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Silicon the Non-Essential Beneficial Plant Nutrient to Enhanced Drought Tolerance in Wheat

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1. Introduction

Present water scarcity is a severe problem and cause of deterioration in quality and productivity of crops to reduce crop yield in arid and semi-arid regions. Silicon is known to better the deleterious effects of drought on plant growth and development. Silicon (Si) found to be an agronomically important fertilizer element that enhances plant tolerance to abiotic stresses (Liang et al., 2005). Silicon also known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic efficiency, erectness of leaves and structure of xylem vessels under high transpiration rates due to higher temperature and moisture stress (Hattori et al., 2005). Similarly, Gong et al., (2003 and 2005) observed improved water economy and dry matter yield of water under application of silicon. A number of possible mechanisms were proposed through which Si may increase salinity tolerance in plants, especially improving water status of plants, increased photosynthetic activity and ultra-structure of leaf organelles. The stimulation of antioxidant system and alleviation of specific ion effect by reducing Na uptake were also drought tolerance mechanisms in plants exposed to silicon application (Liang et al., 2005).

2. Silicon accumulation and its uptake in plants

Silicon (Si) is most abundant in soil next to oxygen and comprises 31% of its weight. It is taken up directly as silicic acid (Ma et al., 2001). It primarily accumulated in leaves because it is distributed with the transpiration stream. In dried plant parts the silica bodies are located in silica cells below the epidermis and in epidermal appendices (Dagmar et al., 2003). Being a dominant component of soil minerals the silicon has many important functions in environment. Many studies have suggested the positive growth effects of silicon, including increased dry mass and yield, enhanced pollination and most commonly

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increased disease resistance (Rodrigues, et al., 2004). Silicon can also alleviate imbalances between zinc and phosphorus supply. Gypsum is known to improve the productivity of dispersive soils and Sodium silicate has shown to maintain root activity under waterlogged conditions (Ma et al., 1989). Water stress is common problem in the rainfed regions of the world now a day, which have caused deviation of plant functions from normal to abnormal. Therefore, it's necessary to provide plants such type of nutrition which can maintain water balance in the plants. Silicon is considered to be important element under stress because it increased drought tolerance in plants by maintaining leaf water potential, assimilation of CO_2 and reduction in transpiration rates by adjusting plant leaf area (Hattori et al., 2005). Maintenance of higher leaf water potential under stress is one of remarkable feature which silicon nutrition does for plants as reported by Lux et al., (2002). Silicon was reported to enhance growth of many plants particularly under biotic and abiotic stresses (Epstein, 1999). A number of possible mechanisms have been proposed by which Si would increase resistance of plants against salinity stress which is a major yield limiting factor in arid and semiarid areas. (Al-aghabary et al., 2004).

3. How silicon can coup biotic and abiotic stresses

Silicon (Si) is reported to have beneficial effects on the growth, development and yield of plants through protection against biotic and abiotic stresses. Silicon has not yet been considered a generally essential element for higher plants, partly because its roles in plant biology are poorly understood and our knowledge of silicon metabolism in higher plants lags behind that in other organisms (such as diatoms). However, numerous studies have demonstrated that silicon is one of the important elements of plants, and plays an important role in tolerance of plants to drought stress. Agarie et al., (1998) reported that silicon could decrease the transpiration rate and membrane permeability of wheat (*Triticum aestivum* L.) under water deficit induced by polyethylene glycerol. In Pakistan, little work has been done on silicon applications mostly on wheat crop being staple food crop of the country, cultivated under a wide range of climatic conditions. Its contribution towards value added in agriculture and GDP is 13.1 % and 2.7 % respectively. Wheat was cultivated on an area of 8.81 million hectares with the production of 24.2 m. tons and yield of 2750 Kg ha^{-1} (Economic Survey of Pakistan, 2010-11). It is estimated that rainfed area contributes only about 12 percent of the total wheat production. The Punjab province contributes over 71 percent of the national wheat production while the Punjab barani tract contributes 25 percent of the wheat production in the province. The yield of the crop can be increased at least two times with proper management of production factors. The crop also suffers from severe moisture stress that plays a major role in lowering the yield under rainfed areas. So, present study was conducted to evaluate the response of two wheat varieties and two lines under different levels of potassium silicate which will be source of silicon in this study. The specific objectives of proposed study were to evaluate the performance of different wheat varieties and lines under silicon enhanced drought tolerance and to verify that silicon may be useful to enhance the drought tolerance.

3.1 Methodology

The experiment relating to the study of Silicon on wheat growth, development and drought resistance index was conducted in Department of Agronomy, Pir Mehr Ali Shah, Arid

Agriculture University, Rawalpindi. Pakistan. Seeds of two varieties Chakwal-50, GA-2002 and two lines NR- 333 and NR- 372 were taken from National Agricultural Research Center (NARC). The experiment was laid out in glass oven sterilized Petri dishes lined with two layers of Whattman filter paper and one layer of toilet roll. The filter paper and toilet rolls were irrigated with respective solutions at their saturation point and excess solution was discarded. Ten seeds of each variety were sown in total 60 Petri dishes which were set in a complete randomized block design. The lid covered Petri dishes were placed in a germinator under constant darkness at a temperature of 20°C and 30-40 % relative humidity. The solution treatments were applied as T1= control (water only), T2= 5 % Potassium silicate, T3= 10 %, Potassium silicate without irrigation, T4= 5% Potassium silicate T5= 10% Potassium silicate with irrigation. In the experiment II earthen pots of dimensions (25cm length 20cm diameter) with an area of 500cm^2 covered with aluminum foils to prevent an increase in soil temperature caused by solar radiation. Pots were irrigated before adding soil. Each pot was filled with 10 kg of well pulverized soil. Fertilizer was added on the basis of soil weight in the pots. Two wheat cultivars and two wheat advanced lines with three replications were used as plant material in the present study. Ten seeds of each cultivars and advanced lines were sown per pot. At three leaf stage, all the treatments were applied and potassium chloride was applied to the control pots to yield the same total potassium as in Si treatment. The pH in both solutions was adjusted to pH 5.5 with HCl prior to application. Plastic sheets coated with aluminum film were placed on the soil surface to prevent evaporation from the pots. The treatments of the study were:T_1: Control, T_2: 5 % level of Potassium silicate (5: 95ml) without irrigation, T_3: 10 % level of Potassium silicate (10: 90ml) without irrigation, T_4: 5 % level of Potassium silicate (5: 95ml) with irrigation. (300mm) and T_5: 10 % level of Potassium silicate (10: 90ml) with irrigation. (300mm). Data was collected about crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR) and leaf area index (LAI) using the formula by Gardner et al. (1985) while leaf area was measured with the help of CI-202 area meter by averaging the value taken from three plant samples. However, leaf area duration (LAD) was calculated by formula proposed by Power et al., (1967). Similarly, physiological parameters like photosynthesis rate (A) (μ mole/m^2/second), transpiration rate (E) (mole/m^2/s), stomatal coductance (gs) (mol m^2 s^{-1}) were measured by Infrared Gas Analyzer (IRGA) at flag leaf stage (Long & Bernacchi, 2003). Leaf membrane stability index (LMSI) was determined according to method described by Chandrasekar et al., (2000). Meanwhile leaf succulence (mg/m^2) was measured by leaves taken randomly from each plant. Fresh leaf weight was taken and their area was measured and leaves were dried at 70°C for one week and dry weight was taken. Succulence was calculated by using formula (Succulence = fresh weight-dry weight/leaf area). Relative water content (RWC) was measured from fully expended leaves. The leaves were excised and fresh weight (FW) was immediately recorded, then leaves were soaked for 4 hours in distill water at room temperature, and turgid weight (TW) was recorded. After drying for 24 hours at 80 °C total dry weight (DW) was recorded. Relative water content was measured according to that formula (Barrs & Weatherly, 1962). Meanwhile epicuticular Wax (mg m^{-2}) were measured from leaves (0.5 g) randomly taken from the plant and their area was measured. Three leaf samples were washed three times in 10 ml carbon tetrachloride for 30 sec per wash. The extract was filtered, evaporated to dryness and the remaining wax was weighed. Wax content was expressed on the basis of leaf area only, i.e. wax content mg cm^{-2}

(Silva Fernandus et al., 1964). SPAD chlorophyll meter was used to measure chlorophyll contents at flag leaf. Drought resistance index is define as DC multiplied by variety minimum yield and then divided by average minimum yield of the varieties used in experiments (DRI =DC× (¥a / Ya) where DC =Drought resistance coefficient=Ya /Ym, Whereas Ya is the average yield of all the varieties with no irrigation, ¥a is yield of the variety without irrigation and Ym is maximum yield of variety under irrigation). Proline content (µg g^{-1}) was estimated spectrophotometerically following the ninhydrine method (Bates et al. 1973). The silicon concentration in leaves (mg) were measured at flag leaf stage according to Lux et al., (2002) The dried powdered plant sample was ashed in a muffle oven at 500 ^{0}C for 5 h. The plant ash was dissolved in diluted HCl (1: 1; 10 ml) at 100 ^{0}C. The process of dissolving in HCl and evaporation to dryness was repeated three times. Then, diluted HCl (1: 1; 15ml) was added and sample was heated at 100 ^{0}C, filtered placed into a ceramic crucible and ashed again in the oven at 540 ^{0}C for 5 h. After cooling, the weight of silicon was determined gravimetrically. At the end observations collected were analyzed for variance by STATISTIX 8.1.

4. Effect of Silicon on growth kinetics

4.1 Crop Growth Rate (CGR) (g m^{-2} day^{-1})

Crop growth rate is unit increase in drymatter of crop on daily basis. Temperature and moisture are the main determinant factors which affects growth and many other physiological processes of plants. Significant findings were observed for CGR at flag leaf stage under present study. The results revealed that maximum CGR was observed for NR-333 line under 10 % silicon application with irrigation followed by Chakwal-50 and NR-372 (Table 1). Whereas, NR-333 under controlled conditions exhibited minimum crop growth rate. Application of silicon enhanced crop growth rate under stressed conditions. Our results were in the line with the findings of Hattori et al., (2005)) who reported an increase in drymatter and growth rate of crop by silicon application under drought stress conditions.

4.2 Relative Growth Rate (RGR) (g g^{-1} day^{-1})

The pattern of relative growth rate for different wheat genotypes under various silicon treatments presented in table 2 .The results of current study depicted that maximum relative growth rate was observed for Chakwal-50 under 10 % silicon application with irrigation, followed by NR-333 under same treatment. While, minimum relative growth rate was exhibited by NR-333 under controlled conditions (without silicon application). This variation in relative growth rate might be due to difference in genetic potential and adaptability measures to cope stress using silicon enhanced treatments. Our results were similar to the findings that RGR decreased under stress conditions and negatively related to plant age.

4.3 Net Assimilation Rate (NAR) (g cm^{-2} day^{-1})

Remarkable increase in net assimilation rate (NAR) was recorded due to silicon treatments. The maximum NAR was recorded for Chakwal-50 (6.54 g cm^{-2} day^{-1}**)** with 10% of silicon application which might increase water conversion capacity toward assimilates by boosting photosynthesizing machinery. However, under control conditions, NAR was 1.99 g cm^{-2} day^{-1}

for NR-333 which further confirmed the significant effect of silicon application on NAR (Table 3). Drought tolerant genotypes have maximum NAR under silicon nutrition as compared to other genotypes. The effect of silicon enhanced treatments to further elucidate effect of silicon on NAR of crop revealed that silicon application has positive effect on crop NAR.

4.4 Leaf area (cm^2)

Leaf area might be an important index in determining crop growth as it directly involved in many plant processes. Photosynthesis, transpiration and stomatal aperture take place in leaves of plants. Leaf area attributed toward good uptake of water and translocation of photoassimilates from source to sink. Results demonstrated significant variation for leaf area among different cultivars under various silicon treatments (Table 4). The results demonstrated maximum leaf area for Chakwal-50 **(**201.67 cm^2**)** under 10 % silicon application with irrigation. While, minimum leaf area was observed for NR-333(173.00 cm^2) under controlled condition. Leaf area significantly contributed toward physiological indices, which boosted up crop growth and accumulation of more photoassimilates from source to sink and consequently, it led to higher grain yield (Fig.1). Our results were in the line with the findings of Ahmed et al., (2011a) who reported significant impact of stress conditions upon leaf area of crop.

4.5 Leaf area index

Leaf area index (LAI) at flag leaf stage among four wheat cultivars under five different concentrations of silicon application revealed that silicon nutrition has depicted significant effect upon crop growth. However, this effect was more significant for Chakwal-50 as compared to other genotypes which are drought resistance exhibiting maximum leaf area and ultimately higher leaf area index as compared to other genotype (Table. 5). While, minimum leaf area index was noted down for GA-2002 under controlled treatment. The increment in LAI due to silicon nutrition was considerable (Ahmed et al., 2011a).

4.6 Leaf area duration

Leaf area duration for all four genotypes under different silicon application was shown in Table.6. Leaf area duration increased from tillering to flag leaf stage and reached maximum at flag leaf stage as it is the critical stage of wheat. Maximum physiological attributes take place at this stage which determines crop productivity. In current study, Chakwal-50 showed maximum leaf area duration (116.00) under 10% application of silicon, whereas, NR-333 exhibited minimum leaf area duration (87.00) under control conditions.

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	10.10ijkl	10.00jkl	9.23l	9.56l	9.72E
T2	11.53ghi	9.83kl	10.10ijkl	11.23hijk	10.68D
T3	12.10fgh	11.36hij	12.85efg	13.50ef	12.45C
T4	16.23bc	13.90de	15.20cd	16.93ab	15.57B
T5	18.10a	16.77ab	18.20a	18.17a	17.80A
Mean	13.61AB	12.73C	13.12B	13.88A	

LSD for Genotypes= 0.64, Treatments=0.72 and Genotypes x Treatments= 1.43

Table 1. Crop growth rate (g m^{-2} day^{-1}) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	87.37fg	81,13k	73.69l	84.00hij	81.55D
T2	92.23e	86.23gh	83.33jk	86.07ghi	86.97C
T3	93.73de	89.30f	96.53bc	89.03f	92.15B
T4	85.37ghi	83.50ijk	83.17jk	94.90bcd	86.73C
T5	103.00a	93.93cde	96.80b	94.27bcde	97.00A
Mean	92.34A	86.82C	86.70C	89.65B	

LSD for Genotypes= 1.18, Treatments= 1.32 and Genotypes x Treatments= 2.64

Table 2. Relative growth rate ($g\ m^{-2}\ day^{-1}$) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	5.46bc	3.90de	1.99g	2.14fg	3.37C
T2	5.78ab	4.30d	2.75fg	2.91f	3.93B
T3	6.58a	4.70cd	2.88fg	3.02ef	4.30B
T4	5.59ab	4.33d	2.87fg	3.87de	4.25B
T5	6.54a	5.48bc	5.42bc	5.39bc	5.71A
Mean	6.06A	4.54B	3.47C	3.18C	

LSD for Genotypes= 0.41, Treatments= 0.46 and Genotypes x Treatments= 0.91

Table 3. Net assimilation rate ($g\ m^{-2}\ day^{-1}$) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	184.33def	184.00ef	173.00g	183.00ef	181.08D
T2	193.33bc	186.00de	179.33fg	186.00de	186.17C
T3	197.67ab	187.67cde	183.00ef	189.00cde	189.33BC
T4	198.00ab	187.00cde	187.00cde	193.33bc	191.33AB
T5	201.67a	183.00ef	190.67cd	198.67ab	193.50A
Mean	195.00A	185.53C	182.60D	190.00B	

LSD for Genotypes= 2.86, Treatments= 3.19 and Genotypes x Treatments= 6.39

Table 4. Leaf area (cm^2) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	1.16d	0.55k	0.85g	0.68j	0.815D
T2	1.13d	0.72ij	0.81gh	0.72ij	0.845D
T3	1.93b	0.94e	0.92ef	0.85g	1.16D
T4	1.83c	0.85fg	0.77hi	0.78ghi	1.06C
T5	2.32a	1.14d	1.11d	0.95e	1.38A
Mean	1.68A	.85C	.89B	0.79D	

LSD for Genotypes= 0.03, Treatments= 0.04 and Genotypes x Treatments= 0.07

Table 5. Leaf area index (LAI) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	101.67h	98.00i	87.00k	96.00i	95.67E
T2	108.67de	103.00gh	91.00j	101.00h	100.92D
T3	114.00ab	107.33ef	97.67i	105.67fg	106.17C
T4	115.00a	111.67bc	101.00h	110.33cd	109.50B
T5	114.00ab	116.00a	105.00fg	115.00a	112.50A
Mean	110.67A	107.20B	96.33D	105.60C	

LSD for Genotypes= 1.23, Treatments= 1.37 and Genotypes x Treatments= 2.74

Table 6. Leaf area duration (LAD) of wheat genotypes under different silicon treatments

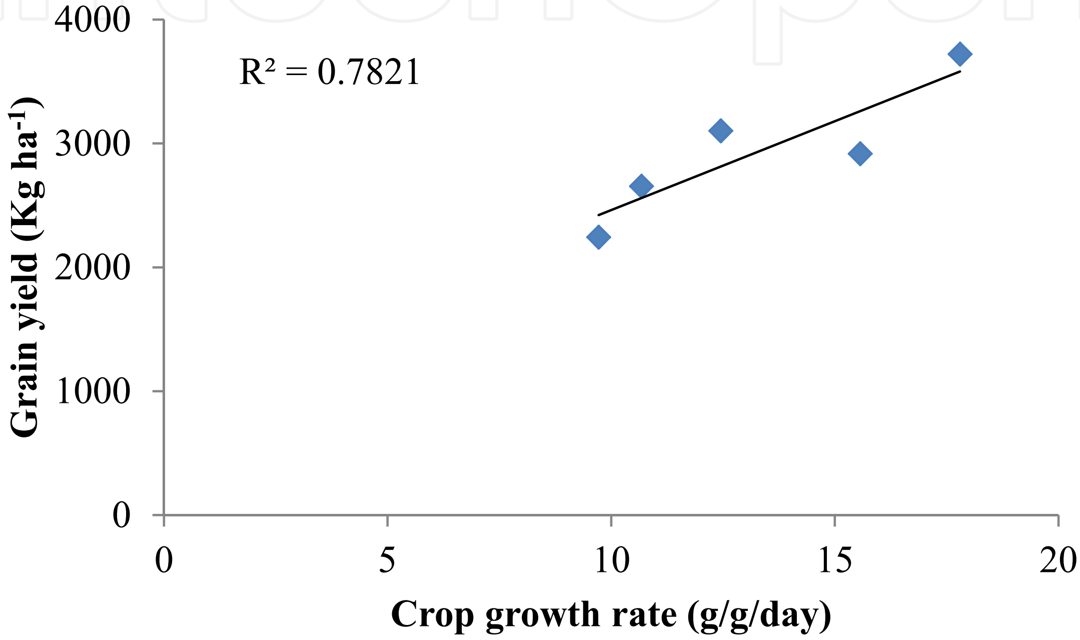

Fig. 1. Crop growth rate and grain yield of wheat genotypes under different silicon treatments

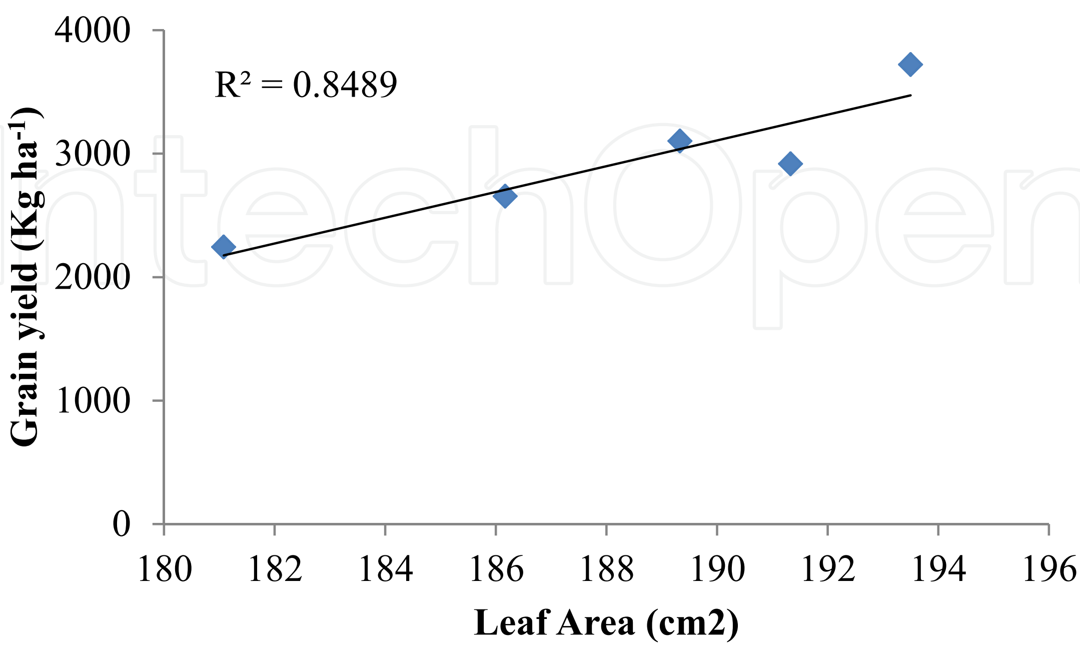

Fig. 2. Leaf area and grain yield of wheat genotypes under different silicon treatments

5. Effect of silicon on physiological parameters

5.1 Photosynthesis (A) (μ mole/m^2/second)

Photosynthesis is a determinant factor for crop growth and development as maximum photosynthesis contributes toward more yield and production. Results demonstrated significant variation for photosynthetic efficiency for various genotypes. Genotypes from diverse climatic regions behaved differently for photosynthetic efficiency. Chakwal-50 (17.47μ mole/m^2/second) performed well over all other genotypes for photosynthesis followed by NR-372 (15.33 μ mole/m^2/second) under 10 % silicon application with irrigation. While, minimum photosynthesis observed in NR-333 (8.23 μ mole/m^2/second) which ultimately led to reduced yield (Table 7). Chakwal-50 genotype has some adaptability characteristics which promoted physiological attributes and ultimately better production due to silicon application. Our results were in the line with the findings of Ahmed et al., (2011b) who reported significant impact of drought variation upon photosynthetic efficiency of wheat crop. Flag leaf stage is crucial stage in crop growth and development as crop produces maximum photosynthate using all available resources and it can only be achieved if suitable genotype sown at optimum time. Increased temperature and reduction in moisture promote photosynthetic efficiency up to an optimum. A linear relationship between photosynthetic rate and grain yield was observed (Fig. 3) which depicted that more photosynthesis led to maximum accumulation of photoassimilates from source to sink and ultimately maximum yield. Chakwal-50 genotypes performed very well due to efficient translocation of photoassimilates from source to sink using available thermal units under drought stress conditions.

5.2 Transpiration rate (E) (mole/m^2/s)

Transpiration is the removal of moisture from plant parts and it has significant impact on yield of crops and a major constituent to measure water use efficiency of agricultural crops. Crop yield is inversely related to transpiration rate. It depends upon climatic variants like solar radiation, temperature, water vapor pressure deficit, wind speed and the water status of the plants (Ahmed et al., 2011a). Present study depicted significant variation among different genotypes under changing silicon concentration which enhanced transpiration rate (Table 8). Resistant cultivars have defensive mechanism to cope with stress and gaining yield potential under limited available resources. The results of present study described maximum transpiration rate for GA-2002 under control and 10% application of silicon, while, minimum transpiration was showed by NR-333 with 5% application of silicon followed by NR-372 under the same treatment. This variation in transpiration might be due to genetic potential of genotypes and various silicon treatments impact. Stomatal aperture plays a vital role in leaves as water evaporates through them. Stomatal conductance and transpiration were positively correlated and stomatal closure led to reduce transpirational losses and ultimately good production. Our results were at par with the outcomes of Ahmed et al., (2011b).

5.3 Stomatal conductance (mol m^2 s^{-1})

Stomata plays important role in plant physiological indices, as water and nutrients enter in plant through stomata. Stomatal conductance is the speed of passage of water and nutrients through stomata. Optimum conductance led to maximum uptake of water and CO_2 for photosynthetic efficiency and ultimately more yield. Stomatal conductance depends upon favourable climatic conditions. Drought resistant genotypes have good conductance of stomata and adaptation strategies to cope stress. The results revealed maximum stomatal conductance for Chakwal-50 (0.42 mol m^2 s^{-1}) with 10% application of silicon as compared to other genotypes and silicon applications. Whereas, NR-333 showed minimum stomatal conductance (0.17 mol m^2 s^{-1}) under controlled conditions (Table 9). Silicon application boosted up physiological attributes under stressed conditions and resistant cultivars showed better response under enhanced silicon concentrations. A positive and linear relationship was observed between stomatal conductance and grain yield which support our results (Fig.4).

5.4 Leaf Membrane Stability Index (LMSI)

Results regarding leaf membrane stability index (Table 10) showed significant variation. It was observed that in control treatment, all the varieties showed little variation in LMSI but all varieties had greater membrane stability as compared to stress conditions. Chakwal-50 showed maximum value of LMSI (84.2%) followed by NR-333 (81.9%) under the 10% application of silicon. On the other hand NR-333 showed minimum value (60.33%) Perhaps this was the distinction which made some varieties able to perform better under water stress condition and others not. Similarly Plants having more LMSI value show less membrane injury by accumulating more saturated fatty acids, which is very important mechanism of plants to resist drought. So the selection of wheat varieties like Chakwal-50 with high LMSI value under drought condition is very essential to increase production.

5.5 Leaf succulence

The outcomes of the current study demonstrated that in controlled condition, Chakwal-50 (15.80 mg/m^2) showed maximum leaf succulence followed by NR-372 (14.70 mg/m^2) (Table 11). On the other hand NR-333 showed minimum value of 6.48 mg/m^2 preceded by GA-2002 (7.42 mg/m^2). It was noted that with increase in water stress, value of leaf succulence was also reduced. Different varieties showed different behaviors, Chakwal-50 and NR-372 showed maximum leaf succulence under enhanced silicon application followed by GA-2002 and NR-333. Some varieties showed less reduction in leaf succulence and some varieties showed much reduction. Here the distinction was developed among drought resistant and drought susceptible varieties. Leaf succulence is important adaptive mechanism of plants to resist drought. Varieties with high LS are considered to be more drought resistant. It has also been observed by many scientists that increased level of leaf succulence under drought conditions is a key adaptive mechanism to resist the drought. Ahmed et al., (2011a) also found that decreasing water potential cause reduction in leaf succulence value. So selection of wheat varieties, having more LS under water stress is very important for water deficit conditions.

5.6 Relative water content

The maximum relative water contents were recorded for drought tolerant genotype due to silicon nutrition. This elaborate that silicon entered inside the plants and might followed an active transport pathway and through xylem it reached inside the leaves in order to maintain water potential under water stress. The results of present study investigated that Chakwal-50 being drought resistant genotype, exhibited maximum relative water contents under enhanced silicon application (91.83%). While, minimum RWC was noted down for NR-372 (71.43) (Table 12). Control treatment (without silicon application) depicted less water contents as compared to silicon enhanced treatments. The findings of Ma et al., (2001) supported our results as they were of the opinion that silicon improved crop relative water potential.

5.7 Epicuticular wax

Epicuticular wax might be an important attribute in drought tolerant genotypes. Maximum epicuticular wax (8.62 mg) was observed in Chakwal-50 (Table 13). Whereas, minimum epicuticular wax was measured for NR-333 (4.36 mg). Drought resistant genotypes develop epicuticular wax on leaves which prohibited loss of water from plant leaves which then be used by plants under stress conditions. Silicon application played a crucial role in development of waxy layer on resistant varieties. The similar result reported by earlier researcher who documented that cuticle wax accumulation increase the drought tolerance in plants and silicon holds a vital place under such circumstances.

5.8 Chlorophyll contents (SPAD)

Crop growth could be related to rate of photosynthesis which is directly proportional to chlorophyll contents in leaves. Plants use chlorophyll to trap light from sun for photosynthesis and green colour of plants is due to absorption of all visible colours instead green by photosynthesizing pigments. In this experiment maximum chlorophyll contents were measured for Chakwal-50 (51.26) followed by GA-2002 (45.60), while, minmum for NR-372(21.33) under control conditions. Our findings were in close agreement with Paknejad et al., (2007) who found that chlorophyll contents in different wheat cultivars could be reduced more than 25% due to drought stress. A linear relationship was observed between chlorophyll contents and grain yield (Fig. 5) which described that increase in chlorophyll contents led to increased photosynthesis and consequently grain yield. So it can be concluded that selection of wheat varieties having more chlorophyll contents under drought stress is very important to increase production.

5.9 Drought resistance index for selected wheat cultivars

Drought resistance index is define as DC multiplied by variety’s minimum yield, and then divided by average minimum yield of the varieties used in experiment. Cultivars showing greater value of DRI are considered to have more resistance against drought. However, the cultivars having less value of DRI were considered to be less resistant to drought. The findings of current study highlighted that Chakwal-50 showed maximum Drought Resistance Index (0.58) whereas GA-2002 showed minimum value (0.34) for drought resistance index. Our results were at par with the findings of previous researcher who calculated the DRI values for seven wheat cultivars grown under irrigated and non-irrigated conditions and found that cultivars having more DRI values were more resistant to drought.

5.10 Proline contents (μg g^{-1})

Proline, accumulates in plants under environmental stresses is proteinogenic amino acid with an exceptional conformational rigidity, and is essential for primary metabolism. It acts as a signal to triggers specific gene action which may be essential for crop recovery from stress.In the present study, proline contents differed significantly among wheat genotypes. Chakwal-50 being a drought resistance genotype, exhibited maximum proline accumulation (52.23 μg g^{-1}) followed by NR-372 (51.70μg g^{-1}). Whereas, minimum proline accumulation observed for GA-2002 (42.70 μg g^{-1}) (Table 16). Similar findings have been documented that proline contents reduced under increased temperature and moisture stress; however, it increased in resistant cultivars which led to higher yield. Grain yield of wheat found to be positively related to proline contents under different silicon regimes (Fig.6).

5.11 Correlation coefficients among physiological attributes with grain yield

Correlation coefficients among physiological attributes with grain yield of various wheat genotypes under silicon enhanced treatments showed variable response. Grain yield of wheat genotypes under stressed conditions and silicon application found to be positively correlated with photosynthesis (A), stomatal conductance (gs), chlorophyll contents (cc), proline contents (PC), relative water contents (RWC) and drought resistance index (DRI). However, significant negative correlation was observed between transpiration rate (E), leaf membrane stability (LMS) and grain yield. Significant and positive relationship led to conclusion that grain yield increase with increase in these physiological indices and application of silicon in this regard holds a vital place. Silicon concentration enhanced resistivity of some genotypes which had adaptability measures to cope stress.

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	11.74fgh	8.56jk	8.23k	9.20ijk	9.42E
T2	13.35def	10.34hij	10.53hi	11.23gh	11.36D
T3	14.34cd	12.49efg	12.5efg	13.47def	13.21C
T4	17.47a	15.15bcd	14.27cde	14.73bcd	14.99B
T5	15.79abc	16.23ab	14.77bcd	15.33bc	15.95A
Mean	14.54A	12.55B	12.06B	12.8B	

LSD for Genotypes= 0.81, Treatments= 0.90 and Genotypes x Treatments= 1.81

Table 7. Net photosynthesis (An) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	5.95bc	6.67a	5.87bcde	5.73cdef	6.05A
T2	5.90bcd	6.13b	6.00bc	5.70def	5.93A
T3	5.90bcd	6.67a	5.73cdef	5.73cdef	6.00A
T4	5.87bcde	5.22gh	4.87i	5.23gh	5.30B
T5	5.47fg	5.60ef	5.30gh	5.17h	5.39B
Mean	5.82B	6.06A	5.55C	5.51C	

LSD for Genotypes= 0.12, Treatments= 0.13 and Genotypes x Treatments= 0.27

Table 8. Transpiration rate (E) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	0.26i	0.24ij	0.37cd	0.24ij	0.28D
T2	0.32fg	0.26i	0.17k	0.28hi	0.26E
T3	0.35def	0.31gh	0.21j	0.33efg	0.30C
T4	0.38bcd	0.37cd	0.26i	0.36cde	0.34B
T5	0.42a	0.39abc	0.30gh	0.41ab	0.38A
Mean	0.35A	0.31B	0.26C	0.32B	

LSD for Genotypes= 0.02, Treatments= 0.02 and Genotypes x Treatments= 0.03

Table 9. Stomatal conductance (Gs) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	80.57bc	76.7efg	80.67abc	60.80i	74.68B
T2	80.03bcde	75.67fgh	77.90c-g	61.27i	73.71BC
T3	80.17bcde	76.90defg	77.93c-g	63.00i	74.5B
T4	78.83b-f	74.80gh	74.83gh	60.37i	72.20C
T5	84.2a	80.33bcd	81.9ab	73.06h	79.88A
Mean	80.70A	76.80C	78.64B	63.70D	

LSD for Genotypes= 1.58, Treatments= 1.77 and Genotypes x Treatments= 3.54

Table 10. Leaf membrane stability index (LMSI) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	15.80a	14.33abc	12.81b-f	14.70ab	14.41A
T2	15.40a	12.59cdef	10.40ghi	12.60cdef	12.74B
T3	14.36abc	11.39defg	9.20hij	12.90bcde	11.96B
T4	13.26bcd	9.24hij	8.53ij	10.80fgh	10.46C
T5	10.86efgh	7.42jk	6.48k	10.40ghi	8.79D
Mean	13.94A	10.99C	9.48D	12.28B	

LSD for Genotypes= 0.91, Treatments= 1.02 and Genotypes x Treatments= 2.03

Table 11. Leaf succulence of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	73.00hij	77.66k	74.76ghi	71.93jk	72.59E
T2	77.03g	72.66ijk	74.80ghi	71.50jk	74.00D
T3	81.66f	76.67g	74.96gh	71.43jk	76.18C
T4	85.20de	81.34f	82.96ef	87.76bc	84.31B
T5	91.83a	86.66cd	88.20bc	89.40b	89.05A
Mean	81.74A	77.60C	79.14B	78.40BC	

LSD for Genotypes= 1.02, Treatments= 1.14 and Genotypes x Treatments= 2.29

Table 12. Relative water content (RWC) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	7.90abc	8.20abc	7.10cdef	8.13abc	7.83A
T2	7.83abc	7.60abcd	6.10fghi	8.16abc	7.42AB
T3	8.26ab	7.33bcde	5.30hij	6.33def	6.88B
T4	5.90ghi	6.36efgh	5.10ij	6.56defg	5.98C
T5	8.66a	5.80ghi	4.36j	5.53ghi	6.09C
Mean	7.71A	7.06B	7.00B	5.60C	

LSD for Genotypes= 0.51 Treatments= 0.57 and Genotypes x Treatments= 1.15

Table 13. Epicuticular wax (EW) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	29.83hi	25.60kl	22.50m	21.33m	24.18E
T2	35.91de	29.67hi	26.63jk	23.10lm	28.82D
T3	45.06b	40.50c	34.13ef	33.06ef	38.19B
T4	39.30c	34.86ef	31.41gh	28.50ij	33.52C
T5	51.26a	45.60b	38.26cd	35.30ef	42.60A
Mean	40.27A	35.24B	30.59C	28.60D	

LSD for Genotypes=0.95 Treatments=0.10 and Genotypes x Treatments= 0.21

Table 14. Chlorophyll contents (cc) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	0.46hi	0.36k	0.38k	0.37k	0.39D
T2	0.52cd	0.48fgh	0.43j	0.49efg	0.48C
T3	0.54bc	0.50def	0.45ij	0.52cde	0.50B
T4	0.5800a	0.525bcd	0.47ghi	0.54bc	0.53A
T5	0.55b	0.54bc	0.49fg	0.55b	0.53A
Mean	0.53A	0.48B	0.44C	0.49B	

LSD for Genotypes= 0.13 Treatments= 0.14 and Genotypes x Treatments= 0.24

Table 15. Drought Resistance Index (DRI) of wheat genotypes under different silicon treatments

Treatments	Chakwal-50	GA-2002	NR-333	NR-372	Mean
T1	50.16def	51.53bcd	50.50cde	51.23bc	51.05B
T2	48.23gh	49.56efg	41.83k	48.00h	46.90D
T3	51.20bcd	44.20i	43.96ij	49.43efgh	47.20CD
T4	48.90fgh	42.70jk	52.00b	48.00h	47.90C
T5	52.23b	51.50bcd	54.06a	51.70bc	52.12A
Mean	49.94A	47.90B	48.47B	49.82A	

LSD for Genotypes=0.66 Treatments= 0.74 and Genotypes x Treatments= 1.4886

Table 16. Proline contents (pc) of wheat genotypes under different silicon treatments

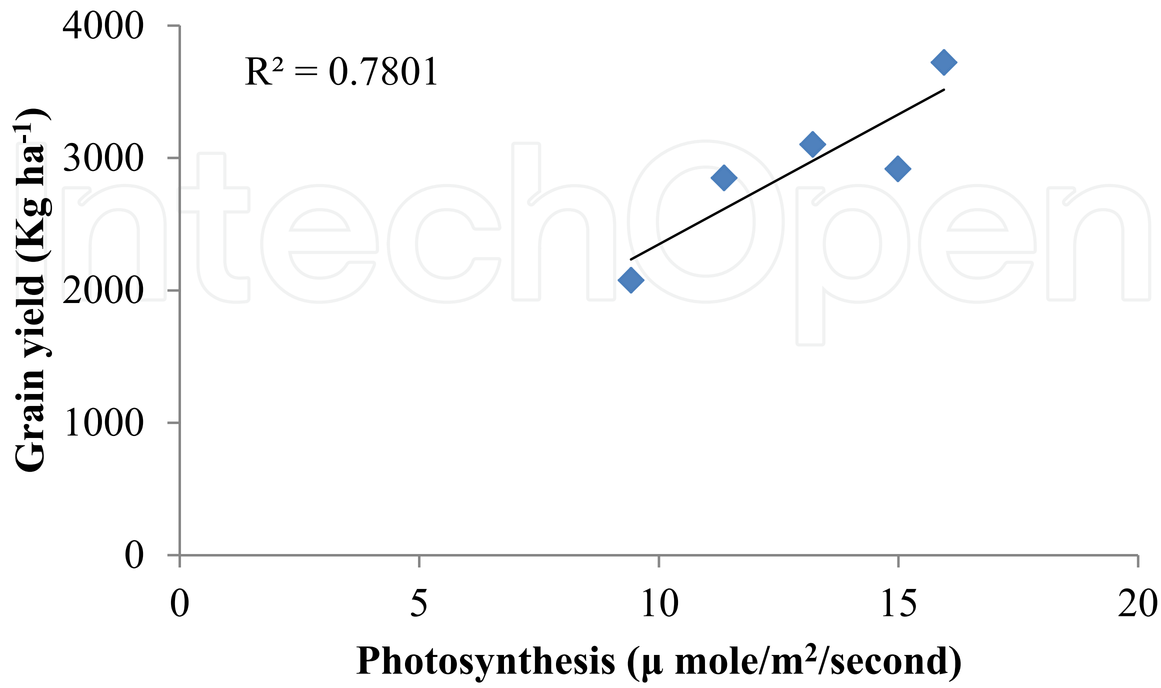

Fig. 3. Photosynthesis and grain yield of wheat genotypes under different silicon treatments

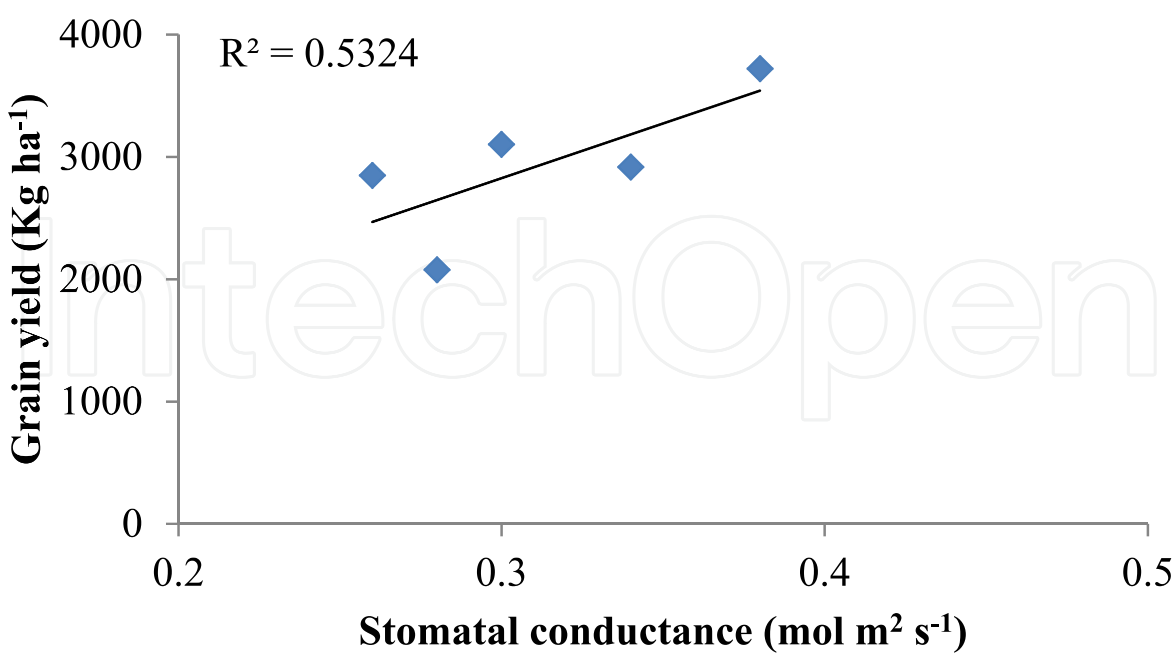

Fig. 4. Stomatal conductance and grain yield of wheat genotypes under different silicon treatments

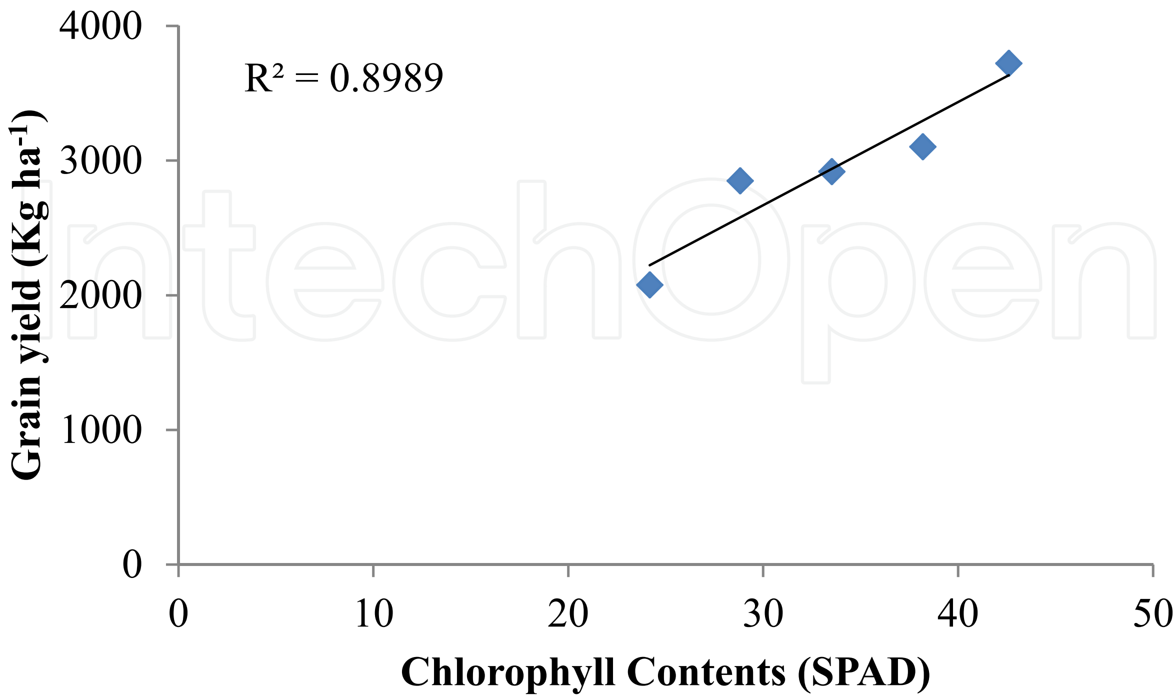

Fig. 5. Chlorophyll contents and grain yield of wheat genotypes under different silicon treatments

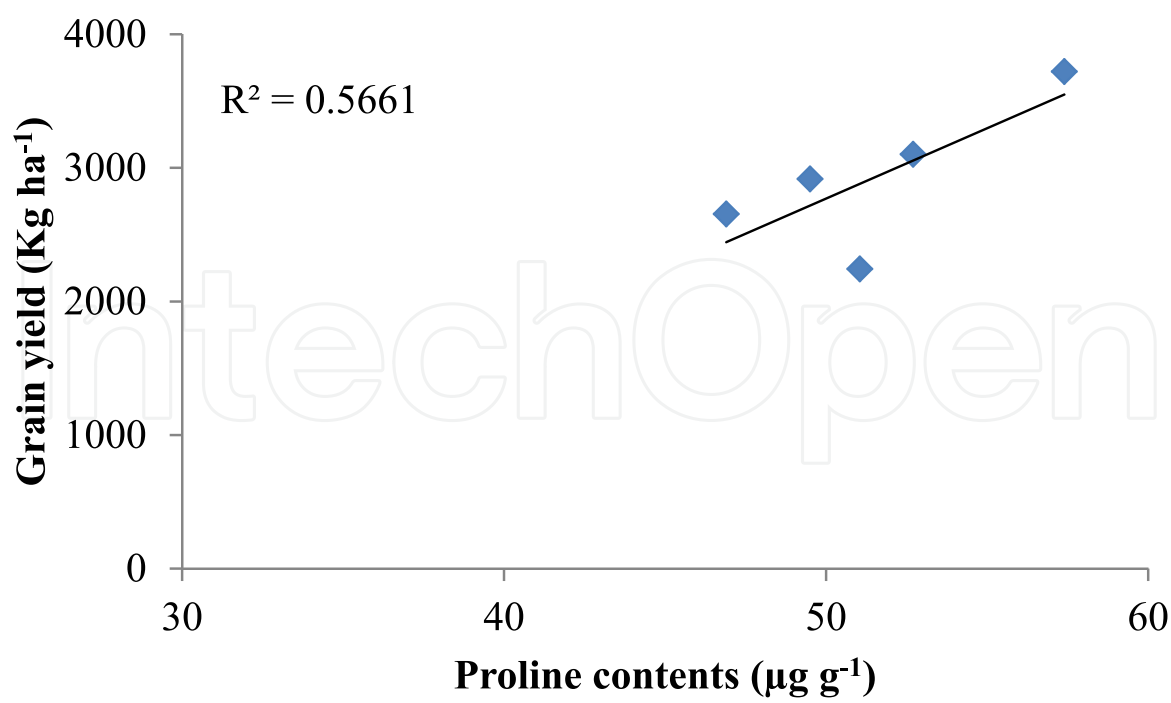

Fig. 6. Proline contents and grain yield of wheat genotypes under different silicon treatments

	GY	An	E	GS	CC	PC	RW	DRI
An	0.52^{***}							
E	-0.28^{**}	-0.34^{***}						
GS	0.35^{***}	0.61^{***}	-0.23^{*}					
CC	0.12^{ns}	0.41^{***}	0.39^{***}	0.26^{**}				
PC	0.28^{**}	0.11^{ns}	-0.20^{ns}	0.29^{**}	0.09^{ns}			
RW	0.16^{ns}	0.69^{***}	-0.57^{***}	0.58^{***}	0.13^{ns}	0.16^{ns}		
DR	0.51^{***}	0.81^{***}	-0.22^{*}	0.65^{***}	0.46^{***}	-0.02^{ns}	0.54^{***}	
LM	-0.25^{**}	0.07^{ns}	0.10^{ns}	-0.04^{ns}	0.43^{***}	0.02^{ns}	0.23^{*}	-0.06^{ns}

(GY= Grain yield, An= Net photosynthesis rate, E= Transpiration rate, GS= Stomatal conductance, PC= Proline contents (PC), RWC= Relative water content, DRI= drought resistance index (DRI)
***, **, * = Significant at 1 %, 5 % and 10 % respectively, ^{ns} = Non-significant)

Table 17. Correlation coefficients among physiological attributes of wheat genotypes with grain yield under different silicon applications

6. Conclusion

Drought is the major threat to agriculture in the world and Pakistan. Amongst different approaches being used to combat the drought stress, exogenous application of nutrients is much more important e.g. k+ the addition of Silicon in the growth medium is also beneficial to enhance the crop growth affected due to drought. Si is reported to accumulate in the plant body of various crops like rice that enables the plants to tolerate the drought stress. Likewise wheat an important serial in Pakistan has been designated as a Si accumulator. In this regard, the present study was undertaken in pots at PMAS, Arid Agriculture University Rawalpindi. Seeds of two varieties i.e. GA-2002, Chakwal-50 and two lines i.e. NR-333 and NR- 372 were taken from National Agricultural Research Center (NARC). The source of silicon, potassium silicate was used in the silicon applied treatments (+Si) and potassium chloride in the silicon deficient treatment (-Si). Effect of potassium silicate at 5 % and 10 % was investigated for germination and compared with control. Secondly two wheat cultivars and two advanced lines with three replications were sown per pot. At three leaf stage, 5 % and 10 % of potassium silicate solution were applied to the pots of the +Si treatments and it was compared with control. Potassium chloride solution was applied to the pots of the –Si treatments to yield the same total potassium as in the +Si treatments. Parameters like leaf membrane stability index, epicuticular wax, crop growth rate, relative water content, stomatal conductance, transpiration rate, photosynthetic rate, leaf area, leaf area index, chlorophyll contents, leaf succulence, relative leaf water contents, silicon concentration in leaves, proline contents, spikelets per spike, no. of grains per spike and weight of 100 grains were measured. The outcomes of the study highlighted maximum crop growth, physiological attributes and yield parameters for Chakwal-50 under 10 % silicon application with irrigation as compared to other genotypes under other levels of silicon concentrations. Drought resistant genotype showed responsive behaviour toward silicon and adaptability measures to cope stress condition. From all the discussion, it can be concluded that A single trait can not make a plant resistant to water stress, rather complex combinations of different traits make a plant able to survive in the drought conditions. Application of silicon in this regard would be beneficial for screening of drought resistant genotypes.

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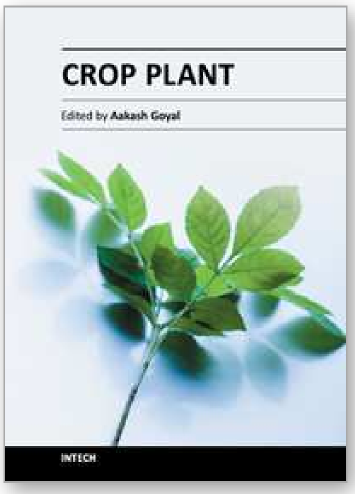

Crop Plant

Edited by Dr Aakash Goyal

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This book provides us a thorough overview of Crop Plant with current advance in research. Divided into two section based on the chapters contents. Chapter 1 provides information about markers and next generation sequencing technology and its use. Chapter 2 is about how we can use Silicon for Drought tolerance. Chapter 3 is to deal with the major problem of rising CO2 and O3 causing environmental pollution. Chapter 4 covers the phenomena of RNAi and its use, application in crop science. Chapter 5 is a review for boron deficiency in soils and how to deal with it for better crops. Chapter 6-10 provide some information regarding recent works going on in crop science.

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