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Exogenous Application of Silicon Can Help Augment Drought Tolerance in Wheat (Triticum aestivum L.) by Enhancing Morpho-physiological and Antioxidant Potential

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Abstract

Drought stress is considered one of the most severe stresses, which can result in devastating yield reduction in agriculture crops. There are many approaches recommended by the researchers and adopted by the farmers to minimize the devastating effect of drought. However, exogenous application of growth regulators in combination to plant nutrients is the innovative attitude to ameliorate the shocking effects of drought stress. So we planned a study to investigate the ameliorative effect of exogenously applied potassium silicate wheat (*Triticum aestivum* L.) crop under water deficit conditions. The current study was conducted at the Agronomic Research Farm area, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur. RCBD-Split plot design with four repeats was used. The treatments consist on “T_0” (Control), “T_1” (exogenous application of potassium silicate @ 1% solution), “T_2” (exogenous application of potassium silicate @ 2% solution), “T_3” (exogenous application of potassium silicate @ 3% solution). The results of our study revealed that drought stress can significantly affect crop yield as a result of the reduction in chlorophyll-a (1.07), chlorophyll-b (0.49), total chlorophyll contents (1.62), flag leaf area (38.33 cm^2), plant height (100.17cm), number of nodes per plant (3.91), tiller height (92.42), number of tillers m^{-2} (191.17), spike length (7.58 cm), number of spikes per plant (10.25), number of grains per spike (25.08), 1000-grain weight (36.66g), total dry weight per plant (309.75g), biomass yield (23424kg/ha) and grain yield (4564.2 kg/ha). On the other hand, the exogenous application of potassium silicate at 2% solution showed promising results in terms of ameliorating the drought effect by significantly enhancing chlorophyll-a (1.21), chlorophyll-b (0.64), total chlorophyll contents (1.92), flag leaf area(45.25 cm^2), plant height (123.50cm), number of nodes per plant (5.25), tiller height (99.42), number of tillers m^{-2} (276.26), spike length (12.92cm), number of spikes per plant (14.25), number of grains per spike (38.33), 1000-grain weight (44.33g), total dry weight per plant (385.00g), biomass yield (24000 kg/ha) and grain yield (5074.8kg/ha). These findings led us to conclude that the exogenous application of potassium silicate has a great ability to compensate for the detrimental effects of drought in wheat crops.

1. Introduction

Among all the cereal crops, wheat (*Triticum aestivum* L.) is considered the second most important nutritious crop of the world after rice (Malav et al., 2017). It accommodates food needs of almost one-fifth of the world’s community (FAO, 2010). Being staple food, wheat gained a central position in farming approaches and contribute 12.5% of the value of agriculture and 2.5% to the GDP of Pakistan (Muhammad *et al* .,2005). Additionally, wheat grains consisted of fats (1.5- 2.0%), protein (6–21%), minerals (1.8%), cellulose (2.0-2.5%) and vitamins (Malav et al., 2017 and Das, 2008). Egypt is the biggest importer of wheat in the world. About 12 million tons of wheat is imported by Egypt in 2016/2017. This estimate is 1.3 million tons higher than the average over the past five years (FAO, 2016). In Pakistan, 866 million hectares of land are used for wheat cultivation. According to the latest survey by the united states department of agriculture 2020, wheat production is 25.7 million metric tons (MMT) approximately 6% higher than wheat production of the previous year 24.3MMT (Raza, 2020).

Wheat grains contain fats (1.5-2.0%), cellulose (2.0-2.5%) and protein (6–21%) and other minerals and nutrients 1.8 % (Malav et al., 2017). Today, Pakistan produces about 26 million tonnes of wheat, compared to 26 million tonnes in 2020 to 8.7 million tonnes in 1980 of wheat today (Tariq, 2020). Among abiotic stresses, drought stress is the major stress factor that can adversely effect on growth and production of plants (Abd El-Gawad, 2015). Osman (2009) observed that water deficiency has a significant effect on the reduction of biomass, flag leaf area, shoot dry weight of the plant. Levy *et al*. (2013) found drought stress can lead to yield loss and quality of the tuber of the potato plant. Siddiqui et al., 2015 reported the decrease in growth parameters may occur due to cell enlargement caused by turgor loss and inhibition of various growth parameters.

Globally one of the largest abiotic stress affecting global production and growth is drought. Availability of sufficient water is very important during all aspects of growth and development of a crop (Abd El-Gawad, 2015). Reception and nutrients transportation to different plant parts occurs through water uptake which makes water a major component of the two way photosynthesis; first, it delivers hydrogen to produce $C_6H_{12}O_{6,}$ and secondly, the stomata opening and closing are controlled by increasing or decreasing the quantity of water. On the other hand water stress can affect plant metabolism as well as morphology. Adaptation levels depend on the diversity, growth stage, intensity of stress, and duration (Araus et al., 2002; Mark and Antony, 2005). Scarcity of irrigation water especially at reproductive stage can drastically decrease crop yields especially in in arid areas (Ullah et al., 2002). Wheat being an important staple food crop is grown in 70% of workds arid and semi-arid areas (Zhang, and Deng, 2000). Despite strong wheat harvests in 2014, up to 47 percent of the country's population was food insecure, driven by severe hunger, unequal food distribution, and water scarcity, according to the World Food Program (Khaliq *et al*., 2019).

Silicon is the second richest element present on the earth's surface (Gong et al., 2006). It’s not available in free form on earth and is always associated with other elements that form silicates and oxides (Richmond and Sussman, 2003). It was found that silicon minimizes the diversity of abiotic and biotic stresses in many plants, which includes the improvement of growth and yield of crops (Soratto et al., 2012). Since silicone addition has significant effects on crop production under water-deficient conditions, it reduces evaporation and increases water absorption (Melo et al., 2003). In stress conditions, foliar applications of “Si” can maintain high water potential and relative water contents in soil. Silicon has a beneficial effect on transpiration, maintain water potential in plants. Silicon has a vital role in enhancing growth and yield because of its beneficial effect under abiotic stress (Salim, 2014).

Silicon increases tolerance in the plant by enhancing leaf erectness, maintain water potential and stomatal conductance under high transpiration conditions (Crusciol et al., 2009; Saud et al., 2014; Shaaban and Nour, 2014). Researchers reported that silicon addition to nutrient solution reduced the inhibition effect on growth and development of plant water-deficient conditions. Silicon enhances the antioxidant effect and reduced the oxidative stress effect under drought stress conditions. “Si” increases carboxylase activities under the water-deficient condition in wheat (Gong and Chen, 2012). Pilon et al., (2014) observed that spraying “Si” on the plant under drought stress conditions then silicon can maintain the chlorophyll content in the plant. Moghsoudi *et al.*, (2015) observed “Si” foliar application increase the production of chlorophyll pigments and leaf area which also boosts up the process of photosynthesis. Oliveira et al., 2016 found that improvement of plant architecture and chlorophyll content under soil water tension with the application of silicon. Mauad et al., 2016 reported drought stress conditions; silicon reduced the proline content in vegetative and reproductive phases of rice plant which is an indicator of stress tolerance. Silicon concentration can be controlled in soil solution with a concentrated solution of silicate mineral range from 0.01-1.99mM (Karathanasis, 2002).

Silicon has been reported to improve germination, development, growth by regulation of antioxidant enzymes and reduction of lipid peroxidation during drought stress in wheat (Pei et al., 2010). Stimulated activity of antioxidants (POD and CAT) observed after treatment with potassium silicate in wheat under stress (Ali et al., 2012). In addition, potassium silicate treatment with decreased oxidative stress by increasing the production of antioxidants (glutathione reductase, catalase, peroxidase and superoxide dismutase) during drought stress in wheat, barley and soybeans (Wang et al., 2011; Miao et al., 2010). The effect of silicon (Si) on the major activities of antioxidant enzymes including catalase (CAT), ascorbate peroxidase (APX), peroxidase (POD), chlorophyll contents, accumulation under drought stress in three different growth stages of wheat plants (*Triticum aestivum* L.) was observed (Sara and Raheem, 2011). The application of Si significantly improved the ability of plants to withstand drought stress by improving Si uptake in plants and also improving Si uptake in plants and increased the production Ascorbate peroxidase (APX), peroxidase (POD), superoxide dismutase (SOD) and catalase activities (CAT)(Adnan *et al.*, 2020).

Environmental stress is resolved in plants by its nutritional status. Plants tolerate the scarcity of water by applying “K” on plants that have a great effect by reducing the stress caused by deficiency of available soil moisture. Potassium shows a vital role in the methods of synthesis of protein, photosynthesis, ionic balance control, stomatal conductance in plants and water use efficiency in plants, enzymes activation in plants, and more processes (Reddya et al., 2004). By increasing “K” application that exposed to increase the photosynthesis rate, growth of plant and yield in various crops under a scarcity of water conditions Egilla et al., 2001. For maximum yield, foliar application treatments can supplement and ensure the availability of nutrients (Arif et al., 2006). Splashing wheat plants with potassium before exposing the plant to dry season treatment reduced the adverse effect of the dry season on development and successively enhance per plant yield (Ashry *et al.*, 2005).

Potassium is an important nutrient of plants and performed a vital role in different physiological processes. Protein synthesis, photosynthesis, and water maintenance in tissues of plants (Marschner, 2012). It also affects photosynthesis, conversion, and storage of carbohydrates and the quality of potato tubers (Dkhil *et al.*, 2011; Ebert, 2009). Potassium silicate increases the potato plant growth, minerals, and nutrients yield parameters (N, P, and K) (Salim et al., 2014). “Si” performs a significant role in the enhancement of corn yield because it provides nutrients that are useful for abiotic stress (Salim, 2014).

Potassium is one of the most important plant nutrients which is considered essential for different physiological processes of plants including photosynthesis, respiration, protein synthesis, and maintaining water potential in tissues of plants (Marschner, 2012). Potassium is required by plant a slightly larger amount than nitrogen. About 50 enzymes required the presence of “K” for optimum working and “K” plays a dynamic role in developing immature seeds, (Rehm *et al.*, 2002). Lakudzala (2013) Potassium plays a significant role in physiological procedures for protein synthesis, transportation of water, and photosynthesis.

Potassium also promotes the transportation of assimilates, control of stomata opening, enzyme activation in plants (Yawson et al., 2011). “K” play important role in improving plant resistance, mineral uptake from roots. Stomata opening is closed due to potassium deficiency result in diminishes the rate of photosynthesis in many crops (Mesbah, 2009). Since potassium silicate is a highly soluble source of silicone and potassium, it is used as fertilizer in the agriculture production system and increases yield by using low levels of potassium (Tarabih et al., 2014). Si has been described to reduce many of the effects including the biological and abiotic stresses of plants at high evaporation rates, and maintain the water potential of plants, photosynthesis, stomatal conductivity, and leaf erection (Das et al., 2017).

In vegetables, the harmful effect of drought stress can be reduced with help of a sufficient amount of potassium availability (Sangakkara et al., 2000). Potassium exogenous application is effective at the blossoming stage under drought stress and improved length of spikes, grains per spike 14.82%, and 25% respectively. In wheat, there is a reduction in grain size and weight occurs due to an insufficient and inadequate form of potassium, because of its effect on grain length, size, and filling.

Vegetative growth parameters, components of yield, and nutrient concentration can be enhanced by the application of potassium silicate (Salim et al., 2014). Potassium silicate provides a highly soluble “K” and “Si” amendment source and potassium help to improve yield quality (Tarabih et al., 2014). Potassium Silicate has significant effects on the availability of macronutrients and improvement in the vegetative growth of the plant. Dkhil *et al.* (2011) studied that potassium silicate has the ability to improve the vegetative growth of the potato.

According to Shabban and Nour (2014), exogenous fertilization of potassium silicate may be beneficial for silica deposition and keep the hairy roots healthy and produce ability in roots to absorb water, macro, and micronutrient absorption. Potassium Silicate has a significant increase in potassium percentage in wheat grain due to potassium silicate spray. Liang et al., 2003 reported that under salinity stress condition potassium ion uptake is significantly increased after silicate application because of the activity of plasma membrane use ATP. Exogenous application of potassium silicate decrease the sodium percentage in wheat grains and also decrease translocation in roots towards shoots in wheat plant significantly (Tahir et al., 2010). Potassium silicate has a great impact on leaf erectness and diminishing the capability of lodging in cereals. (Kamenidou, 2005) illustrated that potassium silicate exogenous application on weekly basis will expand stem thickness and early blooming of blossoming plants.

Keller et al., 2015 observed the mediated effect of "Si" on plants shows a declining uptake of copper and its translocation in leaves of wheat. Iwasaki *et al.*, 2002 clarified that "Si" reduced metal transportation by the Apo-plastic transportation method by removing free metal ions focus on transportation by Apo-plastic. Morsy *et al.*, 2013 examined the impact of potassium silicate on drought stress in wheat and other bean crops and revealed that silicon absorption increase the speed of the metabolic process and also increase uptake of all other nutrients. Silicon has a positive effect on absolute soluble protein contents and reduced the leaching loss effect of all nutrients (Lalithya et al., 2014).

Objectives

- To explore the ameliorative effect of potassium silicate on the physiology, growth, and yield attributes of wheat.
- To observe the effect of exogenous application of potassium silicate on different growth stages (Vegetative and Reproductive) of wheat under water deficit conditions.

2. Material And Methods

2.1 Experimental Site

The current experiment was conducted to assess the effect of exogenous application Potassium Silicate on Wheat (*Triticum aestivum L.*) crop under water deficit conditions. The seeds of JOHAR variety was sown on 20th November 2018 and the seed rate was 148.26 kg/ha. The recommended dose of fertilizers was provided to the crop i.e. 150 kg nitrogen, 112 kg phosphorus, and 60 kg potassium per hectare. The fertilizer sources used were Urea, DAP, and SOP. The split dose of nitrogen and the whole of phosphorus and potassium were used at the time of sowing while the remaining dose of nitrogen was applied in two splits with irrigations. The standard plant protection measures were also used to protect the crop from insects, pests, and diseases.The experiment was conducted at the Agronomic Research Area of the Department of Agronomy, Faculty of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Pakistan, during the growing season 2018–2019. The experiment was laid out as randomized complete block design with split plot arrangements. The exogenously applied potassium silicate was considered as main factor and consisted on four different levels such as T_0 = Control (Exogenous water application), $T_{1,}$ T_2 and T_3 (@ 1%, 2% and 3% Potassium Silicate respectively while irrigation levels was considered sub factor and consist on (I_0 = Control Irrigation, I_1 = Irrigation Skip at Vegetative Stage, (at tillering stage), (30DAS); (I_2 = Irrigation Skip at Reproductive Stage, (at anthesis stage), (75 DAS).

The mean monthly temperature and precipitation was recorded from the time of sowing to harvest. The data regarding physiological, growth, and yield attributes were recorded.

2.1 Soil moisture Contents

The data regarding soil moisture content was recorded on weekly basis by using Theta probe. All the readings were collected randomly from each treatment from 8 am to 10 am to avoid moisture loss by sun light.

2.3 Measurement of leaf pigments

The value of the spade reading was recorded on a biweekly basis by using chlorophyll meter (Model CL-01). The leaves of randomly selected plants from each treatment were used to take spade readings. To estimate chlorophyll contents the method of Arnon, (1949) and Davies, (1976) was used. Fresh leaves of plants 0.5 g were chopped into small pieces and placed into 5ml acetone (80%) at 100 ^{o}C for overnight for chlorophyll content extraction. The extracted material was centrifuge at 4000rpm for 5 min. to calculate chlorophyll a, b and total chlorophyll observe the absorbance of the supernatant at 645, 652, and 663nm on spectrophotometer.

$$\text{Chl a} = [12.7 (\text{OD } 663) - 2.69 (\text{OD } 645)] \times V/1000 \times W$$

$$\text{Chl b} = [22.9 (\text{OD } 645) - 4.68 (\text{OD } 663)] \times V/1000 \times W$$

$$\text{Total Chl} = [20.2 (\text{OD } 645) + 8.02 (\text{OD } 663)] \times V/1000 \times W$$

Where V is the volume of sample extract and W is the weight of the sample

2.4 Growth related parameters

To measure the plant height, number of nodes per plant, tiller length, number of tillers m^{-2}, spike length, number of spike per plant and number of grain per spike; three plants from each treatment were selected and separated by their tillers to measure their values manually by using a measuring scale and an average value is taken. The length and width of the flag leaf was measure by scale to calculate the flag leaf area cm^2.

The plants of each treatment were harvest separately and their seeds were counted manually to measure the 1000 grain weight of each treatment. The quadrate of the one-meter square was placed randomly in each treatment and plants in the quadrate were harvested and threshed manually and separately to calculate grain yield in kg/ha^{-1} and biomass yield kg/acre by measured their weight manually on a digital balance.

To estimate the total dry weight per plant randomly selected plants from each treatment were harvested and oven-dried at 65 ^{0}C till constant weight.

Estimation of antioxidants activity

The peroxidase (POX), catalase (CAT), and ascorbate peroxidase (APX) activities were determined spectrophotometrically (Hitachi-2800). Wheat leaves were homogenised into a 50 mM phosphate buffer composed of 7.0 pH and 1 mM dithiothreitol (DTT) for the determination of these antioxidants, as Dixit et al., (2001) presented a summary.

Catalase Activity (CAT)

Catalase activity (CAT) was measured using the method defined by (Chance B and Maehly AC 1955) to calculate the rate of conversion of hydrogen peroxide to water and oxygen molecules. The activity was tested in a 3 mL reaction solution consisting of a 7.0 pH, 50 mM phosphate buffer containing 5.9 mM of H_2O_2 (HP) extract and 0.1 mL enzyme. Due to consumption of H_2O_2, the activity of catalase was determined by a decrease in absorbance at 240 nm after every 20 s. The 0.01-unit min − 1 absorbance change was defined as a single unit catalase activity.

Peroxidase activity (POX)

Peroxidase activity (POX) was determined by measuring the H_2O_2 peroxidation as an electron donor with guaiacol (Chance B and Maehly AC 1955). The POD reaction solution consists of a 50 mM phosphate buffer with pH 5, guaiacol 20 mM, H_2O_2 40 mM and enzyme extract 0.1 mL. After every 20 seconds, the rise in absorbance due to tetra guaiacol formation at 470 nm was assayed. One unit of the enzyme was the amount of the enzyme that was liable for the 0.01 in 1 min increase in OD value. The activity of the enzyme was determined and expressed as the basis of unit min-1 g − 1FW.

Ascorbate peroxidase Activity (APX)

Ascorbate peroxidase (APX) activity was measured by monitoring a fall in ascorbic acid absorption at 290 nm (extinction coefficient 2.8 mM cm-1) in a 1 mL reaction mixture containing 50 mM phosphate buffer (pH 7.6), 0.1 mM Na-EDTA, 12 mM H_2O_2, 0.25 mM ascorbic acid and sample extract as described in (Cakmak I, 1994).

2.5 Statistical Analysis

The experimental data was analyzed statistically by using Fisher’s analysis of variance technique and Tukey's test at a 5% probability level was used to compare the differences among the treatment means.

3 Results

3.1 Measurement of leaf pigments

The data about leaf pigments of wheat grown under drought condition were presented in table 1. All the leaf pigments recorded significant differences under normal and skipped irrigation condition. The interaction (T x I) or combined effect was also noted substantial. A commonly observed phenomenon is the reduction of photosynthetic pigments produced under water limited condition. The current study proposed a significant reduction of chlorophyll contents in plants facing water limited condition as compared to control. In treatments potassium silicate applied @ of 2% to wheat plant provide maximum chlorophyll contents in contrast to control without silicon application. There was a significant correlation with control levels and skipped irrigation condition. The exogenous use of silicon indicated a significant effect on SPAD value under skipped irrigated conditions. The maximum SPAD value was noted in plants where 2% silicon was applied exogenously under control condition.

Table 1. Analysis of variance for chlorophyll a, b and total chlorophyll, and significance in silicon treatments and limited irrigations under field conditions

ANOVA	Chlorophyll "a"	Chlorophyll "b"	Total Chlorophyll
Irrigation	0.07**	0.0012*	0.03**
Treatments	0.05**	0.05**	0.20**
Irrigation × Treatments	0.02*	0.01**	0.02**

****=P<0.01, *=p<0.05**

3.2 Agronomic and yield components

The statistical analysis for some agronomic and yield related attributes of wheat under skipped irrigation conditions was presented in table 2. All the recorded parameters showed a substantial variation between the control and skipped irrigation condition with silicon treatments. The interaction between silicon treatments and skipped irrigations was significant.

Table 2. Analysis of variance for plant height, flag leaf area, number of tillers m^{-2} and tiller height, and significance in silicon treatments and limited irrigations under field conditions.

ANOVA	Plant height (cm)	Flag Leaf Area (cm^2)	No. of Tillers m^{-2}	Tiller Height (cm)
Irrigation	83.31**	892.27**	13211.1**	389.22**
Treatments	1289.22**	105.91**	17490.0**	104.76**
Irrigation × Treatments	7.62	1.41	80.2	20.52**

****=P<0.01, *=p<0.05**

Antioxidant Enzymes

The antioxidant activities of wheat under drought stress condition were presented in Table 5. The POD, CAT and APX was recorded highly significant at (p < 0.01) (Table 4) Enzymatic activity was enhanced under drought stress relative to normal wheat plants, but Si application was found to be successful by augmenting the function of the enzymes under drought stress conditions. The best performance of each antioxidant enzymes such as, POD, CAT and APX were noted in those plants of wheat where potassium silicate was applied at the rate of 2% under water deficit conditions. Wheat plants exhibited the highest activity of the enzymes in water deficit condition than normal. Drought-stressed wheat plants display maximum ascorbate peroxidase (1.4975 ABA digested g^{-1} FWh^{-1}), peroxidase (752.72 units min^{-1} g^{-1} FW) and catalase (223.87 units min^{-1} g^{-1} FW) with foliar potassium silicate applied at the rate of 2% in water deficiency as presented in table 5.

4 Discussion

The results of our study revealed that the exogenous application of potassium silicate on wheat crop can help to mitigate the effects of drought stress. The chlorophyll contents are the basic vital unit of the plant photosynthetic process. Chlorophyll production is highly affected by water application and mineral application on the plant. Various studies revealed that irrigation had a great relationship with chlorophyll content production and regularize the turgor pressure and activation of the enzyme by maintaining the optimized temperature of the plant (Mengal and Kikerby, 2001). The number of irrigation has a great relationship with stomata opening and chlorophyll pigments production during the photosynthesis process. Our results are also in consistence with the previous studies that silicon application can improves photosynthetic action and builds chlorophyll pigments under typical and saltiness stressed plants (Wang and Han, 2007).Potassium silicate effects positively on most of the metabolic process and it played a vital role in the regulation of photosynthesis, respiration, translocation of assimilates from source to sink, the formation of new proteins like chlorophyll pigments Milford and Johnston, 2007). These results might also be the depiction of potassium silicate foliar application help in improving leaf erectness, and improving photosynthesis efficiency also reducing the capability to lodging in wheat. The flag leaf area plays a very important function in plant growth and yield because it is responsible for the photosynthesis of plants at the initial stage of growth. The foliar application of various essential nutrients increases the fag leaf area of the plant. The wheat plant is more dependent on silicon nutrition at the vegetative growth stage especially at the tillering stage (Ahmad and Haddad, 2011).

Table 3. Analysis of variance for number of nodes per plant, spike length, number of spike per plant and number of grains per spike, and significance in silicon treatments and limited irrigations under field conditions

ANOVA	No. of Nodes/ plant	Spike Length (cm)	No. of Spikes/plant	No. of Grains/spike
Irrigation	4.75**	7.75	103.68**	53.06**
Treatments	4.25**	62.46**	47.22**	403.25**
Irrigation	0.25	1.61	8.57	3.56

×
Treatments

****=P<0.01, *=p<0.05**

In our study, the exogenous application of potassium silicate enhances the area of flag leaf significantly. Our results are in line with (Soratto et al., 2012; Andrade and Miglioranza, 2012) which stated that due to the accumulation of silicon in upper leaves enhanced the flag leaf area in the wheat plant. Plant height was also affected due to irrigation treatments. Water deficiency in plant root zone causes accumulation of toxins in cells and as a result of this dehydration of protoplasm decreased cell production, cell expansion is observed which is directly related to plant height (Abro *et al*., 2009). The increase of plant height in our study might be the result of exogenous application of potassium silicate due to improved nutrient absorption, enzyme activity and protein synthesis. Potassium act as a vital role in biochemical pathways in plants and also acts as a basic nutrient in the carbon cycle, carbohydrate translocation in the plant, Krebs cycle, and energy nutrient for ATP. Potassium silicate increased the plant height, increased stem and leaf strength, and provided maximum tolerance against weed competition by improving plant architecture and maintaining leaf angle to prevent shading effect to the main crop. Plant height may be reduced due to dehydration of protoplasm; decrease in relative turgidity associated with turgor loss and decreased cell expansion and cell division (Hussain *et al.*, 2008). In our study revealed that number of nodes per plant is highly affected by the number of irrigation and showed the dynamic result of treatments. The number of nodes and the number of leaves per plant depends on the water potential of soil (Munns, 2002). Abd El-Monem, (2010) observed that the disturbance of phyto-hormone levels, hormones level in the plant also affects the growth of plants which include the vegetative and reproductive growth stages. The irrigation affected the tiller strength and tiller length which reduced the lodging effects of tillers. The development and viability of primary and secondary tillers are greatly affected by salinity, drought, and other environmental stresses (Ma *et al*, .2004). The maximum potassium ion availability of cause increase in spike length. Talebi *et al.,* (2015) found that potassium silicate utilization of exogenous had a positive significant impact by expanding soluble protein and starch substance in the leaves of potato plants. Silicon application gave the most elevated nitrogen, phosphorous and potassium content in the leaf of plants as it loses from leaching loss of 'N' and aided in more gathering of nitrogen in leaf. Silicon conveyed more 'P' accessible to the plants however its fixation as silicon competed for 'P' fixation. The number of spikes per plant is the key factor used for the estimation of grain yield in wheat. More number of spikes per plant means more production of grain yield. In our findings the number of spikes per plant increased by the exogenous application of potassium silicate. Our results are in lines with which was stated by Araus *et al*., 2002. The number of spikes per plant increased due to exogenous application potassium silicate applied at the vegetative and reproductive stage increased the weight of plants and spikes weight per plants. The number of grains per spike was also affected due to irrigation treatments. The number of grains reduction is caused by empty spikelets and dry and premature seed fillings which caused the shedding of spikes before filling grains. The number of grains reduces in other treatments is due to empty spikelet's or loss of shrinked grains in the air and the grain filling stage is not fulfil all grains due to less available water at this stage. Due to low uptake of nutrients from the soil, the translocations of metabolites are also reduced which affects the grain yield and development of grains. 'K' is the cofactor for several enzymes which also affect starch synthesis in grain. Therefore the availability of 'K' also affects the development, quality, and grains filling. An increase in the number of seeds may produce a higher capacity of sink providing favourable conditions for filling photosynthetic assimilates. The increase in grain weight of the plant is due to an increase in the deposition of silicon and maximum translocation of nutrients and better utilization of nitrogen and maximum photosynthates production in plant leaves.

Table 4. Analysis of variance for thousand grain weight, grin yield, biomass yield and total dry weight per plant, and significance in silicon treatments and limited irrigations under field conditions

ANOVA	1000 grain wt.	Grain yield (kg/ha)	Biomass yield (kg/ha)	Total Dry weight plant^{-1} (g)
Irrigation	132.58**	712649**	8511366**	31993.6**
Treatments	124.05**	660506**	768646**	12140.7**
Irrigation × Treatments	3.05	38178**	38165	52.5

**=P<0.01, *=p<0.05

Table 5. Analysis of variance for antioxidant (Ascorbate Peroxidase Activity, Catalase Activity, and Peroxidase Activity), and significance in silicon treatments and limited irrigations under field conditions

ANOVA	APX	CAT	POD
Irrigation	2.40**	102906**	3539.48**
Treatments	0.10**	823**	287.23**
Irrigation × Treatments	0.03**	128**	11.33

**=P<0.01, *=p<0.05

This study revealed that the 1000 grains weight significantly increased by the foliar application of potassium silicate that caused the significantly increased in 1000 grain weight (White *et al.,* 2017; Hanafy *et al.,* 2008).The reason for reduced yield in other treatments is occurred due to less water availability which causes reduced nutrient uptake for a healthy crop and yield production. The effect of 'Si' on the reduction of lipid peroxidation, an increase in catalase activities, and improvement of fruit quality by the increased in the anti-oxidant pool in fruits (Tesfay *et al.*, 2011). Bozorgi *et al.*, (2011) observed that the effect of potassium silicate on increasing the endogenous cytokines and auxin levels which directly improve the yield of the plant. Biomass yield is the indication of total biomass produced by the plant during the whole period of plant growth and development. Biomass yield indicated that the genetic potential of the seed, fertility status of soil, and the application of plant nutrients that are applied throughout the growing period of plants. The foliar application of different plant nutrients enhanced the plant growth and ultimately biomass yield. In our study, the foliar-applied potassium silicate increases the biomass yield maximum when applied at the rate of 2% at the vegetative stage of plant growth. Our results are in line with Reynolds *et al.,* 2009. The osmotic potential from the reduction of water content and specific toxic effects caused by sodium and chlorides can be reduced by the application of potassium silicate (Abu-Muriefah, 2015).The anti-stress effect also helps in reducing the absorption of toxic substances, was also attributed to increase the cell membrane permeability, respiration, provide help in the uptake of phosphorus by roots, and also provide the root growth strength in pepper under salinity conditions (Pizzeghello *et al.*, 2013). Silicon plays a significant role in wheat biomass production, plant growth, and development, improved the photosynthetic activities, translocation of nutrients (Gong and Chen, 2012). The beneficial effect of potassium on plant development, enhanced the fertilizer absorption efficiency, availability of maximum micronutrients such as iron and zinc (Stevenson, 1994). The effect of potassium silicate on cell membrane function and nutrient uptake, plant growth by acting as hormone-like substances (Nardi *et al.*, 1996).The total dry weight of the plant indicated that the growth of the plant. Under drought conditions, the dry weight of the plant slightly increased while the foliar application of silicon maintain the plant structure and provide the ability to stand under a stressed environment. Our results are similar to Gong *et al.*, (2003) who study the silicon effect on wheat under water-stressed conditions. 'K' concentration provides a significant role in the dry weight accumulation in plants harvested, provides basic regulation in performance metabolic processes and enzyme activities. 'K' encourages vegetative growth and yield of plants, increased dry matter due to maximum accumulation of zinc and iron which increases the production rate of protein in the plant.

Using their enzymatic and non-enzymatic antioxidant mechanisms to prevent oxidative damage to their cells and regulate the amount of the ROS species plants (Osmolovskaya *et al.*, 2018). The catalase enzyme transforms H_2O_2 into molecular oxygen and water. The superoxide radicals formed in plant tissues are converted by SOD enzyme into hydrogen peroxide (H_2O_2) and O_2 (Laxa M., 2019). The breakdown of H_2O_2 is carried out by the combined effort of enzymes CAT and POD. Both CAT and POD function collectively act to scavenge H_2O_2 and singlet oxygen (Ullah *et al.*, 2017). Our results are consistent with the findings of Manivannan *et al.*, (2008), who observed increased CAT and SOD activity in sunflower under conditions of water deficiency. POD increase under stress from drought was similarly observed in sunflower species (Hussain *et al*., 2018) and brassica species (Wang *et al*., 2017). Chlorophyll pigments in vegetable leaves are involved photosynthesis. They are required to maintain an optimal plant photosynthesis rate (Maghsoudi *et al*., 2016).

5. Conclusions

Exogenous application of potassium silicate significantly improved the plant growth, grain yield, and production of wheat (*Triticum aestivum* L.) when applied at the time of different irrigation to impose drought stress under agro-ecological conditions of Bahawalpur. At the rate of 2%, potassium silicate under drought at tillering and anthesis performed better in improving growth, yield, and quality of wheat. In contrast to previous studies on reducing water availability and the need for new crop varieties that are tolerant of water deficit stress and grow well under dry conditions, we have planned to investigate the impact of various treatments of exogenously applied potassium silicate on wheat crops. We found that wheat plants that are foliar treated with potassium silicate grow well with four treatments at the rate of 1%, 2%, and 3% respectively, and three levels of irrigation. Various physiological, biochemical, growth, and yield parameters of wheat have been significantly affected by drought stress. However, potassium silicate treated plants were more effective in preserving these attributes at a rate of 2 percent compared to plants treated with other treatments, so treatment with potassium silicate at a rate of 2 percent is suggested to find an economical crop yield under conditions of drought. This experiment concluded that exogenous application of potassium silicate has significant effects to improve plant physiology, enhanced tolerance against water deficit conditions with different growth stages, and development of the wheat crop.

Declarations

Author Contributions MA plan and supervise the research and MIJ conduct research work; MRS and MA write the introduction part; AH and MKE write the manuscript; MAT help to statically analysis and graphical representation; ZA read the manuscript as proofreading; MFN and MA help in English editing and final formatting according to journal style.

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