Influence of silicon treatments on some growth, physiological and biochemical traits of five Egyptian wheat varieties

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ABSTRACT

In Egypt there is a big gap between production and consumption of wheat. Hydroponically experiment was conducted in a randomized complete block design with three replicates. The herein experiment was carried out to study the effect of silicon (Si) treatments (0, 25, 50 and 100 mg/L) on some growth parameters, physiological, biochemical traits, some nutrients and Si content on different plants parts in five Egyptian wheat varieties (Gemmeza 7, Gemmeza 9, Gemmeza 11, Masr 1 and Giza 168). The results showed enhancing in all studied parameters. Moreover, the best effect of Si was observed when plants treated with 25 mg/L than the other treatments and control. The plants showed an improve in growth parameters by increasing in shoot length, flag leaf area, fresh, dry weights of shoot and root. Chlorophyll a, chlorophyll b, carotenoids, relative water content and membrane stability were higher in different wheat varieties treated compared to the control. The application of silicon had a biostimulative effect in some antioxidant enzymes and modulation inducible importance in polyphenol oxidase and proline in treated plants compared to control. Also, the plants treated by silicon showed increase of some nutrients content especially N, K, Ca, Mn, Cu and Fe, leading to increasing photosynthetic pigments content, flag leaf area, and amelioration of growth parameter. In conclusion, Si application could improve growth parameters, some nutrients content, and photosynthetic pigments content in five Egyptian wheat varieties.

Keywords: Growth parameters; Flag leaf; Chlorophyll; Antioxidant enzymes; Proline; Silicon.

INTRODUCTION

Wheat is the most important economic crop so that, we should improve the best amount and best content of the nutrients to give a good plant and yield. In Egypt, it is well known that there is a big gap between production and consumption of wheat. Undetected deficiency of micronutrients and useful nutrients would probably severely restrict food production. Silicon is the only known element that does not damage plants with excess accumulation. Although soluble silicic acid occurs in the range of 0.1-0.6 mM, most of the silicon is present in the soil as insoluble oxides or silicates. The International Plant Nutrition Institute (IPNI) added Si to its list of beneficial nutrients. Si has been recognized as an agronomically essential element in Japan. The essentiality of silicon for plant growth has long been a question of interest to plant nutrition researchers. Richmond and Sussman, (2003) stated that silicon is an essential micronutrient, and deficiencies significantly affect plant health. It was declared that foliar applications of Si (50 and 100 mg/L) resulted in greater shoot and total dry weight, plant height and leaf area of calendula plants specialist under salt stress because the benefits of Si are due to the reduction of Na content in the shoots, (Hassan *et al.*, 2013). Ratnakumar *et al. (*2016) demonstrated that Si treatments increased photosynthesis pigments (chlorophyll a, b and total carotenoids) as well as chlorophyll stability index (CSI) in different wheat cultivars under drought conditions. (Liang *et al.*, 2007) found that, silicon-treated plants had decreased membrane lipid peroxidation, leading to greater membrane stability enhanced leaf water potential specialty under stress condition. Lee *et al. (*2010) they reported that Si slightly decreased antioxidant activity, decreased abscisic acid and proline. Pang *et al. (*2019) demonstrated that Si could be enhanced the growth plant through improvement the nitrogen metabolism and signaling of phytohormones.

The main goal of this research is to study the effect of silicon treatments on plant growth, physiological, biochemical parameters and some nutrient contents of five Egyptian wheat varieties.

MATERIALS AND METHODS

Experimental design

A hydroponic culture experiment was conducted in a randomized complete block design with three replicates, at the growth room in laboratory of plant physiology, Faculty of Agriculture, Al-Azhar University-Cairo- Egypt. 40 grains for each treatment at three replicates were planted in water culture (Hoagland's nutrient solution) in plastic pots, with silicon concentrations treatments (0, 25, 50 and 100 mg/L).

Hoagland's nutrient solution

"Used as macronutrient sources, KH_2PO_4 (0.74M) – KNO_3 (1M) – $Ca(NO_3)_2.4H_2O$ (0.42M) and $MgSO_4.7H_2O$ (0.41M). For micronutrient sources H_3BO_3 (8.87mM) – $MnCl_2.5H_2O$ (1.77mM) – $ZnSO_4.7H_2O$ (0.31mM) – $CuSO_4.5H_2O$ (0.32mM) – $(NH_4)_6MO_7O_2.4H_2O$ (0.026mM) and $FeSO_4.7H_2O$ (2.59 mM)" (Hoagland and Arnon, 1950).

Five Egyptian wheat varieties

G7= Gemmeza 7, G9= Gemmeza 9, G11= Gemmeza 11, MS = Masr 1 and GZ = Giza 168.

Treatments of silicon

The experiments were carried out to study the effect of different concentrations of silicon treatments (as potassium silicate) were 25, 50 and 100 mg/L beside the control. Seedlings were grown for about 33 days in Hoagland strength solution. The different growth parameters (shoot length, flag leaf area, fresh and dry weight) were measured. Also, physiological and biochemical parameters were determined (photosynthetic pigments, relative water content, membrane stability, antioxidants enzymes activity and proline content). The plants were divided to shoot and root to determinate some nutrient elements (N, P, K, Ca, Na- Fe, Cu, Mn, Zn) and Si content in different tissues of plants.

Growth parameters measurements

Shoot length (cm): A sample of 10 plants / Pot was randomly taken at (33 days from planting) from surface of water media to top of flag leaves.

Flag leaf area (cm^2): It was calculated by the formula (length × maximum width × 0.75)

Fresh and dry weights of shoot and root (g): Average of 10 plants was randomly determined.

Physiological and biochemical parameters determination

photosynthetic pigments content (chl.a, chl.b and carotenoids)

Fresh leaves samples (0.1g) homogenized in 6 mL (90%) aqueous methanol solution and leaved for 3 hours. The analytical determination was performed with spectrophotometer at the following wavelengths: 666, 653 and 470 nm for chlorophyll a, b and Carotenoids respectively and the amount of these pigments was calculated according to the formulas of Lichtentaler and Wellburn (1985).

Chl *a* =15.65 A666 - 7.340 A653
Chl *b* =27.05 A653 - 11.21 A666
Carotenoids = 1000 A470 - 2.860 Chl.a - 129.2 Chl.b/245.

Relative water content (RWC)

The estimation of leaf RWC was conducted by incubating fresh leaf samples (0.1g) in 20 ml distilled water for 4h according to (Weatherley, 1950).

RWC = (fresh weight - dry weight) / (turgid weight - dry weight) ×100.

Membrane stability index (MSI)

MSI was determined according to the method of Sairam and Tyagi (2004).

Antioxidant enzymes assay

Tissue preparation for antioxidant enzymes

Fresh leaves samples (0.2 g) were ground in liquid N_2 and homogenized in an ice-bath in 4 ml homogenizing solution containing 50 mM potassium phosphate buffer and 1% (w/v polyvinyl pyrrolidone (pH 7.8). The homogenate was centrifuged at 14000 rpm at 4 °C for 10 min and the resulting supernatant was utilized for enzyme activities.

Assay of Catalase activity

Catalase action was precise according to the method described by (Aebi, 1984). The enzyme activity was accounted by calculating the quantity of decomposed H_2O_2.

Assay of Peroxidase activity

The determination of Peroxides activity at 420 nm the test solution was prepared by mixing 0.03 mL of enzyme solution with 1.57 mL of 100 mM potassium phosphate buffer, pH 6.0 (at 20°C), 0.3 mL of 5% (w/v) pyrogallol solution, 0.10 mL of 0.50% (w/w) hydrogen peroxide solution (H_2O_2). Peroxidase activity was measured by the method of Chance and Maehly, (1955).

Assay of Polyphenol oxidase activity

The determination of polyphenol oxidase activity was done according to the method Duckworth and Coleman, (1970) at 420 nm at 25 °C.

Estimation of proline content

Proline was extracted from 0.2 g fresh leaf tissues homogenized in 4 mL 3% aqueous sulfosalicylic acid using the method described by Bates *et al.* (1973).

Nutrient determination

At 33 days from planting, the plants were harvested. Plant samples were collected washed with distilled water and divided into shoot and root., dried at 70 °C; then representative portions were wet digested using $HClO_4$ and H_2SO_4 acids to determine some nutrients and (Si) content in plants parts.

Total N was determined by micro-Kjeldahl technique while total P was determined by ascorbic acid method. Additionally, total K was determined using flame photometer; Si, Ca, Mg, Na, Fe, Cu, Mn, Zn were determined by Inductively Coupled Plasma Spectrometer (ICP) plasma 400; According to Page *et al. (*1982). The obtained data were statistically analysis according to Sendecor and Cochran (1980) method.

RESULTS AND DISCUSSION

Effect of silicon treatments on growth parameters

All growth parameters as shoot length, flag leaf area, shoot and root fresh and dry weights were illustrated in (Table 1) on tested varieties as affected by different concentrations of Si treatment.

Effect of (Si) treatments on shoot length and flag leaf area

The data revealed that growth performance of the five wheat varieties were significantly affected, depending on the level of silicon concentration (Table 1) when compared with control. The shoot length gradually increased with increasing silicon levels from 0 to 100 mg potassium silicate for all the five wheat varieties. The best length of shoot was recorded in general with 25 mg/L potassium silicate after 33 days from planting for the Gemmeza varieties, but the maximum shoot length for Masr1 (MS1) and Giza 168 (GZ) were observed with 50 mg potassium silicate, respectively. Gemmeza 11 variety gave highest shoot length (28.2 cm) when compared with the other varieties under same concentration. The application of silicon increased the flag leaf area in all different wheat varieties used. The increasing of flag leaf area recorded in major wheat varieties with 25 and 50 mg/L of Si respectively (Table 1), the increasing ranged between (0.3: 0.8 cm^2). The best value was observed with (G9) which recorded 5.8 cm_2 and the minimum values were recorded with 100 mg/L of Si treatment.

Effect of (Si) treatments on shoot and root fresh and dry weight

The results in Table (1) indicated that Si treatment led to increase the fresh and dry weights in both shoots and roots of all wheat varieties. The best effect of Si treatment was observed when plants treated with 25 mg/L Si than the other treatments. As for fresh and dry weight, plants treated with 25 mg/L of Si had the highest fresh and dry weight in shoot and root with all varieties, except G9 which gave maximum value (0.52 and 0.14 g/plant) in fresh and dry weight shoot respectively, at 50 mg/L. But the results were significantly different with plants treated at 50 and 100 mg/L of Si. Our results agree with Bakhat *et al.*, 2009 and Somayeh *et al. (*2019) as they found that application of Si enhanced growth and resulted in an increase the leaf area, leaf thickness and dry mass of wheat plant. Gong *et al.* (2003) found that 7.14 mmol Na_2SiO_3 per 8 kg of soil resulted in an increase in wheat leaf area of 8.3 cm^2 per plant, an increase in dry mass of 45.3 mg per plant, and an increase in leaf thickness. Also, Hassan *et al.* (2013) and Pang *et al.* (2019) found that Si application enhanced Gibberellins (GA), which affects on cell enlargement and division, consequently lead to internodes elongation in stems and increases stem height. On the other hand, Bakhat *et al.* (2009) found that 3 mM Na_2SiO_3 supplied in hydroponic solution reduced leaf area and caused no significant increase in dry mass.

Effect of (Si) treatments on physiological and biochemical traits

Data recorded in Tables (2 and 3) explained the efficiency of Si treatments on (photosynthetic pigments, relative of water, stability of membrane, antioxidants enzymes activity, proline content) of tested wheat varieties as affected by different rates of Si treatment.

Effect of (Si) treatments on photosynthetic pigments content

The results illustrated in Table (2) showed that the chlorophyll a and b content increased with Si treatments when compared with control. Gemmeza varieties and MS1 showed the highest value with 100 mg/L. Gemmeza 9 and (GZ) gave the highest responding (31.73 and 29.53 mg/g FW) by Si treatment with 100 and 25 mg/L of Si treatments, respectively. Also, the best content of chlorophyll b was observed with GZ (14.85 mg/g FW) at 50 mg/L of silicon. It was found that the rate of 25 mg/L Si treatment gave relatively highest effect on carotenoids content in all wheat varieties, (G9 then GZ) variety gave the highest value (1.42 and 1.57). These results were in accordance with Nabati *et al.* (2013) who demonstrated that chlorophyll content is an important factor in plant productivity because it is directly proportional to the photosynthesis rate of plant for biomass production. (Si) treatment led to delays leaf senescence and increases chlorophyll content and ribulose, 1-5- bisphosphate carboxylase activity. Kaya *et al.* (2006) found that 2 mM Na_2SiO_3 increased chlorophyll content by 125 mg ml^{-1} greater than well-watered plants. Also, Lee *et al. (*2010) found the addition of 2.5 mM (Si) to hydroponically grown soybean plants increased chlorophyll content. Similarly, Si foliar application on wheat increased leaf chlorophyll content (Ratnakumar *et al*., 2016). Meantime Hasanuzzaman *et al. (*2018) various studies have exposed that by absorbing (Si), photosynthetic pigments can be increased in various plant species.

Effect of (Si) treatments on relative water content

Data in Table (2) showed that the effect of Si treatments on water content of different wheat varieties. It was clearly noticed that the increasing in water content of different wheat varieties depended on the concentration of Si supply. The highest value of relative water content was observed with G7 variety which recorded (80.70 %) at 100 mg/L of silicon treatment. Gong *et al. (*2003 and 2005) found that Na_2SiO_3 supplied to the soil resulted in an increase in leaf relative water content and an increase in leaf water potential. Similar conclusion was obtained by Gao *et al. (*2006) noticed that the addition of Si increased water use efficiency by reducing leaf transpiration because silica-cuticle double layer formed on leaf epidermal tissue, the water flow rate in the xylem vessel and increased leaf water potential in potted wheat. Also, Sattar *et al*. (2017) stated that application of Si enhanced the osmotic, relative water contents, turgor and water potential of wheat (*T. aestivum*) flag leaf, deposition of (Si) on leaf surface might reduce transpiration through controlling molecules of water.

Effect of (Si) treatments on stability of membrane

The results in Table (2) showed that increasing stability of membrane in wheat plants treated by Si. The best effect of silicon concentration on stability of membrane showed by 25 mg/L treatment when compared with the other treatments beside control. G9 and MS1 varieties showed highest stability (4%) when compared with the other varieties. Our results agree with Gong *et al. (*2005) and Sattar *et al. (*2017) who stated that silicon appears to be involved in the fortification of plants against oxidation of cell membranes, leading to the protection of cell structures than various plant structures. Liang *et al. (*2007) concluded that using Si leads to its deposition in cell membrane, certification and hardening beside decrease of membrane damage in shoots; without Si cell membrane is hurt and material leakage from cell to outside increases.

Effect of (Si) treatments on antioxidant enzymes activity

The results from Table (3) showed that the catalase activity significantly increased when increasing Si treatment as cleared in G9, GZ and G11 varieties. Moreover, peroxidase activity increased in gemmeza varieties, the 25 mg/L treatment had the best activity.

Nevertheless, peroxidase activity decreased in varieties (MS1 and GZ). Polyphenol oxidase activity decreased with increasing concentration of Si. The induction of antioxidant enzymes and their protective role of membranes caused increasing in the tolerance of plant to damages, these results agreement with Hussein and Abou-Baker (2014) they reported that Si partially offset the negative impacts and increased tolerance plants by enhancing SOD and CAT activities. Moreover, Karmollachaab *et al. (*2013) found that Si benefits to drought tolerance in wheat have been related to its effect on the antioxidant enzyme activity, Si alleviated oxidative stress, enhance membrane stability index and decrease electrolyte leakage under drought.

Effect of (Si) treatments on proline content

In Table (3), we observed decrease in proline content when treated wheat plants with Si, also, the rate of 25 mg/L of Si caused the lowest content of proline when compared with other treatments and control, but gemmeza 11 and masr1 recorded lowest content with 50 mg/L Si. Proline is frequently measured as an osmotic protector, which may be effective to support plants against of stress. Results obtained by Shen *et al. (*2010) and Lee *et al. (*2010) stated that the addition of 25 mg/L Si to hydroponically grown soybean plants decreased proline and abscisic acid.

Effect of silicon treatments on Si and some nutrients content in shoot of wheat varieties

Data in Table (4) revealed that the silicon content was increased with increasing of silicon concentration treatments for shoots wheat varieties compared with control; the highest values of Si content were 25.1 mg/kg DW which obtained with MS1 variety at 50 mg/L concentration treatment compared to other treatment for wheat varieties. While, the lowest values of silicon content were obtained at control for five shoots wheat varieties. These results are in conformity with the results of Patil *et al. (*2018) who stated that the higher silicon uptake was associated with increased levels of silicon; this might be due to the increase in root growth and available form of silicon in soil, the addition of silicate material to soil and increased in silicon availability might have been the reason for higher silicon uptake. Also, the application of silicon leads to improvement in crop stand, enhanced photosynthesis and resistance against biotic stress. These are the certain other factors might have responsible for higher silicon uptake by plants.

Concerning the effect of silicon on nitrogen, phosphorus, potassium calcium and sodium content of five shoots wheat varieties, data presented in Table (4) showed that, the uptake of nutrients under all treatments was significantly increased in shoots, excluding sodium and some treatments of phosphorus uptake, compared with control. The highest values of nitrogen being 3.60, 3.40, 3.60, 3.70 and 3.60 % which obtained at 25 mg/L Si treatments for G9, G7, G11, MS1 and GZ wheat varieties respectively, additionally the highest values of potassium were 4.11, 3.72, 4.23, 3.79 and 4.14% which obtained at 100 mg/L Si concentration for G9, G7, G11, MS1 and GZ wheat varieties, respectively, compared with the lowest values of treatments and control. Also, the mentioned trend of nitrogen and potassium was observed for calcium. In this concern, Chen *et al. (*2002) stated that the N and K content were increased by increasing Si concentrations of shoots and grains of rice plant; while, Abou-Baker *et al. (*2011) found that, the nutrients concentration and uptake were significantly affected with foliar treatment silicate and sulphate solutions. These results may be attributed that Si plays an active role in the biochemical processes of plant and also may plays an important role in the intercellular synthesis of organic compounds (Matichenkov *et al.*, 2008). A similar finding is reported by Tahir *et al. (*2006) whom reported that, the silicon concentration was positively correlated with potassium concentration in shoots and significantly increased concentration and uptake in leaves of wheat genotypes under normal and in saline environments.

Effect of silicon treatments on Si and some macronutrients content in root of wheat varieties.

Data presented in Table (5) showed that the silicon content in roots was higher comparing to silicon content of shoots. In this concern, Maria *et al. (*2018) stated that, silicon influences soil availability and accumulation of mineral nutrients in various plant species; and found that, the concentration of Si was increased more in roots than in shoots at lettuce and wheat plants. Also, the silicon content was increased with increasing the treatments of wheat roots varieties

excluding G11 varieties, compared with control; the values of Si content were 43.5, 46.4, 49.2, 46.5 and 53.3 mg/kg DW obtained with G9, G7, G11, MS1 and GZ varieties, respectively, compared to control. With regard to the effect of silicon on nitrogen, phosphorus, potassium calcium and sodium content of roots wheat varieties, data presented in Table (5) showed that, the uptake of nutrients under all treatments was significantly increase in roots, excluding sodium and some treatments of Si on phosphorus uptake, compared with control. These results are in harmony with Siam *et al.* (2018) who stated that, the N, P and K uptake by the different parts of rice plant (roots, shoots and grains) significantly increased by Si addition.

Concerning the decreasing of P content in roots as a result of Si addition may be due to the high amounts of Si content in the roots; which may partial by substitute for phosphorus. Although the partial substitution of Si for P in physiological processes is doubtful, an interaction between Si and P in plants may occur Hinman and Lindstrom (1996). Additionally, Kabata-Pendias (2001) suggested that silicate and phosphate ion compete for sites on mineral soil particles. These results a good agreement with those obtained by Lux *et al.* (2003), who stated that silicon deposited on the roots and/or Si induced decrease in transpiration may be responsible for the decreased uptake of P when the P concentration in the medium is high; Si has been found to be deposited in the endodermal cells of roots in many plant species. Regarding for decreases of sodium, Ahmad *et al.* (1992) reported that 0.33 mM silicon supplied to salt-stressed wheat reduced leaf sodium content, but had no effect on chlorophyll content. While, Ahmad (2013) found that, the application of potassium silicate led to reduced sodium uptake and increased potassium uptake.

Effect of silicon treatments on micronutrients content in shoot of wheat varieties.

Data tabulated in Table (6) reveal that the micronutrients content were increased with increasing concentration treatments of five shoots wheat varieties compared to control; the highest values of Cu content were 46.7, 42.0, 41.1 and 46.5 mg/kg DW which obtained with 100 mg/L silicon treatments for G9, G7, MS1 and GZ wheat varieties, respectively, while the lowest values of Cu content were obtained at without treated control. In this concern, Gunes *et al.* (2008a) state that, the application of Si significantly improved Si, K, S, Fe, Cu, Mn and Cl uptake. Concerning the effect of silicon on iron, manganese and zinc content of five shoots wheat varieties, data presented in Table (6) showed that, the uptake of these nutrients under all treatments was significantly increase in shoots, excluding zinc at G7 variety compared to control.

Results a good agreement with those obtained by Gunes *et al.* (2008a) and Maria, *et al.* (2018) studied that, silicon influences soil availability and accumulation of mineral nutrients in various plant species; and found that, the obtained results were the concentration of Mn, Fe and B increased with Si treatment of wheat plant. They added that, the effect of Si was influencing the available fraction of elements in various soil types, as well as direct effect on the nutrient uptake from nutrient solution.

Effect of silicon treatments on micronutrients content in roots of wheat varieties.

Data in Table (7) summarized that, the micronutrients content were increased with increasing Si treatments of five roots wheat varieties compared with control; the values of Cu content were 52.7, 49.6, 59.3, 49.4 and 51.1 mg/kg DW at without treated control; and increased to 59.0, 61.0, 69.6, 61.1 and 57.3 mg/kg DW at 50 mg/L silicon treatment for G9, G7, G11, MS1 and GZ wheat varieties, respectively. This results agreement with results obtained by, Gunes *et al.* (2008b).

Concerning the effect of silicon on iron, manganese and zinc content of five shoots wheat cultivars, data presented in Table (7) showed that the uptake of these nutrients under all treatments was randomly increase in roots; this effect might be attributed to the antagonistic or compotation (interactions) effects of these nutrients and silicon. Sajal *et al.* (2018) showed that translocation of micronutrients, particularly zinc (Zn) and iron (Fe), may be affected by (Si) fertilization in rice by the probable mechanisms: (1) binding sites for Zn and Fe may be occupied by silicon; (2) chelation of Fe by Si induced biosynthetic chelates and (3) Silicon improves citrate concentration controlling long distance transport along with utilization of Fe in leaves.

Conclusion

From our previous results, it could be concluded that, the application of Si in hydroponic culture will improve physiological and biochemical parameters. The growth parameters will be substantially improved as Si is thought to keep the best results. The results obtained so far indicates that Si applied at 25 mg/L as topdressing at the vegetative stage was optimum and indeed has a beneficial effect that enhances the growth and development of the five wheat varieties. The application of silicon has a biostimulative effect in some antioxidant enzymes and modulation inducible importance in polyphenol oxidase and proline in plants treated compared to control. Also, silicon treated plants showed significant increase some nutrient uptake leading to increase in photosynthetic pigments content, flag leaf area, and amelioration of growth parameter. Some modification importance in K and Na contents, that is when potassium increased was sodium decreased in the five wheat varieties with increasing silicon concentration treatments, that is logically indicate the plant have best osmoprotection and more tolerance for some stress conditions.

REFERENCES

Abou-Baker, N.H., Abd-Eladl, M., Abbas, M., 2011. Use silicate and different cultivation practices in alleviating salt stress effect on bean plants. Aust. J. Basic appl. sci., 5 (9), 769-781.

Aebi, H. 1984. Catalase *in Vitro*. Method Enzym. 105, 12126.

Ahmad, B., 2013. Interactive effects of silicon and potassium nitrate in improving salt tolerance of wheat. J. Integr. Agric. 13 (9), 1889-1899.

Ahmad, R., Zaheer, S., Ismailm S. 1992. Role of silicon in salt tolerance of wheat (*Triticum aestivum* L.). Plant Sci., 85, 43-50.

Ahmed, M., Hassen, F., Qadeer, U., Aslam. M.A., 2011. Silicon application and drought tolerance mechanism of sorghum. Afr. J. Agric. Res. 6, 594-607.

Bakhat, H.F., Hanstein, S., Schubert, S., 2009. Optimal level of silicon for maize (*Zea mays* L. c.v. Amadeo) growth in nutrient solution under controlled conditions. The Proceedings of the International Plant Nutrition Colloquium XVI, Davis, CA.

Bates, L.S., Waklren R.P., Teare I.D., 1973. Rapid determination of free proline water stress studies. Plant Soil. (39), 205-207.

Chance B., Maehly A.C., 1955. Methods in Enzymology II, pp. 773-775.

Chen, J.H., Mao, G.J., Zhang G.P., Guo, H.D., 2002. Effects of silicon on dry matter and nutrient accumulation and grain yield in Hybrid Japonica rice (*Oryza sativa* L). J. of Zhejiang Unviersity (Agricutlure and life Science). (28), 22-26.

Duckworth H.W., Coleman J.E., 1970. Physicochemical and kinetic properties of mushroom tyrosinase. J. Biol. Chem. 245 (7), 1613-1625.

Gao, X., Zou, C., Wang L., Zhang F., 2006. Silicon decreases transpiration rate and conductance from stomata of maize plants. J. Plant Nutr., 29, 1637-1647.

Gong, H., Chen, K., Chen, G., Wang, S., Zhang, C., 2003. Effects of silicon on growth of wheat under drought. J. Plant Nutr. 26, 1055-1063.

Zhu, X., Chen, K., Wang, S., Zhang, C., 2005. Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci. 169, 313–321.

Gunes, A.D., Pilbeam, J., Inal, A., Coban, S., 2008a. Influence of silicon on sunflower cultivars under drought stress, I: growth, antioxidant mechanisms, and lipid peroxidation. Comm. Soil Sci. Plant Analysis, 39, 1885–1903.

Kadioglub, Y.K., Pilbeam, D.J., Inala, A., Cobana, S., Aksu, A., 2008b. Influence of silicon on sunflower cultivars under drought stress, II: essential and nonessential element uptake determined by polarized energy dispersive x-ray fluorescence. Comm. Soil Sci. Plant Analysis, 39, 1904–1927.

Hasanuzzaman, M., Nahar, K., Anee, T.I., Khan, M.I.R., Fujita, M., 2018. Silicon-mediated regulation of antioxidant defense and glyoxalase systems confers drought stress tolerance in (*Brassica napus* L.). South Afr. J. Bot., 115, 50–57.

Hassan B., Morteza A., Hossein N., Ali, A.S., 2013. Effect of silicon on growth and ornamental traits of salt-stressed calendula (*Calendula officinalis* L.). J. Ornamental Plants, 3 (4), 207-214.

Hinman, N.W., Lindstrom, R.F., 1996. Seasonal changes in silica deposition in hot spring systems. Chem. Geol., 132, 237-246.

Hoagland, D.R., Arnon, D.I., 1950. The water-culture method for growing plants without soil. Circular 347, Berkeley, CA: California Agricultural Experiment Station, pp 1-32.

Hussein, M.M., Abou-Baker, H.N., 2014. Growth and mineral status of moringa plants as affected by silicate and salicylic Acid under salt stress. Int. J. Plant Soil Sci., 3 (2), 163-177.

Kabata-Pendias, A., 2001. Trace elements in sois and plants, third edition. Taylor and Francis, Dec 12, 2010. Technol. Eng., p. 432.

Karmollachaab, A., Bakhshandeh, A., Gharinenh, M.H., Moradi, T.M., Fatahi, G., 2013. Effect of silicon application on physiological characteristics and grain yield of wheat under drought stress condition. Int. J. Agron. Plant Prod., 4 (1), 30-37.

Kaya, C., Tuna, L., Higgs, D., 2006. Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. J. Plant Nutr., 29, 1469-1480.

Lee, S.K., Sohn, E.Y., Hamayun, M., Yoon, J.Y., Lee, I.J., 2010. Effect of silicon on growth and salinity stress of soybean plant grown under hydroponic system. Agroforest. Syst., 80, 333-340.

Liang, Y.C., Sun, W., Zhu, Y.G., Christie, P., 2007. Mechanisms of silicon mediated alleviation of abiotic stress in higher plants: a review. Environ. Pollut., 147, 422-428.

Lichtenthaler, H.K., Wellburn, A.R., 1985. Determination of total carotenoids and chlorophylls a and b of leaf in different solvents, Biol. Soc. Trans., 11, 591-592.

Lux, A., Luxová, M., Abe, J., Tanimoto, E., Hattori, T., Inanaga, S., 2003. The dynamics of silicon deposition in the sorghum root endodermis, New Phytol., 158, 437-441.

Matichenkov, V.V., Bocharnikova, E.A., Kosobryukhov, A.A., Biel, K.Y., 2008. Mobile forms of silicon in plants. Doklady (Proceedings). Biol. Sci., 418, 39-40.

Maria G., Tommy L., Marek, V., 2018. Silicon influences soil availability and accumulation of mineral nutrients in various plant species. Plants, 7 (2), 41.

Nabati, J., Mohammad K., Ali, M., Mohammad, Z.M., 2013. Effect of salinity and silicon application on photosynthetic characteristics of sorghum (*Sorghum bicolor* L.). Int. J. Agric. Sci., 3 (4), 483-492.

Page, A.L., Miller, R.H., Keeny, D.R., 1982. Methods of soil analysis. Part π. Chemical and microbiological properties (2nd ed.) Amer. Soc. Agron. Monograph no. 9 Madison, Wisconsin, USA.

Pang, Z., Tayyab, M., Islam, W., Tarin, M.W., Sarfa-raz, R., Naveed, H., Zaman, S., Zhang, B., Yuan, Z., Zhang, H., 2019. Silicon mediated improvement in tolerance of economically important crops under drought stress. Appl. Ecol. Environ. Res., 17 (3), 6151-6170.

Patil, A.A., Durgude, A.G., Pharande, A.L., 2018. Effect of silicon application along with chemical fertilizers on nutrient uptake and nutrient availability for rice plants. Int. J. Chem. Stud., 6 (1), 260-266.

Ratnakumar, P., Deokate, P.P., Rane, J., Jain, N., Kumar, V., Berghe, D.V., 2016. Effect of ortho-silicic acid exogenous application on wheat (*Triticum aestivum* L.) under drought. J. Func. Environ. Bot., 6, 34-42.

Richmond, K.E., Sussman, M., 2003. Got silicon? The non-essential beneficial plant nutrient. Curr. Opin. Plant Biol., 6, 268-272.

Sairam, R.K., Tyagi, A., 2004. Physiological and molecular biology of salinity stress tolerance in plants. Curr. Sci. J., 86, 407-421.

Sajal, P., Susmit, S., Sushanta, S., Biplab, P., Bholanath, S., Hazra, G.C., 2018. Soil application of Silicon: Effects on economic yield and nutrition of phosphorus, zinc and iron in rice (*Oryza sativa* L.). J. Ind. Soc. Soil Sci., 66 (3), 329-335.

Sattar, A., Cheema, M.A., Abbas, T., Sher, A., Ijaz, M., Wahid, M.A., 2017. Physiological response of late sown wheat to exogenous application of silicon. Cereal Res. Commun., 45, 202-213.

Siam, H.S., Abd El-Moez, M.R., Holah, Sh.Sh., Abou Zeid, S.T., 2018. Effect of silicon addition to different fertilizer on yield of rice (*Oryza sativa* L.) plants. I- Macro Nutrients by Different Rice Parts. Middle East J. Appl. Sci., 8 (1), 177-190.

Shen, X., Zhou, Y., Dugn, L.L., Eneji, A.E., 2010. Silicon effects on photosynthesis and antioxidant parameters of soybean seedlings under drought and ultraviolet - B radiation. J. Plant Physiol., 167, 1248-1252.

Snedecor, G.W., Cochran, W.G., 1980. Statistical Methods, 6th Ed., The lowa State College, Ames, lowa, U.S.A.

Somayeh, S.R., Babak, M., Farhadm M., Hossein, M.H., Hossein, A.A., 2019. Silicon utilization efficiency of different wheat cultivars in a calcareous soil. Springer Nature, 11, 2159-2168.

Tahir, M., Rahmatullah, A., Aziz, T., Ashraf, M., Kanwal, S., Magsood, M.A., 2006. Beneficial effects of silicon in wheat (*Triticum aestivum* L.) under salinity stress. Pak. J. Bot., 38 (5), 1715-1722.

Weatherley P.E., 1950. Studies in the water relations of the cotton plant. New Phytol., 49, 81-87.

Table 1. Effect of silicon treatments on shoot length, flag leaf area, fresh and dry weights of shoot and root.

Parameters	Sitreatments mg/L	Varieties					
		G9	G7	G11	MS1	GZ	Mean
Shoot length (cm)	0	25.5	24.9	22.8	24.8	25.7	**24.7**
	25	28.2	27.1	25.6	25.6	26.8	**26.7**
	50	27.6	27.0	25.3	25.9	27.4	**26.6**
	100	26.5	25.9	24.9	25.2	27.2	**25.9**
	Mean	**26.9**	**26.5**	**24.6**	**25.4**	**26.7**	
Flag leaf area (cm^2)	0	5.2	4.3	4.6	4.3	5.2	**4.7**
	25	5.8	4.9	4.8	4.8	5.6	**5.2**
	50	5.5	5.1	4.8	4.3	5.3	**5.0**
	100	5.1	4.9	4.3	4.0	5.0	**4.7**
	Mean	**5.4**	**4.7**	**4.6**	**4.3**	**5.3**	
Shoot fresh weight (g/plant)	0	0.38	0.40	0.37	0.39	0.42	**0.41**
	25	0.51	0.49	0.49	0.51	0.51	**0.50**
	50	0.52	0.43	0.43	0.49	0.50	**0.47**
	100	0.28	0.45	0.31	0.38	0.43	**0.37**
	Mean	**0.45**	**0.44**	**0.40**	**0.44**	**0.43**	
Shoot dry weight (g/plant)	0	0.04	0.06	0.05	0.07	0.08	**0.06**
	25	0.12	0.11	0.11	0.13	0.11	**0.11**
	50	0.14	0.09	0.10	0.08	0.10	**0.10**
	100	0.04	0.07	0.04	0.07	0.08	**0.07**
	Mean	**0.08**	**0.08**	**0.07**	**0.09**	**0.09**	
Root fresh weight (g/plant)	0	0.13	0.15	0.12	0.08	0.11	**0.12**
	25	0.14	0.17	0.13	0.11	0.13	**0.14**
	50	0.11	0.12	0.09	0.09	0.11	**0.10**
	100	0.08	0.11	0.08	0.08	0.09	**0.09**
	Mean	**0.05**	**0.05**	**0.05**	**0.06**	**0.05**	
Root dry weight (g/plant)	0	0.03	0.03	0.02	0.01	0.02	**0.02**
	25	0.04	0.04	0.03	0.03	0.03	**0.03**
	50	0.03	0.02	0.02	0.02	0.02	**0.02**
	100	0.02	0.02	0.02	0.01	0.01	**0.02**
	Mean	**0.03**	**0.03**	**0.02**	**0.02**	**0.02**	

L.S.D at 0.05 level for:	Shoot length	Flag leaf area	Shoot fresh weight	Shoot dry weight	Root fresh weight	Root dry weight
Si	0.17	0.14	0.025	0.017	0.019	0.002
V	0.19	0.15	0.029	0.020	0.021	0.003
Interaction Si × V	0.39	0.31	0.057	0.039	0.042	0.006

Table 2. Effect of silicon treatments on chlorophyll a, b and carotenoids content (mg/g FW), relative water content and stability of membrane (%) of wheat varieties.

Parameters	Si treatments mg/L	Varieties					
		G9	G7	G11	MS1	GZ	Mean
Chlorophyll a content (mg/g FW)	٠	22.38	21.14	21.24	21.44	21.55	21.55
	25	25.36	26.80	24.48	22.03	29.53	25.64
	50	22.74	23.46	21.79	22.71	26.58	23.45
	100	31.73	26.16	25.24	27.04	22.72	26.57
	Mean	25.55	24.39	23.18	23.31	25.10	
Chlorophyll b content (mg/g FW)	٠	11.77	11.39	11.53	11.59	11.35	11.52
	25	13.51	13.78	13.52	12.27	11.19	12.85
	50	12.27	11.84	12.13	13.44	14.85	12.91
	100	13.84	13.76	14.29	13.45	12.27	13.52
	Mean	12.85	12.69	12.86	12.68	12.42	
Carotenoids content (mg/g FW)	٠	0.94	1.50	1.31	1.17	1.38	1.22
	25	1.42	1.55	1.39	1.35	1.57	1.46
	50	0.82	0.93	1.00	0.82	0.83	0.85
	100	0.64	0.90	0.65	0.70	0.82	0.75
	Mean	0.92	1.21	1.09	1.01	1.15	
Relative water content (%)	٠	66.69	70.28	64.39	66.85	68.55	67.35
	25	73.39	74.12	68.71	77.76	68.93	72.58
	50	75.11	72.97	72.25	77.37	70.12	73.56
	100	79.94	80.70	76.79	75.09	70.40	76.58
	Mean	73.78	74.51	70.53	74.26	69.50	
Stability of membrane (%)	٠	81.81	77.77	75.00	80.75	79.16	78.89
	25	85.18	78.57	78.78	84.00	80.00	81.30
	50	81.89	77.42	75.75	81.48	81.48	79.60
	100	78.78	80.00	76.19	80.94	80.64	79.31
	Mean	81.91	78.44	76.43	81.79	80.32	

L.S.D at 0.05 level for:	Chlorophyll a	Chlorophyll b	Carotenoids	Relative water content	Stability of membrane
Si	0.09	0.07	0.04	1.88	1.53
V	0.10	0.08	0.05	2.10	1.71
Interaction Si × V	0.19	0.15	0.10	4.21	3.42

Table 3. Effect of silicon treatment on antioxidant enzymes activity (Catalase, Peroxidase, Polyphenol oxidase) and proline content of wheat varieties.

parameters	Si treatments mg/L	Varieties					
		G9	**G7**	**G11**	**MS1**	**GZ**	**Mean**
Catalase	**٠**	100.00	100.00	100.00	100.00	100.00	**100.00**
	25	100.00	116.66	150.00	133.33	125.00	**124.99**
	50	200.00	100.00	133.33	100.00	140.00	**134.66**
	100	200.00	71.42	125.00	150.00	157.14	**140.71**
	Mean	**150.00**	**97.02**	**127.08**	**120.83**	**130.53**	
Peroxidase	**٠**	100.00	100.00	100.00	100.00	100.00	**100.00**
	25	96.23	108.05	145.52	57.03	70.34	**95.43**
	50	120.58	106.38	108.95	57.04	75.49	**93.68**
	100	113.82	108.00	116.44	60.45	96.55	**99.05**
	Mean	**107.66**	**105.61**	**117.72**	**68.63**	**85.59**	
Polyphenol oxidase	**٠**	100.00	100.00	100.00	100.00	100.00	**100.00**
	25	66.70	40.00	100.00	57.1	100.00	**72.76**
	50	50.01	80.00	100.00	71.42	100.00	**80.28**
	100	66.66	60.00	75.00	57.14	100.00	**71.76**
	Mean	**70.84**	**70.00**	**93.75**	**71.41**	**100.00**	
Proline content (mg/g FW)	**٠**	23.81	23.24	22.57	22.95	27.42	**23.99**
	25	15.33	16.38	17.42	20.28	19.14	**17.71**
	50	19.52	19.04	14.33	17.05	20.19	**18.03**
	100	21.43	22.85	20.47	22.00	20.95	**21.54**
	Mean	**20.02**	**20.37**	**18.69**	**20.57**	**21.92**	

L.S.D at 0.05 level for:	**Catalase**	**Peroxidase**	**Polyphenol oxidase**	**proline content**
Si	6.37	2.81	2.40	1.68
V	7.12	3.15	2.69	1.88
Interaction Si × V	14.24	6.29	5.38	3.77

Table 4. Effect of silicon treatments on silicon and some nutrients content in shoot of wheat varieties.

Nutrients content	Si treatments mg/L	Varieties					
		G9	G7	G11	MS1	GZ	Mean
Si (mg/kg DW)	0	18.7	19.4	16.2	21.6	22.7	**19.72**
	25	23.8	22.5	19.5	22.4	23.3	**22.3**
	50	21.3	24.9	20.1	25.1	23.9	**23.06**
	100	20.7	24.2	24.7	24.3	23.5	**23.48**
	Mean	**21.12**	**22.75**	**20.12**	**23.35**	**23.35**	
N (%)	0	3.40	3.10	3.30	3.50	3.30	**3.32**
	25	3.60	3.40	3.60	3.70	3.60	**3.58**
	50	3.40	3.30	3.40	3.70	3.50	**3.46**
	100	3.30	3.30	3.50	3.50	3.50	**3.42**
	Mean	**3.42**	**3.27**	**3.45**	**3.60**	**3.47**	
P (%)	0	1.01	1.25	1.04	1.00	0.81	**1.02**
	25	1.02	1.30	1.08	0.98	1.17	**1.11**
	50	0.91	1.31	0.94	0.73	0.95	**0.96**
	100	0.85	1.32	0.94	0.62	0.88	**0.92**
	Mean	**0.94**	**1.29**	**1.00**	**0.83**	**0.95**	
K (%)	0	3.03	2.47	2.85	2.80	3.50	**2.93**
	25	3.41	3.33	3.35	3.50	3.98	**3.51**
	50	4.05	3.63	4.17	3.78	3.86	**3.89**
	100	4.11	3.72	4.23	3.79	4.14	**3.99**
	Mean	**3.65**	**3.28**	**3.65**	**3.46**	**3.87**	
Ca (%)	0	0.22	0.20	0.20	0.17	0.16	**0.19**
	25	0.31	0.26	0.22	0.21	0.19	**0.23**
	50	0.24	0.21	0.21	0.23	0.16	**0.21**
	100	0.24	0.21	0.21	0.19	0.16	**0.20**
	Mean	**0.25**	**0.22**	**0.21**	**0.2**	**0.16**	
Na (%)	0	1.61	1.45	1.55	1.24	1.71	**1.51**
	25	1.49	1.22	1.29	1.21	1.49	**1.34**
	50	1.19	1.36	1.37	1.18	1.55	**1.33**
	100	0.97	1.17	1.32	1.09	1.34	**1.17**
	Mean	**1.31**	**1.3**	**1.38**	**1.18**	**1.52**	

L.S.D at 0.05 level for:		Si	N	P	K	Ca	Na
Si		0.17	0.12	0.03	0.09	0.01	0.02
V		0.19	0.13	0.03	0.11	0.02	0.02
Interaction Si × V		0.38	0.26	0.07	0.21	0.04	0.05

Table 5. Effect of silicon treatments on silicon and some nutrients content in root of wheat varieties.

Nutrients Content	Si treatments mg/L	Varieties					
		G9	G7	G11	MS1	GZ	Mean
Si (mg/kg DW)	0	43.5	46.4	49.2	46.5	53.3	**48.2**
	25	51.7	53.8	42.7	49.8	52.8	**49.6**
	50	47.8	50.6	53.6	50.5	58.2	**52.4**
	100	46.1	49.8	48.9	53.6	52.40	**50.1**
	Mean	**46.6**	**50.3**	**47.0**	**50.10**	**54.60**	
N (%)	0	3.50	3.70	3.80	3.80	3.50	**3.70**
	25	4.00	4.40	4.50	4.00	3.60	**4.10**
	50	4.00	3.90	4.00	4.50	3.90	**4.10**
	100	4.30	4.00	3.90	4.20	3.60	**4.00**
	Mean	**3.90**	**4.00**	**4.10**	**4.10**	**3.70**	
P (%)	0	1.00	1.32	1.08	0.79	0.96	**1.06**
	25	1.16	1.06	0.89	1.20	1.11	**1.13**
	50	0.96	0.97	0.96	1.11	0.89	**1.01**
	100	1.01	0.80	0.79	0.76	0.78	**0.84**
	Mean	**1.03**	**1.08**	**0.93**	**0.96**	**1.89**	
K (%)	0	2.85	2.70	2.96	2.54	3.04	**2.81**
	25	2.97	3.03	3.03	2.74	3.06	**2.96**
	50	3.01	3.20	2.97	3.05	2.96	**3.03**
	100	3.16	3.60	3.15	3.34	3.37	**3.32**
	Mean	**2.99**	**3.13**	**3.02**	**2.91**	**3.10**	
Ca (%)	0	0.23	0.15	0.18	0.17	0.13	**0.17**
	25	0.28	0.17	0.22	0.22	0.18	**0.21**
	50	0.25	0.18	0.19	0.25	0.20	**0.23**
	100	0.27	0.13	0.16	0.15	0.17	**0.17**
	Mean	**0.26**	**0.16**	**0.19**	**0.20**	**0.17**	
Na (%)	0	2.45	2.11	1.95	2.04	2.21	**2.14**
	25	2.22	2.09	1.69	1.96	2.09	**2.03**
	50	2.36	1.88	1.77	1.88	1.87	**1.94**
	100	2.17	1.90	1.51	1.69	1.54	**1.74**
	Mean	**2.32**	**1.94**	**1.76**	**1.81**	**1.83**	

L.S.D at 0.05 level for:	Si	N	P	K	Ca	Na
Si	0.21	0.03	0.03	0.03	0.02	0.04
V	0.24	0.03	0.04	0.04	0.02	0.05
Interaction Si × V	0.47	0.06	0.07	0.09	0.04	0.11

Table 6. Effect of silicon treatment on the content of micronutrients (mg/kg DW) in shoots of wheat varieties.

Micronutrients content (mg/kg DW)	Si treatment mg/L	Varieties					
		G9	G7	G1 1	MS1	GZ	M ea n
Cu	0	31.2	38.9	37.3	40.0	37.2	**37.0**
	25	36.8	43.3	39.0	41.6	39.0	**39.4**
	50	38.8	44.3	41.3	43.1	39.3	**41.3**
	100	42.0	46.7	38.5	46.5	41.1	**43.1**
	Mean	**37.6**	**43.1**	**39.1**	**42.8**	**39.0**	
Fe	0	218.6	219.4	184.4	189.2	118.5	**186.0**
	25	259.8	279.2	218.4	187.8	193.6	**227.7**
	50	230.4	231.3	246.0	211.4	205.9	**221.4**
	100	216.5	193.6	230.4	193.4	213.6	**209.5**
	Mean	**231.32**	**230.87**	**219.8**	**195.45**	**182.9**	
Mn	0	8.03	8.92	8.93	8.27	10.27	**8.88**
	25	9.48	8.91	9.00	9.17	10.09	**9.33**
	50	8.33	9.18	9.22	8.82	10.22	**9.15**
	100	7.72	8.12	9.08	9.00	10.02	**8.78**
	Mean	**8.39**	**8.78**	**9.05**	**8.81**	**10.15**	
Zn	0	11.0	10.7	10.9	11.0	10.4	**11.0**
	25	11.3	10.6	11.4	11.6	11.1	**11.0**
	50	12.2	10.0	11.6	11.3	10.9	**11.1**
	100	11.4	9.9	10.6	10.9	10.5	**10.5**
	Mean	**11.4**	**10.4**	**11.1**	**11.4**	**10.8**	

L.S.D at 0.05 level for	Cu	Fe	Mn	Zn
B	0.14	0.16	0.04	0.09
V	0.16	0.17	0.05	0.11
Interaction B × V	0.23	0.35	0.09	023

Table 7. Effect of silicon treatments on the content of micronutrients (mg/kg DW) in roots of different wheat varieties.

Micronutrients content (mg/kg DW.)	Si treatment mg/L	Varieties					
		G9	G7	G11	MS1	GZ	Mean
Cu	0	52.7	49.6	59.3	49.4	51.1	**54.4**
	25	55.3	59.3	66.4	58.5	55.5	**58.7**
	50	59.0	61.0	69.6	61.1	57.3	**63.3**
	100	58.2	52.2	58.2	50.0	49.9	**53.2**
	Mean	**56.3**	**55.5**	**63.8**	**54.0**	**53.4**	
Fe	0	304.8	292.7	264.0	289.7	305.8	**291.4**
	25	318.2	324.3	274.5	363.8	317.2	**319.6**
	50	294.1	291.9	289.7	420.8	296.4	**318.6**
	100	270.0	306.1	210.3	286.3	298.5	**274.2**
	Mean	**296.8**	**303.7**	**259.5**	**340.2**	**304.4**	
Mn	0	13.13	18.81	16.25	22.88	22.50	**18.71**
	25	13.47	14.44	16.85	19.80	19.04	**16.72**
	50	18.77	16.87	14.46	14.37	21.88	**17.27**
	100	14.33	14.95	13.85	14.74	18.00	**15.17**
	Mean	**14.92**	**16.26**	**15.35**	**17.94**	**20.35**	
Zn	0	19.50	16.60	17.60	19.40	13.80	**17.40**
	25	16.70	13.70	17.90	19.50	14.40	**16.10**
	50	16.50	14.20	16.40	17.80	14.60	**15.90**
	100	14.90	12.70	16.00	17.60	13.70	**14.70**
	Mean	**16.90**	**14.30**	**17.00**	**18.60**	**14.10**	

L.S.D at 0.05 level for	Cu	Fe	Mn	Zn
Si	0.17	10.27	0.13	0.12
V	0.20	11.48	0.15	0.15
Interaction Si × V	0.39	22.96	0.30	0.29

تأثير المعاملات بالسيليكون على بعض صفات النمو والقياسات الفسيولوجية والبيوكيميائية لخمسة أصناف من القمح المصري

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الملخص العربي

توجد في مصر فجوه كبيرة بين إنتاج واستهلاك القمح. أقيمت تجربة مزارع مائية بمعمل فسيولوجيا النبات – قسم النبات الزراعى –كلية الزراعة – جامعة الأزهر بالقاهرة. وذلك لدراسة تأثير المعاملة بالسيليكون بتركيزات (صفر، ٢٥، ٥٠ و١٠٠ ملليجرام /لتر) على بعض صفات النمو (طول النبات، ومساحة ورقة العلم، والوزن الرطب والجاف لكلاً من الساق والجذر) وبعض القياسات الفسيولوجية والبيوكيميائية (محتوى صبغات البناء الضوئى، محتوى الماء الحر بالخلية، الثبات الغشائى، ونشاط بعض الإنزيمات المضادة للأكسدة ومحتوى البرولين) بجانب محتوى النبات من بعض العناصر المغذية. وذلك على خمس أصناف من القمح (جميزة ٧، ٩، ١١ - مصر١ – جيزة ١٦٨).
وأوضحت النتائج أن للسيليكون دوراً محسناً على كل القياسات المسجلة، وكان أفضل تأثير ملحوظ للسيلكون على النبات مع المعاملة ٢٥ ملليجرام /لتر، مقارنة بالكنترول. حيث أوضحت النتائج أن كل معاملات السيلكون كان لها دور محسن على قياسات النمو بواسطة زيادة المجموع الخضرى ومساحة ورقة العلم ووزن المادة الغضة والجافة للمجموع الخضرى والجذور وكذلك زيادة الكلوروفيل (أ وب) والكاروتيين،المحتوى الماء النسبى بالخلية وثبات الأغشية وكذلك كان للسيليكون دور فى التنشيط الحيوى لبعض الإنزيمات المضادة للأكسدة وتعديل نسبة البرولين فى النباتات المعاملة بالسيليكون.كما أدت المعاملات بالسيلكون إلي زيادة ملحوظة فى محتوى بعض العناصر الغذائية مقارنة بالكنترول مما أدى إلي زيادة صبغات البناء الضوئى ومساحة ورقة العلم وتحسين صفات النمو.

الكلمات المفتاحية: قياسات النمو، ورقة العلم، الكلوروفيل، إنزيمات مضادة الأكسدة، البرولين، السيليكون.