSiP100, (100 ppm); NaSiP200, (200 ppm); NaSiP300, (300 ppm)) on plant height (cm), Chlorophyll (Brix), leaf area (cm2), and yield (kg plant-1) of cucumber .

Fruit yield increased significantly when NaSiPs rates were increased from 0 (2246.7 g/plant) to 400 mg L-1 (3379.5 g/plant). . Fruit yield was higher at SiNP400 after a salinity shock. While the plant treated with SiNP100 under frost shock produced a higher value of fruit yield. Under the effect of drought shock, however, the higher yield was in plant treated with SiNP200, with percentage increase of 42.90% over the control plants of the same shock. As shown in Fig.1d, the treated plant with heat shock had a higher yield at rate of SiNP400, with a percentage increasing equal to 70.11% over the control plants of the same shock . At each shock of control, salinity, frost, drought, and heat, the values were 2236.81, 2734.01, 2124.97, and 1861.69 g plant^{-1}, respectively. The minerals in saline irrigation water may be responsible for the higher salinity shock value. According to the findings of Barlow *et al*., (2015), the effect of temperature extremes, frost and heat, on wheat (Triticum aestivum L.) revealed that frost caused sterility and abortion of formed grains, whereas excessive heat caused grain number reduction and reduced duration of the grain-filling period. They came to the conclusion that the effects differed from crop to crop.

Na^+, K^+, Si, and proline concentrations by different-shocked cucumber under NaSiPs application

Variance analysis

Table 2 shows variation analyses of Na^+, K^+, Si, and proline in cucumber plants under the effects of tested variables in different parts of the roots, leaf, and fruit of cucumber plants .The results showed that there were significant differences in sodium, potassium of roots, leaves, and fruits as well as proline and silicon in roots and leaves, under the effect of shock treatments (except for silicon of roots and leaves) and NaSiPs (except Na content in roots and K in fruits). While the two-way interaction between the treatments had no significant effects on all parameters studied.

Table 2. The main effect of different stress (S: Salinity, D: Drought, F: Frost, and H:Heat) in comparison control (C: without stress), nanosilica doses (NaSi0, (0 ppm); NaSi100, (100 ppm); NaSi200, (200 ppm); NaSi400, (400 ppm)) and anova values of roots sodium (NaR), leaves Sodium (NaL), fruits sodium (NaF), roots potassium (KR), leaves potassium (KL), fruits potassium (KF), roots silicon (SiR), leaves silicon (SiL), roots proline (PR), and leaves proline(PL) of cucumber plant

Treat	NaR	NaL	NaF	KR	KL	KF	SiR	SiL	PR	PL	K/Na		
											Root	Leaf	Fruit
Stress													
C	0.189b	0.092a	0.145b	0.820a	0.362b	1.34a	5.011a	4.128a	2.99bc	6.16a	4.37ab	4.08c	9.56a
D	0.178b	0.075ab	0.184a	0.780ab	0.391ab	1.23b	4.397a	3.776a	3.10bc	3.03b	4.45a	5.32b	6.78c
F	0.190b	0.088ab	0.137b	0.764b	0.370ab	1.29ab	4.158a	3.354a	4.88a	4.24ab	4.10b	4.34cb	9.65a
H	0.190b	0.081ab	0.146b	0.804ab	0.357b	1.34a	4.034a	3.797a	3.48b	1.86b	4.25ab	5.30b	9.32ab
S	1.241a	0.066b	0.152b	0.788ab	0.417a	1.24b	4.037a	3.794a	2.44c	2.53b	0.64c	6.44a	8.61b
LSD0.05	0.042	0.026	0.017	0.042	0.053	0.08	1.116	0.818	0.887	2.394	0.324	1.04	0.937
Nano-silica (NaSiPa)													
NaSi0	0.390a	0.742c	0.0953a	0.338c	0.165a	1.253	3.805b	3.343b	2.62c	1.91c	3.07b	3.87c	7.88c
NaSi100	0.400a	0.774bc	0.083ab	0.373bc	0.159a	1.270	3.994b	3.447b	3.02bc	3.28bc	3.37b	4.69b	8.23cb
NaSi200	0.391a	0.812ab	0.075bc	0.388ab	0.151ab	1.300	4.262b	3.935a	3.65ab	3.85ab	3.78a	5.38b	8.97b
NaSi300	0.409a	0.838a	0.068c	0.418a	0.137b	1.330	5.893a	4.353a	4.23a	5.22a	4.02a	6.43a	10.06a
$LSD_{0.05}$[&]	NS	0.064	0.014	0.041	0.016	0.069	1.194	0.420	0.871	1.595	0.342	0.715	0.867
ANOVA													
Stress	****	*	**	**	**	*	NS	NS	**	*	****	**	****
NaSiPa	NS	*	**	**	**	NS	**	***	**	**	****	****	****
Stress* NaSiPa	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	***
CV%[&&]	8.23	10.79	22.83	14.34	13.75	7.22	30	14.95	30.57	29.99	12.88	18.83	13.23

[&]: **least significant difference (p>0.05)**

[$$]: **Coefficient of the variance %**

Na^+ content

The results showed that the effect of different shocks were in the following order D<F<H<S, whereas the concentration of Na^+ in the un-shock plant (C) was lower than in the other shocked plants, except in the roots and leaves. The results revealed that the accumulation of Na^+ in various cucumber tissues occurs in the following order: root > fruit > leaf under shock, the values of Na^+ content of roots, leaves, and fruits were for salinity (1.241, 0.066, and 0.152 %) > heat (0.190, 0.081, and 0.146%) frost (0.190, 0.088, 0.137 %) > drought (0.178, 0.075, 0.184%) > heat (0.190, 0.081 and 0.146%), and un-shock plants (0.189, 0.092, 0.145 %), respectively. The sodium concentrations in roots, leaves, and fruits increased with increasing NaSiPa rates, from 0.390 at NaSiP0 and 0.409 at NaSiP300, with no significant differences between them, whereas the Na^+ content in leaves ranged from 0.742 at NaSi0 to 0.838 at NaSi300, with a significant difference between treatments' means. Fruit sodium concentrations ranged between 0.068 at NaSiP300 to 0.095 at NaSiP0, with significant differences between treatment means. The addition of nano-silica reduced sodium accumulation in fruits while increasing sodium concentrations in roots and leaves. In terms of sodium content in cucumber tissue, the addition of NaSiPa rates reduced sodium content in roots, fruits, and leaves. In comparison to the control (NaSiP0), the decreasing percentage of sodium content of roots treated with 300 mg L^{-1} NaSiPs at control, drought, frost, heat, and salinity shocks was 11.33, 15.79, 16.42, 9.85 and -0.56%, respectively (Fig. 2a). The reduction % of leaves Na^+ concentration at each shock recorded in plants treated with NaSiP300 were 17%, 19.28%, 17.20%, 50%, and 33.75% for un-shock, drought, frost, heat, and salinity shock treatments, respectively, over the control treatment (NaSiP0) (Fig 2b).

Also, As comparison with control (0 mg L^{-1}NaSiPs) at control (unshock), drought, frost, heat and salinity shocks the decreasing percentage of sodium content of fruits treated with 300 mg L^{-1} NaSiPs was 32.64, 5.26, 16.99, 22.15 and 2.44%, respectively(Fig. 2c).

K^+ content

In control and salinity, drought, frost, and heat-shocked plants, the accumulation of K^+ was greater than the accumulation of Na^+ in the different cucumber tissues, namely root, leaf, and fruit (Figure 2a, b, and c). The results showed that K^+ accumulates in cucumber tissues in the following order: fruit > root > leaf. Under shock, the K^+ content of roots, leaves, and fruits was 0.820, 0.362, 1.34% (control), 0.780, 0.391, 1.23% (drought), 0.764, 0.370, 1.29 (frost), 0.804, 0.357,1.34% (heat), and 0.788, 0.417, 1.24% (salinity). The K^+ content in control and drought, frost, heat salinity-shocked plants exhibits a dose-response relationship to NaSiPs in all tissues except salinity-shocked plant fruit. The K^+ content increased as the NaSiPs dose was increased. The effects of different shock treatments on roots were found to be in the following order: C (0.820) > H (0.804) > S (0.788) >D (0.780) > F (0.764%), whereas the concentration of K^+ in leaves was found to be in the following order: S (0.417) > D (0.391) > F (0.370) < C (0.362) < H (0.357%). And the K^+ content of the fruits was in the following order C (1.34) = H (1.34) > F (1.29) > S (1.24) > D (1.23%). Except for the roots and leaves, the un-shocked plant (C) was less than the other shocked plants.

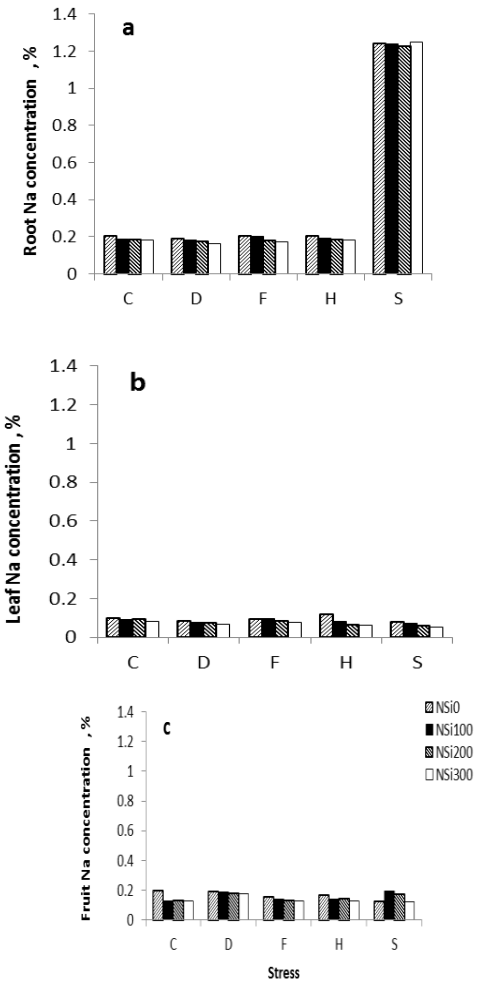

Fig. 2. Sodium concentration, Na % in roots, leave, and fruits of cucumber under the interaction between nano silica (NaSiP0= zero Si, NaSiP100= 100 ppm Si, NaSiP200= 200 ppm Si , and NaSiP300= 300 ppm Si) and stress(C=without stress, D = drought, F = frost, H = heat, and S= salinity).

The application of nano-silica increased the K^+ content in roots and fruits, but had the opposite effect on the leaves. In comparison to the control control (NaSiP0), the increasing percentage of K^+ content of roots treated with 300 mg L^{-1} NaSiPs was 5.10%, 21.82, 16.87, 6.72, and 6.53%, respectively (Fig. 3a). The increasing % of leaves K^+ concentration at each shock recorded in plants treated with NaSiP300 were 8.62, 16.98, 11.75, 44.39, and 12.04% for un-shock, drought, frost, heat, and salinity shock treatments, respectively, over the control treatment (NaSiP0) (Fig 3b).

Also, As comparison with control (NaSiP0) at control (unshock), drought, frost, heat and salinity shocks the increasing percentage of K^+ content of fruits treated with NaSiP300 was 2.94, 10, 11.03, 3.62, and -0.81%, respectively(Fig. 3c).

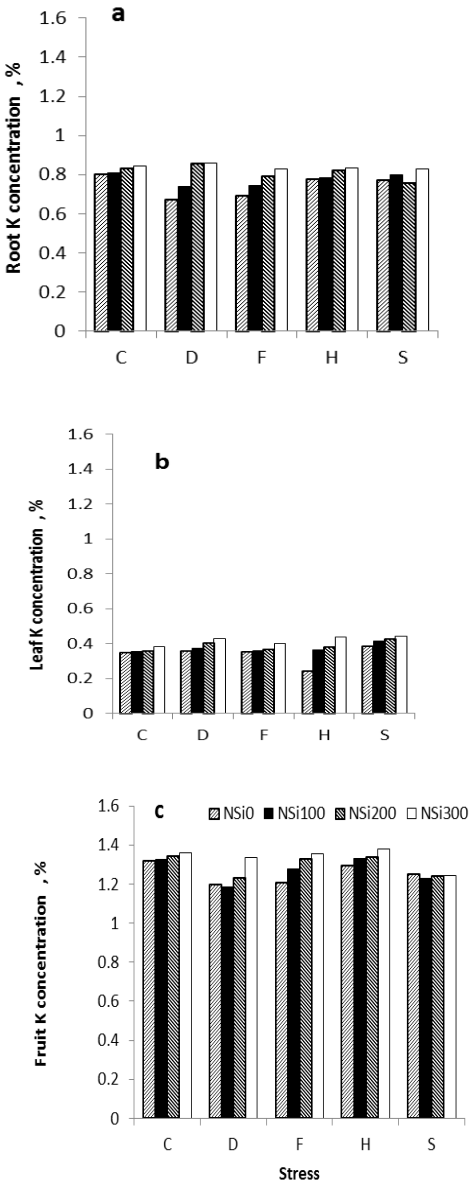

Fig. 3. Potassium concentration, K^+ % in roots, leave, and fruits of cucumber under the interaction between nano silica (NaSiP0= zero Si, NaSiP100= 100 ppm Si, NaSiP200= 200 ppm Si, and NaSi300= 300 ppm Si) and stress(C=without stress, D = drought, F = frost, H = heat, and S= salinity).

Silicon content, Si %

The Si content of roots (SiR) was higher than Si content of the leaves (SiL) (Table 2). The results revealed that there were no significant effects of different shock treatments on the Si content of cucumber root and leaves. SiR was 5.011 (C), 4.397 (D), 4.158 (F), 4.034 (H), and 4.037% (S) while SiL were 4.128 (C), 3.776 (D), 3.354 (F), 3.797 (H), and 3.794 % (S). With increasing NaSiPa doses, the SiR and SiL content increases significantly. The mean SiR values ranged from 3.805% at NaSiP0 and 5.893% at NaSiP300, while the SiL values ranged from 3.805% at NaSiP0 and 5.893% at NaSiP300. In comparison to the control (NaSi0), the increasing percentage of SiR content treated with SiNP300 was 152.24, 26.12, 66.20, 15.37, and 34.39% at each control, drought, frost, heat, and salinity shock, respectively (Fig. 4a). Similarly, the increasing percentage of SiL content treated with SiNP300 was 33.61%, 17.82, 11.88, 74.63, and 22.29%, respectively (Fig. 4b).

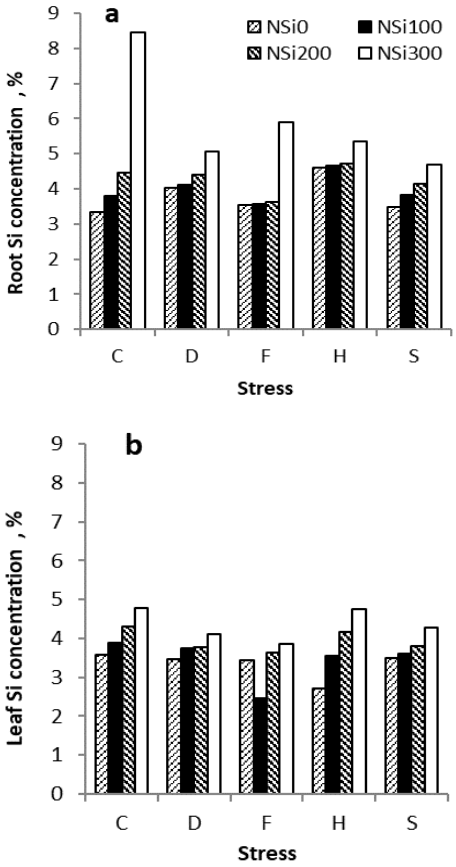

Fig 4. Silicon concentration, Si % in roots, and leave of cucumber under the interaction between nano silica (NSiP0= zero Si, NSiP100= 100 ppm Si, NaSiP200= 200 ppm Si, and NaSiP300= 300 ppm Si) and stress(C=without stress, D = drought, F = frost, H = heat, and S= salinity).

Proline concentration, %

The effects of different shocks on proline content in roots (PR) were found to be in the following order: F (4.88%) > H (3.48%) > D (3.10%) > C (2.99%) > S (2.44%) whereas the concentration of leaf (PL) was C (6.16%) > F (4.24%) > D (3.03%) > S (2.53%) > H (1.86%). The effect of the chock treatments on the proline content of cucumber plant roots and leaf tissues were found to be significant. The proline content in roots and of cucumber plant roots and leaf tissues were found to be significant. Proline concentrations in roots, and leaves increased with increasing NaSiPa rates, from 2.62% at NaSiP0 and 4.23% at NaSi300 for roots, with significant differences between treatments, and from 1.91% at NaSi0 to ٥,٢٢% at NaSi300 for leaves, with significant differences between treatments. The addition of nano-silica increased proline accumulation in leaf more than it did in roots (Table 2). In comparison to the control (NaSi0), the decreasing percentage of proline content of roots treated with 300 mg L^{-1} NaSiPs at control, drought, frost, heat, and salinity shocks was 11.33, 15.79, 16.42, 9.85, and -0.56 percent, respectively (Fig. 2a). The

reduction % of leaves Na^+ concentration at each shock recorded in plants treated with NaSiP300 were 17%, 19.28%, 17.20%, 50%, and 33.75% for un-shock, drought, frost, heat, and salinity shock treatments, respectively, over the control treatment (NaSiP0) (Fig 2b).

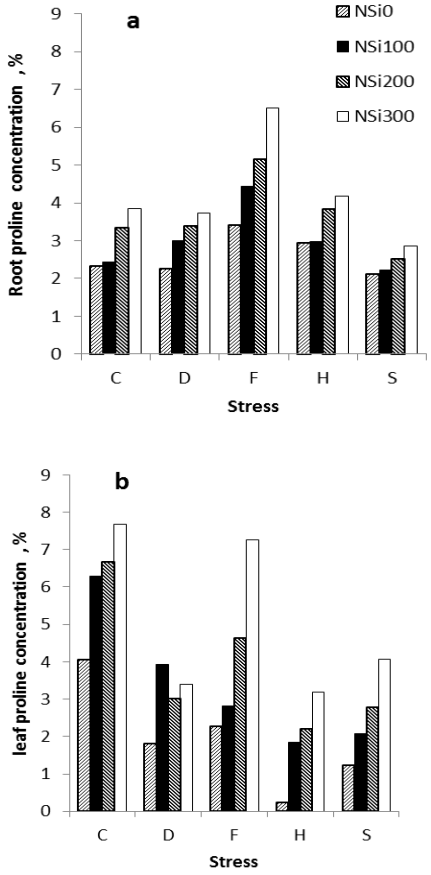

Fig. 5. Proline concentration, Si % in roots, and leave of cucumber under the interaction between nano silica (NaSiP0= zero Si, NaSiP100= 100 ppm Si, NaSiP200= 200 ppm Si , and NaSi300= 300 ppm Si) and stress(C=without stress, D = drought, F = frost, H = heat, and S= salinity).

Potassium sodium Ratio in roots, leaves, and fruits

The data in Table 2 showed that the K^+/Na^+ of different tissues of cucumber significantly differed between the shock treatments. The differences in the effect of different shocks differed according to the type of tissues. Results showed that the K^+/Na^+ in different cucumber tissues is in the following order: Fruit > leaf > root. The values of K^+/Na^+ content of roots, were 4.45 (D) > 4.37 (C) > 4.25 (H) > 4.10 (F) > 0.65 (S). While, these ratios values in leaf were 6.44 (S) > 5.32 (D) > 5.30 (H) > 4.34 (F) >4.08 (C). In Fruit the ratio values was 9.65 (F) > 9.56 (C) > 9.32 (H) > 8.61 (S) > 6.78 (D). The K^+/Na^+ ratio in roots, leaves, and fruits increased with increasing NaSiPa rates from 3.07 at NaSiP0 and 4.02 at NaSiP300 for roots, while in leaf, the K^+/Na^+ content ranged from 3.87 at NaSi0 to 6.40 at NaSi300. The K^+/Na^+ of fruits varied from 7.88 at NaSiP0 to 10.06 at NaSiP300. The treatment of 300 mg L^{-1} NaSiPs treatment resulted in the highest K^+/Na^+ ratio in all plant tissues. All SiNPs treatments displayed significantly higher K^+/Na^+ ratio than control (0 mg L^{-1} NaSiPs) in all different plant organs of plants grown in the presence or absence of shock, except the treatments of 100 and 200 mg L^{-1} NaSiPs that showed lower ratios in fruit tissue (Figure 6c). As comparison with control (NaSiP0) at control, drought, frost, heat and salinity shocks K^+/Na^+ of roots treated with 300 mg L^{-1} NaSiPs was 17.04, 44.92, 30.36, 19.27 and 0, respectively (Fig. 6a). The leaf K^+/Na^+ ratio at every shock recorded in plants treated with NaSiP300 were 13.24, 60.03, 45.87, 144.19, and 60.49 for un-shock, drought, frost, heat, and salinity shock treatments over the control treatment (NaSiP0) at every shock treatment, respectively (Fig. 6b). Also, in comparison with control (0 mg L^{-1}NaSiPs) for control (un-shock), drought, frost, heat, and salinity shock treatments the increase percentage of K^+/Na^+ of fruits treated with 300 mg L^{-1} NaSiPs was 55.64, 17.30, 37.11, 32.09 and 4.46%, respectively (Fig. 2c). The higher increasing K^+/Na^+ ratio was in roots of plants treated with drought shock, while the higher increase of this ratio in leaf was in treated plants with heat shock. In fruit, the higher increase of K^+/Na^+ ratio was in untreated plants with shock.

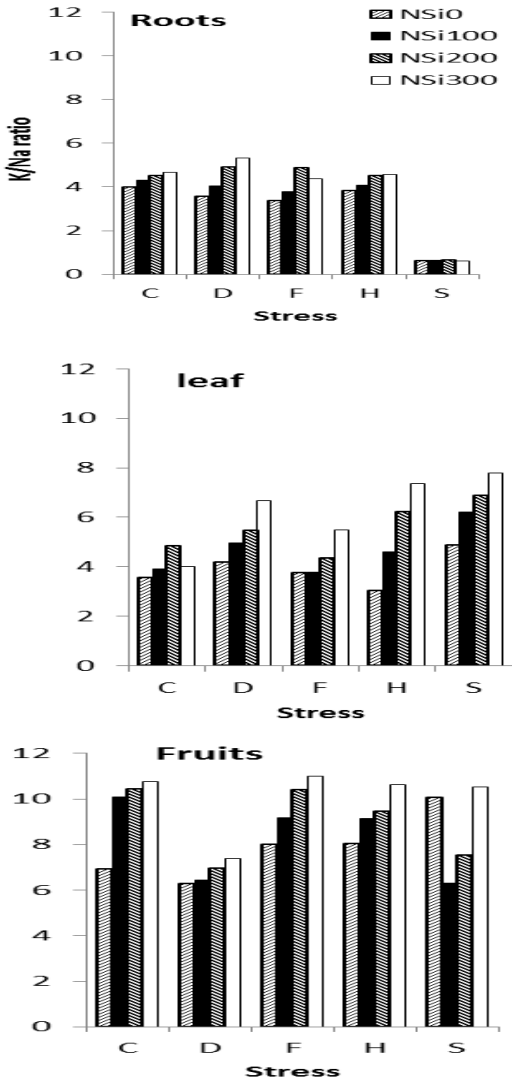

Fig. 6. K^+/Na^+ ratio in roots, leave, and fruits of cucumber under the interaction between nano silica (NaSiP0= zero Si, NaSiP100= 100 ppm Si, NaSiP200= 200 ppm Si, and NaSiP300= 300 ppm Si) and stress(C=without stress, D = drought, F = frost, H = heat, and S= salinity).

Discussion

The different shocks have strong effect on the Na^+, K^+, K^+/Na^+ ratio in cucumber plant roots, leaf, and fruits, as well as Si and proline cucumber plant roots and fruits. These shock effects have been reflected in the plant's biometrics.. The findings revealed that the drought, saline, heat, and frost shocks have different effects on the cucumber plant's biometric measurements. As a result, the yield of shocked plants was lower than the yield of un-shocked plants.

The findings of this study agree those of Barlow *et al* (2015). They stated that the effect of temperature extremes, frost, and heat have different effects on wheat (Triticum aestivum L.). Their findings revealed that frost caused sterility and abortion of formed grains, whereas excessive heat reduced grain number and duration of the grain-filling period .If these changes of environmental shocks on plants are expected, understanding the potential impacts on plant growth and development will aid in the development of adaptation strategies to mitigate these impacts. The shocks influenced cucumber yield, with yield decreases of approximately 3.65, 5.95, 12.85, and 15.91% compared to the control treatment for various salinity shocks.

The decrease in yield is caused by changes in plant metabolism, physiological, and biochemical processes. This is consistent with the findings of Lobato *et al*., (2007) and Singh (2014), who found that environmental shocks such as high winds, low or high temperatures, soil salinity, drought, or flooding can have an impact on crop production in the line of Shahbaz and Ashraf (2013).

The addition of nano-silica particles modified the effect of shocks on the cucumber plant, increasing K+, K+/Na+ ratio, Si, and proline in cucumber tissues while decreasing Na with increasing the rate of NaSiPs, which reflect on yield due to increased chlorophyll and leaf area. According to Alsaeedi *et al*., (2018) and Pilon *et al.* ,(2018), these findings support the idea that silicon plays an important role in protecting plants from various biotic and abiotic stresses, such as diseases, pets, drought, salinity and heavy metals toxicity, as well as restoring nutritional balance Pilon *et al*., (2013). The addition of the NaSiP300 rate at various shocks decreased Na+ content while increasing K+ content, K+/Na+ ratio, Si, and proline in various parts of the cucumber plant. Heidari *et al*., (2011) and Kolupaev *et al*., (2016) conformed these findings, stating that proline modifies the plant's osmotic property against the risks of salinity and drought stresses, as well as other shocks. When plants are stressed by salinity or drought, proline accumulates more than other amino acids. K+ acts as a catalyst in many enzymes and cannot be replaced by Na+ to perform the same function. Because of its association with RNA, particularly, in ribosomes, high K+ concentrations are required to induces protein synthesis (Zhu, 2002).

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دور النانو سيليكا في تخفيف التأثير السلبي للصدمات المختلفة على نمو نبات الخيار

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الملخص

يهدف البحث الحالي إلى تحديد ماإذا كانت الملوحة في مياه الري والصقيع والجفاف والتلف الحراري للخيار يمكن تقليلها أو تجنبها باستخدام جزيئات (NaSiPs) النانو سيليكا المصنعة. بعد نقع البذور لمدة ٣ ساعات في معلق النانو سيليكا ، تم رش الشتلات بطول ١٥ سم في البيت المحمي بتركيزات مختلفة من NaSiPs (٠ ، ١٠٠ ، ٢٠٠ ، و ٤٠٠ مجم لتر-١). عندما وصل طول النبات إلى ٣٠ سم ، تم تطبيق معالجات الصدمة المختلفة. عند الحصاد، تم تحديد بعض المتغيرات الخضرية وكذلك التحليل الكيمياتي للنبات (الجذر، الأوراق، الثمار). أكدت النتائج أن NaSiPs كان لها تأثير معنوي في الحد من الآثار السلبية للصدمات المختلفة على القياسات الحيوية النباتية والكلوروفيل ومحصول الثمار. أوضحت النتائج أنه لا توجد آثار معنوية للتفاعل ثنائي الاتجاه بين معاملات الصدمة ومعدلات النانو سيليكا على القياسات الحيوية للنبات والكلوروفيل ومحصول الثمار. تم العثور على نفس التأثيرات لتركيزات الصوديوم والبوتاسيوم في الجذور والأوراق والثمار وكذلك السليكون والبرولين في الجذور والأوراق. باستثناء الصوديوم والبوتاسيوم في الأوراق و الثمار ، زادت جميع المتغيرات المدروسة مع زيادة معدلات النانو سيليكا ، باستثناء تركيز صوديوم الفاكهة وبوتاسيوم الأوراق. كان للصدمات الترتيب التالي: المقارنة> الملوحة> الصقيع> الجفاف> الحرارة. خفضت النباتات المعالجة بتركيز ٤٠٠ ملجم NaSiPs لتر-١ السلبية للصدمات المختلفة.