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ORIGINAL PAPER

Foliar Spray of Silicon Confers Drought Tolerance in Wheat (*Triticum aestivum* L.) by Enhancing Morpho-Physiological and Antioxidant Potential

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Abstract

Drought stress is one of the most severe environmental stresses and is a significant contributor to yield reductions in agricultural crops. Several agronomic approaches are recommended by the researchers and later followed by the farmers to minimize the drastic effects of drought. However, the exogenous application of plant growth regulators in combination with mineral nutrients is a recent, innovative strategy to overcome the damaging effects of drought. Here, we report a study aimed at investigating the protective effects of exogenously applied silicon (using potassium silicate or $K_2Si_2O_5$ as a source) to improve drought tolerance in wheat (*Triticum aestivum* L.) grown under field conditions. The present study was carried out at Agronomic Research Farm area, Faculty of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur. The experimental field was laid out in a randomized complete block design with split plot arrangements (RCBD-Split), and four repeats. The treatments included: T_0 (control, water spray), and T_1, T_2, T_3 i.e. foliar application of $K_2Si_2O_5$ solutions at the rate of 1, 2 and 3%, respectively. The results showed that drought stress significantly affected the wheat yield by decreasing chlorophyll-*a* (1.07), chlorophyll-*b* (0.49), total chlorophyll contents (1.62), flag leaf area (38.33 cm^2), plant height (100.17 cm), 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 (36.66 g), total dry weight per plant (309.75 g), biological yield (23,424 kg/ha), and grain yield (4564.2 kg/ha). On the contrary, the foliar application of 2% $K_2Si_2O_5$ considerably reduced the drought-induced damages by enhancing the chlorophyll-*a* (1.21), chlorophyll-*b* (0.64), total chlorophyll contents (1.92), flag leaf area (45.25 cm^2), plant height (123.50 cm), number of nodes per plant (5.25), tiller height (99.42), number of tillers m^{-2} (276.26), spike length (12.92 cm), number of spikes per plant (14.25), number of grains per spike (38.33), 1000-grain weight (44.33 g), total dry weight per plant (385.00 g), biological yield (24,000 kg/ha), and grain yield (5074.8 kg/ha). These findings suggest that the exogenous application of $K_2Si_2O_5$ could be utilized as a rapid, easy and effective approach to reduce drought-induced damages on wheat yield.

Keywords Drought stress · Foliar application · Pigments · Grain yield · Potassium silicate · Wheat

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1 Introduction

Among cereal crops, wheat (*Triticum aestivum* L.) is the second most important food crop after rice [1, 2]. It fulfils the dietary needs of almost one-fifth of the global human population [3]. Wheat grain consists of fats (1.5–2.0%), protein (6–21%), minerals (1.8%), cellulose (2.0–2.5%) and vitamins [1, 4]. Being a staple food, wheat gained a central position in farming approaches and contributes 12.5% to the value added agriculture and 2.5% to the gross domestic production (GDP) of Pakistan [5]. In Pakistan, wheat is cultivated on 866 million hectares. According to a recent survey by United States Department of Agriculture (USDA), wheat production in Pakistan was 25.7 million metric tons (MMT) in 2020, approximately 6% higher than the 24.3 MMT achieved during the previous year [6].

Drought is one of major environmental stresses that adversely affects the growth and production of plants [7, 8]. Levy et al. [9] observed considerable losses in yield and quality of potato tuber under water limitations. Drought-induced damages in plants could be associated to reduction in cell enlargement as a consequence turgor loss, thereby limiting growth and development [10, 11]. Hence, the availability of sufficient water is crucial for normal plant growth and development [7]. Plants uptake nutrients dissolved in water solution, which is readily absorbed through roots, suggesting the importance of water as a vital component of photosynthesis. In contrast, water stress negatively affects plant metabolism as well as morphology. Plants adaptation levels against drought stress depend on the diversity, growth stage, intensity of stress, and duration [12]. The scarcity of irrigation water, especially at reproductive stage, may drastically decrease crop yields in arid areas [13]. Wheat, being an important staple food crop, is mostly cultivated in arid and semi-arid regions of the world [14]. Therefore, it is imperative to develop strategies aimed at increasing wheat production in dry soils.

Silicon (Si) is the second most abundant element present on the earth's surface [15] but it is not available in free form as it is always associated with other elements in the form of silicates and oxides [8]. Recent studies provide evidence that Si minimizes the drastic effects of biotic and abiotic stresses to improve the growth and yield of crops [2]. Si availability markedly enhances crop production by reducing transpiration and increasing water absorption in plants under water deficit conditions [16]. Foliar application of Si helps to maintain high water potential and relative water content in plants exposed to osmotic stress conditions [17]. Moreover, it promotes leaf erectness, increases tissue water potential and regulates stomatal conductance under high transpiration conditions [18]. Also, Si ameliorates the oxidative damages by increasing the antioxidant potential, and enhances carboxylase activities under drought stress conditions [19]. Pilon et al. [20] reported that Si spray helps to maintain the chlorophyll content that increases photosynthesis under drought stress conditions. More recently, Bukhari et al. [2] showed the protective effects of Si by regulating the antioxidant enzymes such as catalase (CAT), ascorbate peroxidase (APX), peroxidase (POX) in wheat under water limitations.

Like Si, potassium (K) is a key nutrient that helps plants to withstand water limitations by regulating various metabolic functions such as synthesis of proteins, ionic homeostasis, stomatal conductance, and activation of enzymes [21]. Foliar K application can supplement and ensure the availability of nutrients for higher yields [22]. Spraying wheat plants with K, before the onset of dry season, may help to reduce the adverse effects of drought on plant development, and thereby increases wheat yield [23]. Also, K plays a crucial role in the conversion and storage of carbohydrates to enhance the quality of produce [21]. The positive effects of K are related to the increased availability of minerals and nutrients (N, P, K etc.) to increase plant growth and development under extreme conditions [24]. About 50 enzymes require K as an intermediate for activation and regulation [25]. Moreover, K promotes the transportation of assimilates and regulation of stomatal aperture in plants [26]. Deficiency of K may reduce grain size and weight as K availability grain length, size, and filling in wheat [24]. Tahir et al. [27] found that exogenous application of Si (using potassium silicate or $K_2Si_2O_5$ as a source) decreases sodium percentage in wheat grains by reducing its translocation from roots towards shoots.

Considering the beneficial effects of Si and K on crop growth and yield, the present study was performed to evaluate the physiological and biochemical events regulated by exogenous Si and K application ($K_2Si_2O_5$) to increase wheat yield under water deficit conditions. We hypothesized that foliar spray of $K_2Si_2O_5$ helps to maintain photosynthetic machinery and regulates antioxidant enzymes to improve wheat yield under drought stress conditions.

2 Materials and Methods

2.1 Experimental Site

The seeds of local wheat variety "Johar" were obtained from Regional Agriculture Research Institute (RARI) Bahawalpur. The sowing was done on 20th November 2018, and the seed rate was 148.26 kg/ha. The inorganic fertilizers were applied at the recommended rates of 150 kg/ha, 112 kg/ha, and 60 kg/ha respectively for nitrogen (N) phosphorus (P) and K. The fertilizer sources used were urea, diammonium phosphate, and sulfate of potash for N, P and K, respectively. The split dose of

N, and the whole of P and K were applied at the time of sowing while the remaining half dose of N was applied in two splits with second and third irrigations. The standard plant protection measures were 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 in a randomized complete block design with split plot arrangements. The foliar application of $K_2Si_2O_5$ was considered as main factor with four different levels i.e. T_0 = control (foliar application of water), and $T_{1,}$ $T_{2,}$ T_3 (i.e. foliar application of potassium silicate solution at the rate of 1%, 2% and 3%, respectively). The Knapsack sprayer was used to perform the foliar application of $K_2Si_2O_5$. The irrigation levels were considered a sub-factor with varying irrigation regimes (i.e. I_0 = control irrigation, I_1 = irrigation skipped at vegetative stage (at tillering stage around 30 days after sowing), I_2 = irrigation skipped at reproductive stage (at anthesis stage around 75 days after sowing).

The mean monthly temperature (Fig. 1a) and precipitation (Fig. 1b) data during crop life cycle was collected from agrometrological station situated adjacent to the experimental site. The data regarding physiological, growth, and yield attributes were recorded manually.

2.2 Soil Moisture Content

The data regarding soil moisture content was recorded (Fig. 1c) on weekly basis by using theta probe (Delta Devices). All the readings were collected randomly from each treatment from 8 am to 10 am to avoid moisture loss by sunlight.

2.3 Measurement of Leaf Pigments

The fresh leaf samples were collected seven days after the foliar application of potassium silicate and the chlorophyll contents were measured using the method of Arnon [28] and Davies [29]. Fresh leaves of plants (0.5 g) were chopped into small pieces and placed into 5 ml acetone (80%) at 100 °C for overnight for chlorophyll content extraction. The extracted material was centrifuge at 4000 rpm for 5 min to calculate the chlorophyll *a, b* and total chlorophyll observe the absorbance of the supernatant at 645, 652, and 663 nm on spectrophotometer.

$$\text{Chlorophyll a} = [12.7\ (\text{OD } 663) - 2.69\ (\text{OD } 645)] \times \text{V}/1000 \times \text{W}$$
$$\text{Chlorophyll } b = [22.9\ (\text{OD } 645) - 4.68\ (\text{OD } 663)] \times \text{V}/1000 \times \text{W}$$
$$\text{Total Chlorophyll} = [20.2\ (\text{OD } 645) + 8.02\ (\text{OD } 663)] \times \text{V}/1000 \times \text{W}$$

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 as previously describe by Ahmad et al. [8]. 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 and biological yield in kg ha^{-1} by measuring the weight of harvested plant material manually on a digital balance. To estimate the total dry weight per plant, randomly selected plants from each treatment were oven-dried at 65 °C till the constant weight was obtained.

2.4.1 Estimation of Antioxidants Activity

The three enzymes such as peroxidase (POX), catalase (CAT), and ascorbate peroxidase (APX) activities were determined spectrophotometrically (Hitachi-2800). Wheat leaves were homogenized into a 50 mM phosphate buffer composed of 7.0 pH and 1 mM dithiothreitol (DTT) for the determination of these antioxidants by using the standard method as described by Dixit et al. [30].

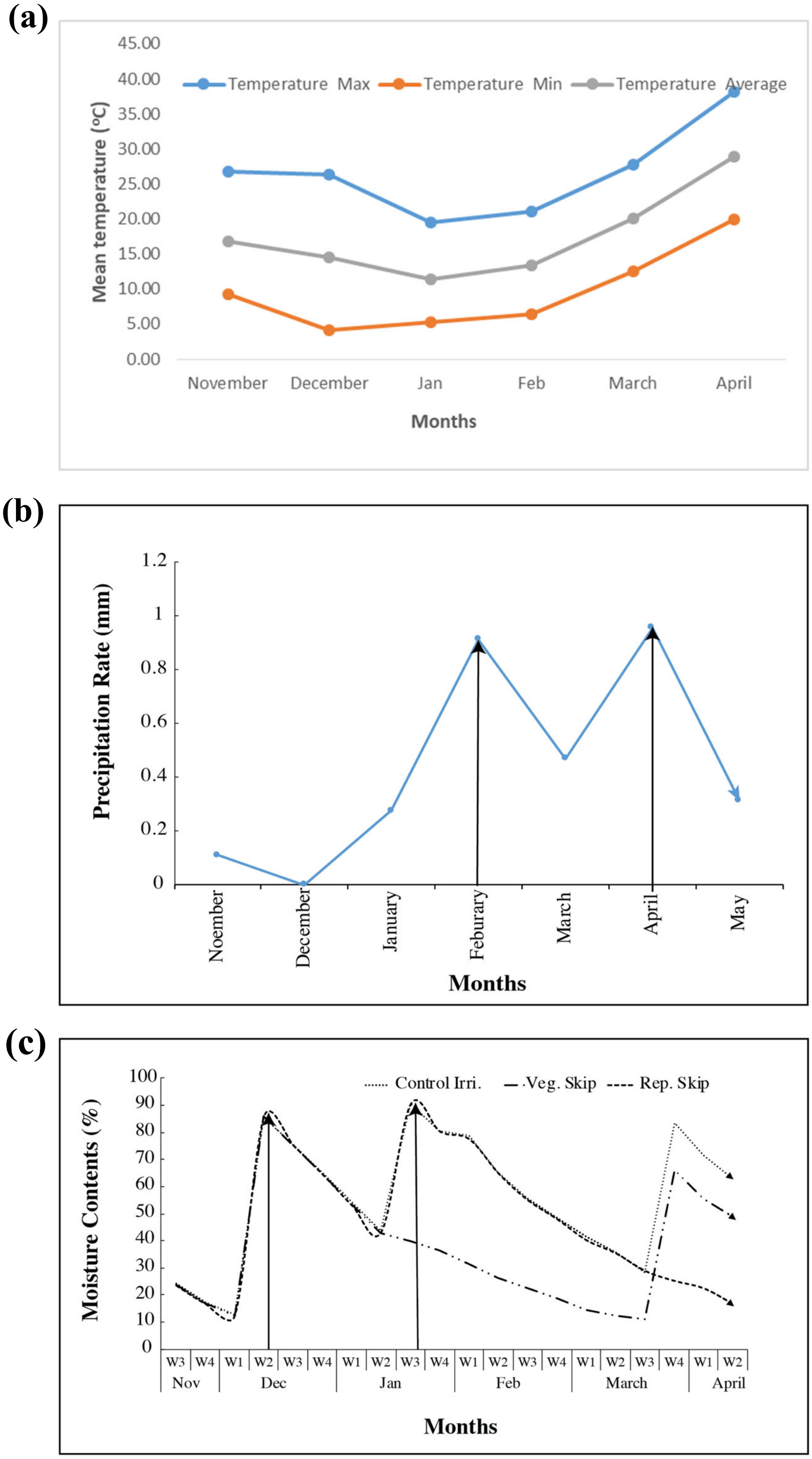
2.4.2 Catalase Activity

The CAT activity was measured using the method defined by Chance and Maehly [31] 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 CAT 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 CAT activity.

2.4.3 Peroxidase Activity

The enzymatic activity of POX was determined by measuring the H_2O_2 peroxidation as an electron donor with guaiacol (Chance and Maehly 1955). The POX reaction solution consists of a 50 mM phosphate buffer with pH 5, guaiacol 20 mM,

Fig. 1 The mean monthly temperature (**a**), precipitation (**b**) and soil moisture content (**c**) during wheat growth period in the field



H_2O_2 40 mM and enzyme extract 0.1 mL. After every 20 s, 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^{-1} FW.

2.4.4 Ascorbate Peroxidase Activity

The 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,

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**

** = $p < 0.01$, * = $p < 0.05$

12 mM H_2O_2, 0.25 mM ascorbic acid and sample extract as described by Cakmak [32].

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 regarding leaf pigments of wheat grown under drought condition is 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 found significant. A commonly observed phenomenon is the reduction of photosynthetic pigments produced under water limited conditions. The current study proposed a significant reduction of chlorophyll contents in plants facing water-limited conditions as compared to control. In treatments potassium silicate applied at 2% to wheat plants provide maximum chlorophyll contents in contrast to control without silicon application. There was a significant correlation with control levels and skipped irrigation condition. The foliar spray of Si showed a significant effect on leaf pigments under skipped irrigation conditions. The maximum leaf pigments were noted in plants treated with 2% potassium silicate under well-watered conditions (Fig. 2a–c).

3.2 Agronomic and Yield Components

The statistical analysis for the agronomic and yield related attributes of wheat under skipped irrigation conditions is presented in Tables 2, 3 and 4. All the recorded parameters showed a substantial variation between the control and skipped irrigation conditions with potassium silicate treatments. The interaction between potassium silicate treatments and skipped irrigations was also significant. The maximum values for all recorded agronomic parameters were noted in plants foliar applied with 2% potassium silicate as compared to treatments under normal as well as drought stress conditions imposed by skipped irrigation (Fig. 3a–c, as well as Fig. 4a–i).

3.2.1 Antioxidant Enzymes

The antioxidant activities of wheat under drought stress condition are presented in Table 5. The POX, CAT and APX activities were markedly increased ($p < 0.01$) under water deficit conditions (Table 5) 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. Wheat plants exhibited the increased enzymatic activity in water deficit condition than normal. The highest POX, CAT and APX concentrations were observed in wheat plants where potassium silicate was applied at the rate of 2% under water deficit conditions. Drought-stressed wheat plants had maximum ascorbate peroxidase (1.4975 ABA digested g^{-1} FW^{-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% (Fig. 5a–c).

4 Discussion

The results of our study showed that the exogenous application of Si and K in wheat could help to mitigate the negative effects of drought stress. The chlorophyll contents are the basic vital unit of the plant photosynthetic process. The chlorophyll biosynthesis is highly associated to the availability of water and mineral nutrients to the plant [33]. Several studies provided evidence 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 [34]. The number of irrigations regulate stomatal opening and biosynthesis of chlorophyll pigments during photosynthesis. Our results are in consistence with the previous studies that Si application can improves photosynthetic action and builds chlorophyll pigments under typical and salt stressed plants [2]. Potassium silicate ($K_2Si_2O_5$) positively affects most of the metabolic process and plays a vital role in the regulation of photosynthesis, respiration, translocation of assimilates from source to sink, the formation of new proteins like chlorophyll pigments [35]. These results suggest that foliar application of $K_2Si_2O_5$ helps in improving leaf erectness, and improves photosynthetic efficiency by increasing chlorophyll content in wheat. The flag

Fig. 2 Effects of various levels of foliar applied potassium silicate on leaf chlorophyll *a* (**a**), chlorophyll *b* (**b**), and the total chlorophyll content (**c**) of wheat under normal and water deficit conditions

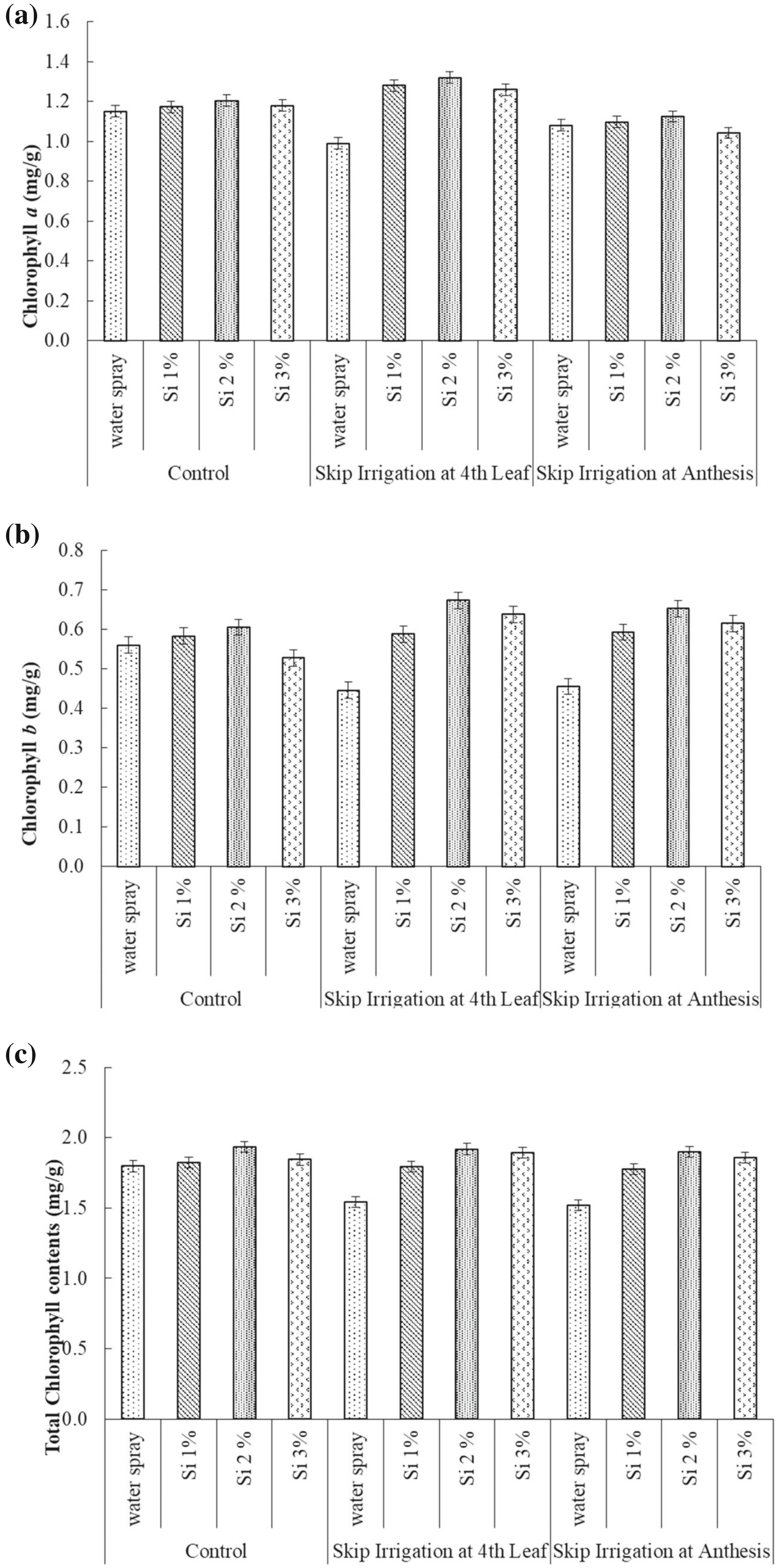


Table 2 Analysis of variance for plant height, flag leaf area, number of tillers m^{-2} and tiller height, and significance in silicon treatments and limited irrigations under field conditions

ANOVA	Plant height (cm)	Flag Leaf Area (cm^2)	No. of Tillers m^{-2}	Tiller Height (cm)
Irrigation	83.31**	892.27**	13,211.1**	389.22**
Treatments	1289.22**	105.91**	17,490.0**	104.76**
Irrigation × Treatments	7.62	1.41	80.2	20.52**

** = $p < 0.01$, * = $p < 0.05$

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 × Treatments	0.25	1.61	8.57	3.56

** = $p < 0.01$, * = $p < 0.05$

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 Si nutrition at the vegetative growth stage, especially at the tillering stage [36].

In our study, the exogenous application of $K_2Si_2O_5$ enhanced the flag leaf area significantly. Our results are in line with Soratto et al. [37] and Andrade et al. [38] who reported a significant increase in flag leaf area of wheat plants due to accumulation of Si in upper leaves. Irrigation treatments significantly affected plant height which might be due to the deficiency of moisture in plant root zone which ultimately causes dehydration of protoplasm; decrease in relative turgidity associated with turgor loss and decreased cell expansion and cell division and also accumulation of toxins in cells [39]. The increase of plant height in our study might be the result of exogenous application of $K_2Si_2O_5$, which might have helped to improve nutrient absorption, enzymatic activities and protein synthesis. K also plays a vital role in biochemical pathways in plants and acts as a key nutrient in the carbon cycle, carbohydrate translocation in the plant, Krebs cycle, and energy nutrient for ATP. The treatment with $K_2Si_2O_5$ increased the plant height, stem diameter, 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 [39].

We found that the nodes per plant were considerably affected by the number of irrigations. The number of nodes and the number of leaves per plant depend on the water potential of soil [40]. Irrigation levels affect the tiller number and tiller length, which reduce the lodging effects of tillers. These findings are in line with Wołejko et al. [41] who reported that development and viability of primary and secondary tillers are greatly affected by salinity, drought, and other environmental stresses. The same phenomenon might have helped the wheat plants to have greater spike length due to higher K availability. Talebi et al. [42] found that $K_2Si_2O_5$ had a positive impact by increasing soluble protein and starch substances in the leaves of potato plants. Silicon application gave

Table 4 Analysis of variance for thousand grain weight, grin yield, biological 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)	Biological yield (kg/ha)	Total Dry weight plant^{-1} (g)
Irrigation	132.58**	712649**	8511366**	31,993.6**
Treatments	124.05**	660506**	768646**	12,140.7**
Irrigation × Treatments	3.05	38178**	38,165	52.5

** = $p < 0.01$, * = $p < 0.05$

Fig. 3 Effects of various levels of foliar applied potassium silicate on growth attributes such as leaf area (**a**), plant height (**b**), and the number of nodes (**c**) of wheat under normal and water deficit conditions

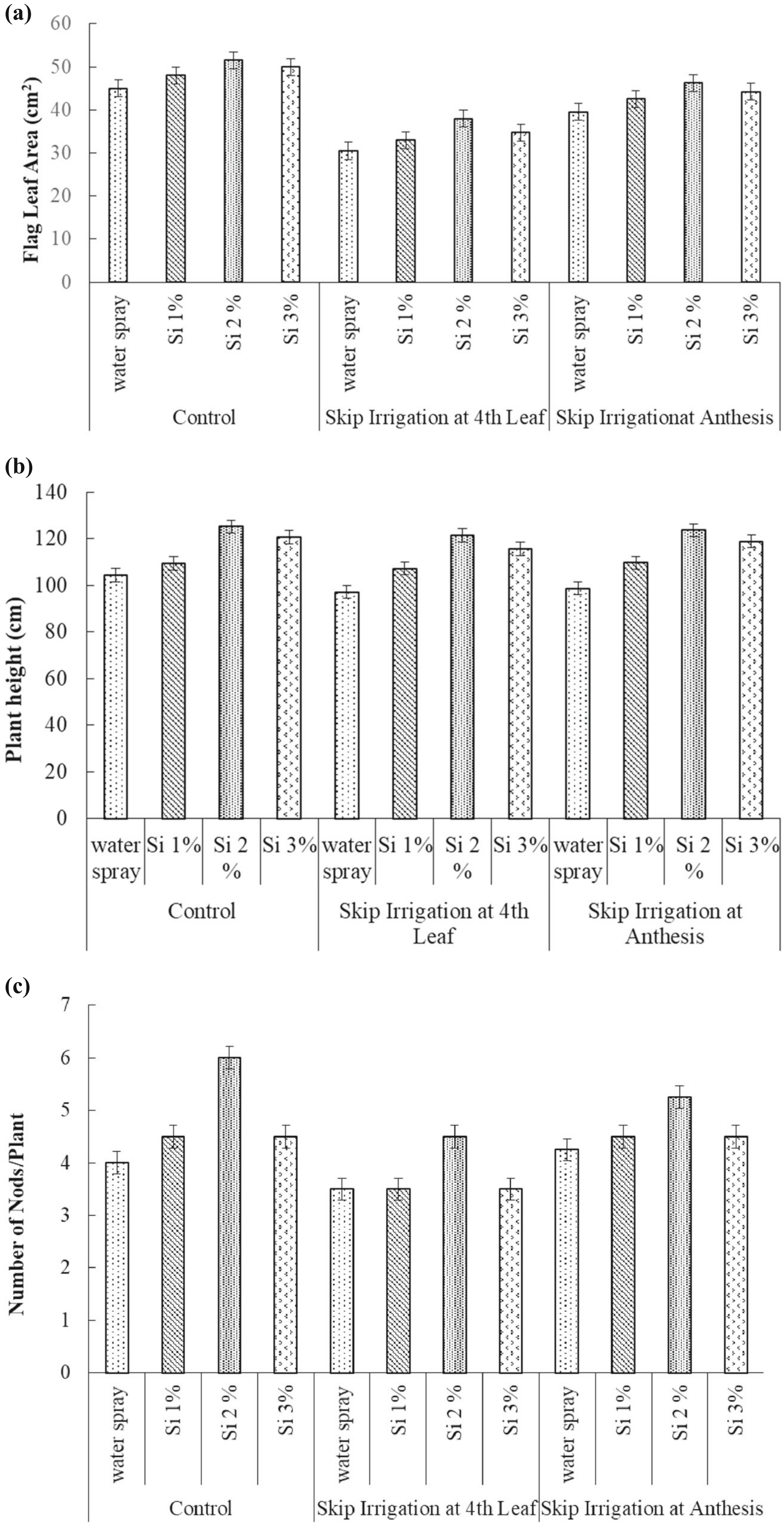
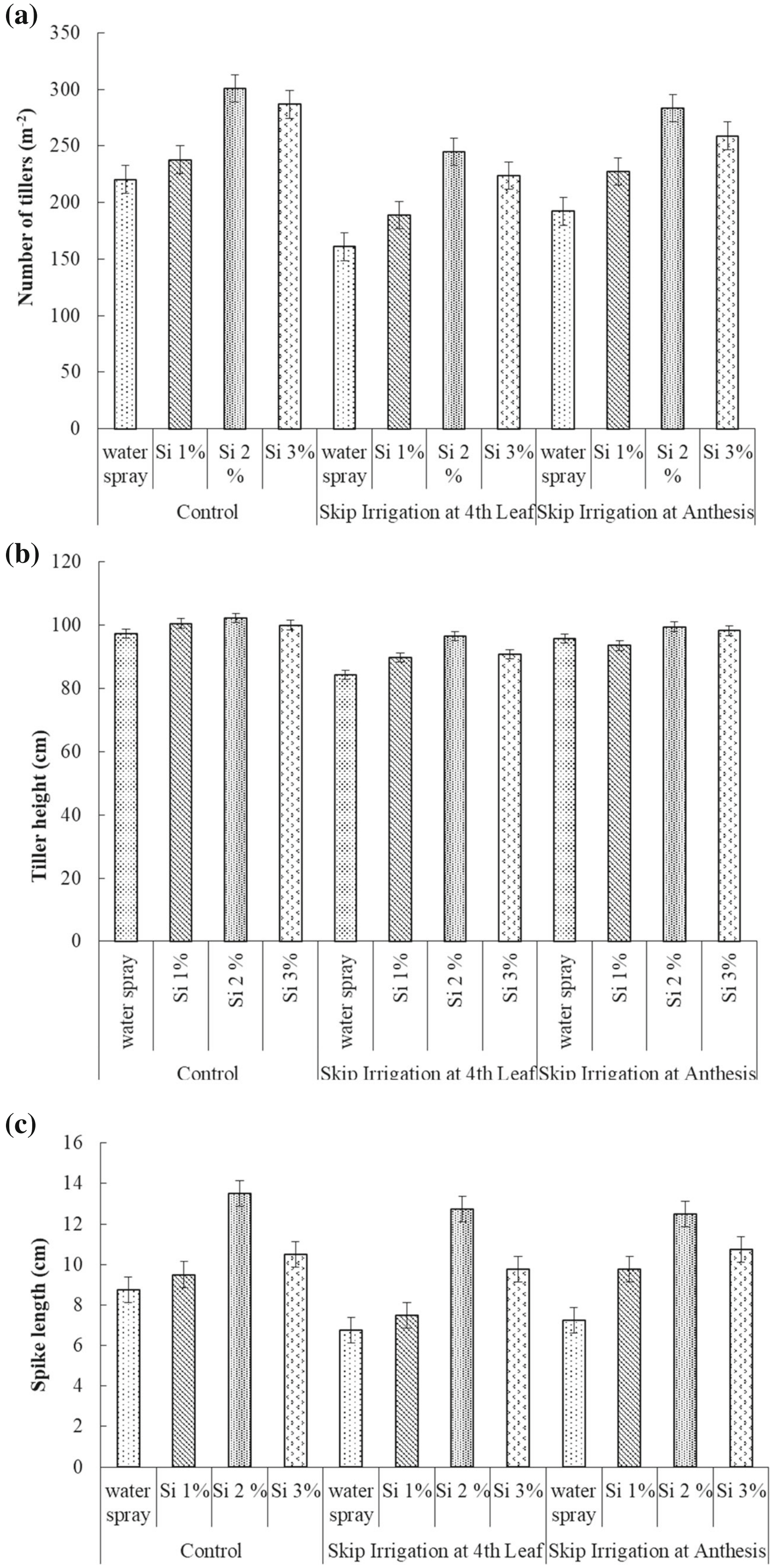


Fig. 4 Effects of various levels of foliar applied potassium silicate on yield and yield attributes such as tiller number (**a**), tiller height (**b**), spike length (**c**), number of spikes per plant (**d**), number of grains per spike (**e**), thousand grain weight (**f**), grain yield (**g**), biological yield (**h**), and total dry weight per plant (**i**) of wheat under normal and water deficit conditions



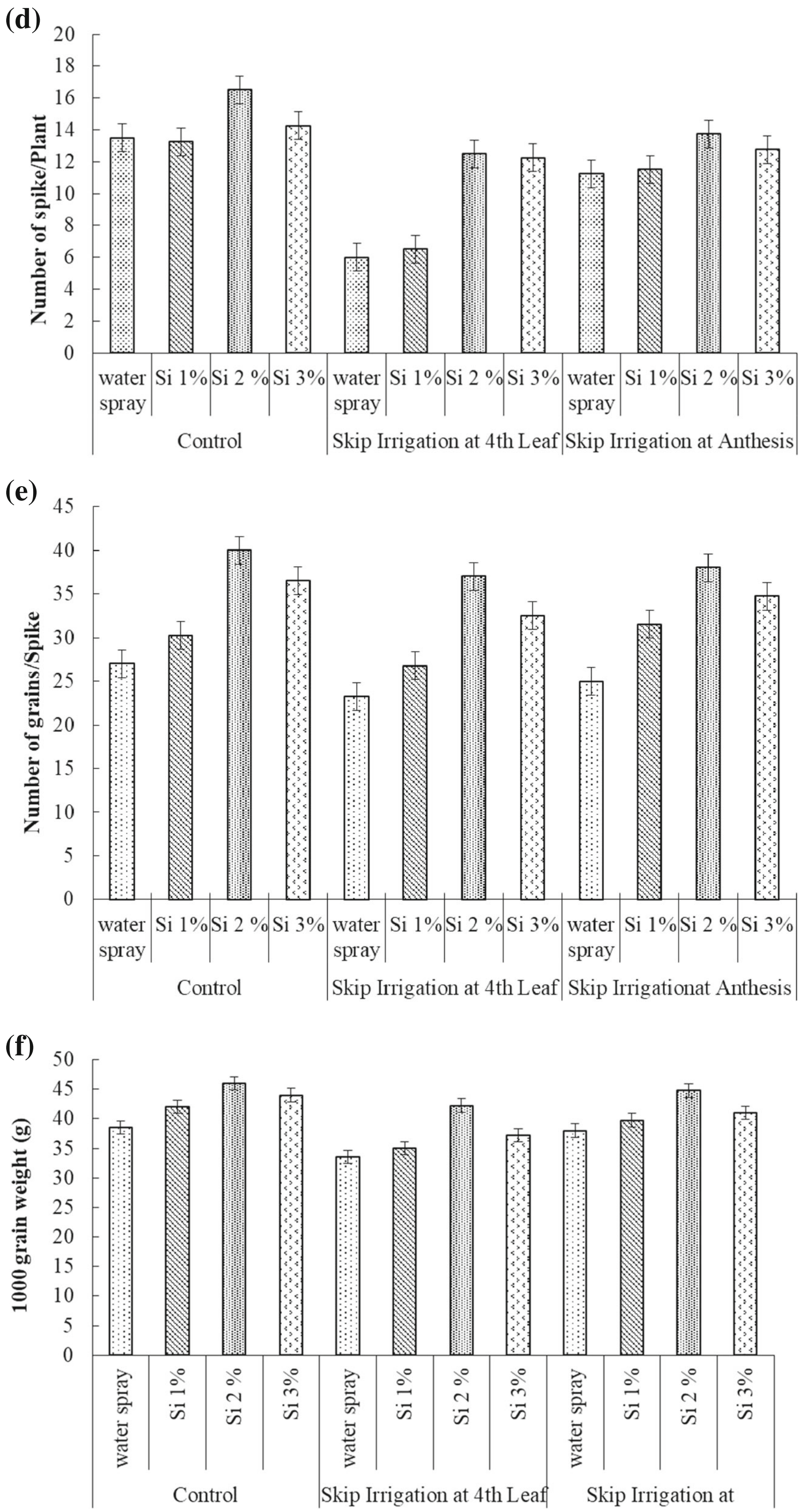


Fig. 4 (continued).

the most elevated N, P and K contents in plant leaves, which might due to their higher absorption rate in the plant roots. Si helps P to become more accessible to the plants however it can also compete with plants for its fixation [8].

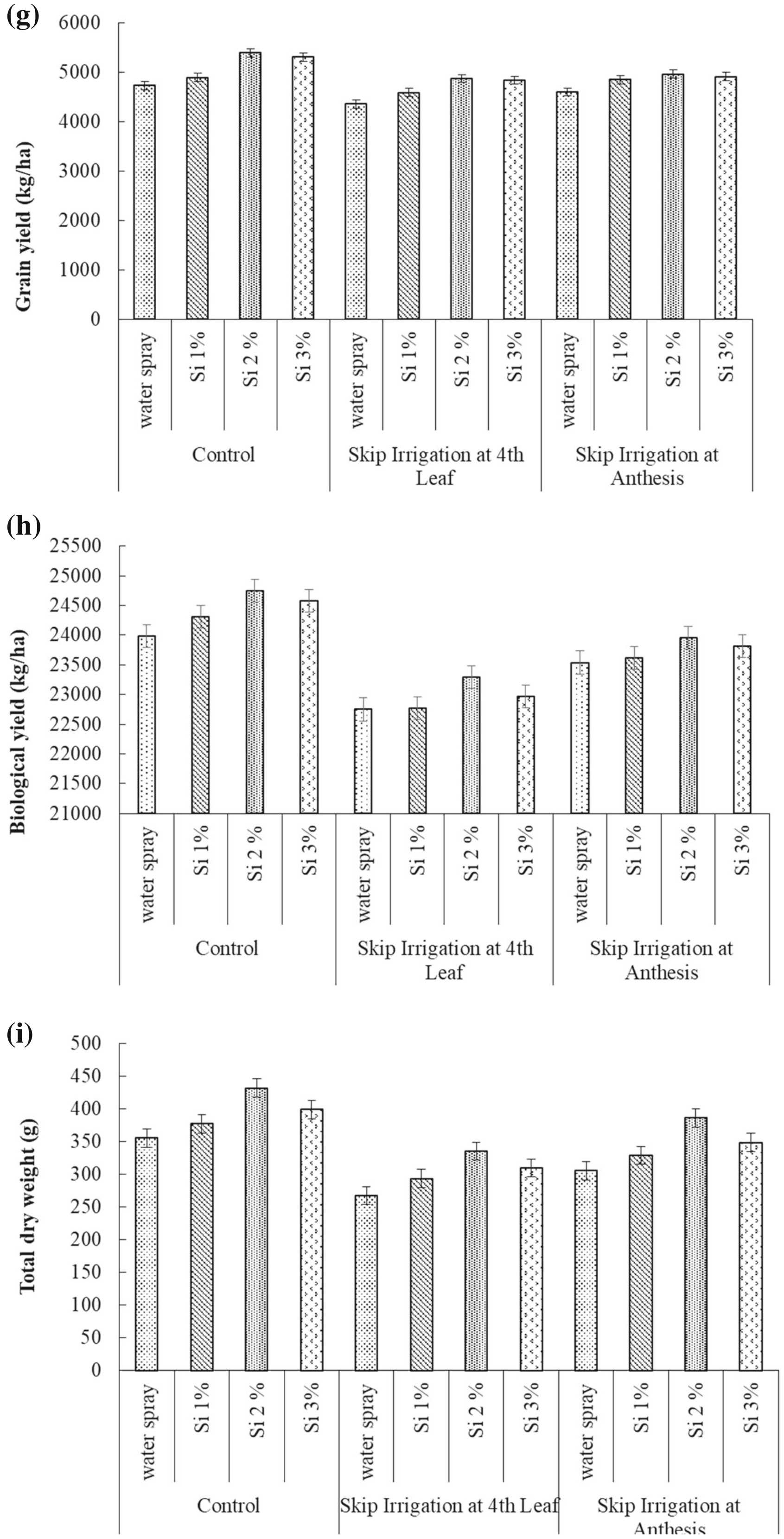


Fig. 4 (continued).

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	POX
Irrigation	2.40**	102906**	3539.48**
Treatments	0.10**	823**	287.23**
Irrigation × Treatments	0.03**	128**	11.33

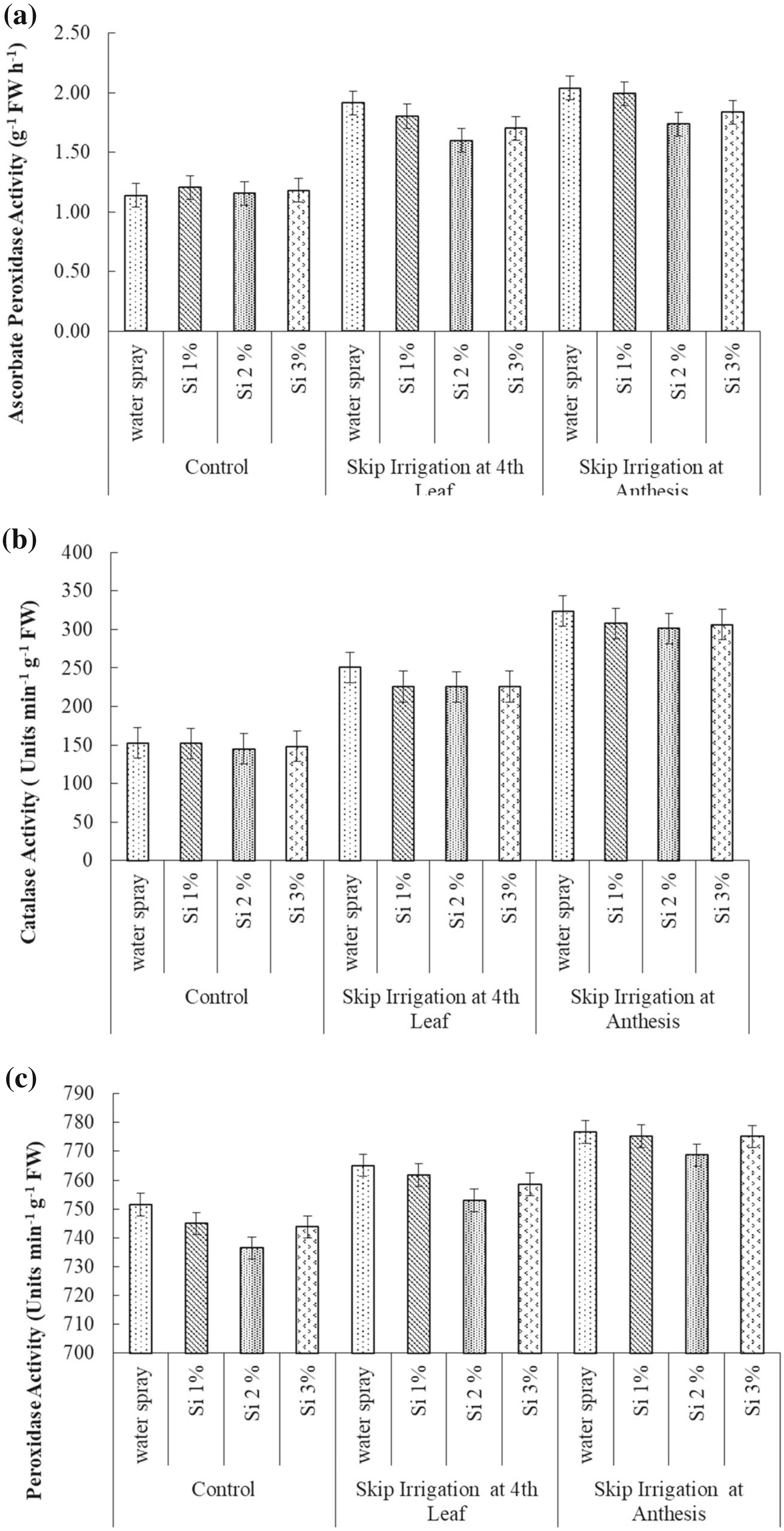
** = $p < 0.01$, * = $p < 0.05$

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. In the present study the number of spikes per plant also increased with exogenous application of $K_2Si_2O_5$. Treatments with foliar application of potassium silicate at vegetative and reproductive stages resulted in more spikes and spike weight per plant. These results are also in agreement with Latati et al. [43]. In skipped irrigation treatments, the grains in each spike were greatly reduced due to empty spikelets and premature seed fillings which also caused the shedding of spikes before grain filling. Water stress especially during reproductive development disturbs the uptake of nutrients from the soil and inefficient translocations of metabolites, which ultimately affects the grain yield and development of grains. K is the cofactor for several enzymes, which also affects starch synthesis in grains. 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 Si and maximum translocation of nutrients and better utilization of N and maximum photosynthates production in plant leaves. The 1000-grain weight was also significantly higher in wheat plants treated with foliar spray of $K_2Si_2O_5$. The reason for reduced yield in other treatments was possibly due to less water availability, reduced nutrient uptake and inefficient metabolic process required for a healthy crop and yield production [44]. The biological yield is the indication of total biomass produced by the plant during the whole period of plant growth and development. The biological 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. In the present study, the highest biological yield was attained with potassium silicate applied at the rate of 2% at the vegetative stage of plant growth, also reported by Reynolds et al. [45].

The osmotic potential from the reduction of water content and specific toxic effects caused by sodium and chlorides can also be reduced by the application of $K_2Si_2O_5$ [46]. 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 P by roots, and also provide the root growth strength in pepper under salinity conditions [47]. Si plays a significant role in wheat biomass production, plant growth, and development, improved the photosynthetic activities, translocation of nutrients [19]. The beneficial effect of K on plant development includes the increase in the fertilizer absorption efficiency leading to the maximum availability of micronutrients such as iron and zinc [48]. The effect of $K_2Si_2O_5$ on cell membrane stability and nutrient uptake are mainly due to its ability to act as phytohormones [49]. Under drought conditions, the dry weight of the plant may slightly increase while the foliar application of $K2Si_2O_5$ maintains the plant structure and provide the ability to withstand extreme conditions [49]. Our results are similar to Iqbal et al. [50] who studied the effect of Si on wheat under water stress conditions. The K concentration highlights 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, increases dry matter due to maximum accumulation of zinc and iron, which increases the production rate of protein in the plant [26].

The increase in antioxidant and physiochemical potential in the treatments with Si application might have greatly helped in ameliorating the drastic effects of drought stress. Tesfay et al. [51] also reported the effect of Si on the reduction of lipid peroxidation, increase in CAT activities, and improvement of fruit quality due to increase in the antioxidant pool in plants. Bozorgi et al [52] observed that application of $K_2Si_2O_5$ increased the endogenous cytokinins and auxin levels, which directly improve the yield of a plant. Plants, with the help of their enzymatic and non-enzymatic antioxidant mechanisms, prevent oxidative damage to their cells and regulate the amount of the ROS species in plants [53]. 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 [54]. The breakdown of H_2O_2 is carried out by the combined effort of enzymes CAT and POX. Both CAT and POX function collectively act to scavenge H_2O_2 and singlet oxygen [55]. Increase in POX contents might also be the as a result of the plants exposed to the drought. Our findings are in agreement with Hussain et al. [56] and Wang et al. [57].

Fig. 5 Effects of various levels of foliar applied potassium silicate on enzymatic activities of ascorbate peroxidase (**a**), catalase (**b**), and peroxidase (**c**) of wheat under normal and water deficit conditions



5 Conclusions

In conclusion, we found that drought stress negatively affects the physiological and biochemical events that ultimately reduce wheat growth and yield under water limitations. However, the foliar spray of $K_2Si_2O_5$ at anthesis stage could be used as a promising approach to mitigate the damaging effects of drought stress in wheat.

Author Contributions MA planned and supervised the research, MIJ conducted the research work; MRS and AH wrote the introduction part; MIJ and MKE wrote the manuscript; MA and MIJ did the statically analysis and graphical representation; ZA read the manuscript as proofreading and arrange according to journal style; FN provided reagents, assisted in the analytical work and improved the English language quality of the manuscript.

Data Availability Raw data and materials are available.

Declarations

Not applicable.

Consent to Participate All authors participate for the preparation of manuscript.

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Conflict of Interest All authors declare that they have no conflict of interest.

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