



Silicon Alleviates Alkalinity Stress of Sorghum (*Sorghum Bicolor* L.) Plants by Improving Plant Water Status, Pigments, Protein, Nucleic Acids and Carbohydrates Contents

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Abstract

Alkalinity is a major constraint for sorghum production in Egypt. Silicon (Si) has been verified to play an important role in enhancing plant resistance to abiotic stress. In this study, two sorghum (*Sorghum bicolor* L.) cultivars of Giza 15 (alkalinity sensitive cultivar) and ICSR 92003 (alkalinity tolerant cultivar), were selected to study the effects of exogenous Si application on plant water status, pigments, protein, nucleic acids and carbohydrates contents of sorghum plants under alkalinity stress. In general, alkalinity stress was found to reduce water potential, photosynthetic parameters, protein, nucleic acids and carbohydrates contents in both sorghum cultivars, while Si application enhanced all these physiological parameters in stressed or unstressed sorghum plants in both cultivars. These results suggested that silicon application was useful to increase alkalinity resistance of sorghum through the enhancement of plant water status, pigments, protein, nucleic acids and carbohydrates contents in sorghum plants.

Keywords: Sorghum; Alkalinity; Silicon; RWC; SWD; Pigments; Protein; DNA; RNA; Polysaccharides

Abbreviations: Si: Silicon; Cont: Control; RWC: Relative Water Content; SWD: Saturation Water Deficit; S: Sensitive; T: Tolerant; ANOVA: Analysis Of Variance; LRWC: Leaf Relative Water Content;

Introduction

Alkalinity stress is considered to be one of the most important agricultural problems. Alkalization and

salinization induce severe effects on the natural grass lands and farming lands in Egypt nowadays. The presence of alkaline salts (Na_2CO_3 or NaHCO_3) in the soil caused mainly alkaline stress, which is one of the most crucial abiotic stressors. Many studies have been showed that alkaline stress is more harmful than saline stress, and this is mainly due to its additional high pH stress [1, 2].

Si plays an important role in plant-environment relationships because it can enhances plants' abilities to

withstand edaphoclimatic and/or biological adversities by acting as a “natural anti-stress” mechanism that enables higher yields and a better-quality end product. Silicon has a large number of diverse roles in plants, and does so primarily when the plants are under stressful conditions, whereas under precious conditions, its role is often minimal or even nonexistent [3].

Zea mays are classified as a Si accumulator and are relatively sensitive to alkaline stress. The inhibition of plant growth under water stress conditions is associated with altered water relations. Hence, less absorbed water means less water content indicated by relative water content (RWC), saturation water deficit (SWD), degree of succulence and degree of sclerophylly. Hence, leaf succulence is a descriptive indicator for the amount of water present in the unit leaf area [4-8].

Leaf relative water content (RWC) is proposed as a more important indicator of water status than other water potential parameters under water stress, as it is believed that RWC is a reliable parameter for quantifying the plant-drought response. During plant development, water deficiency significantly reduces RWC [9-11]. A decrease in RWC in response to water deficit had been reported in several studies [12]. As a practical proof, Shinde *et al.* [13] observed that water stress considerably reduced RWC in four groundnut varieties. Additionally, water-stressed wheat and rice plants had lower relative water content than non-stressed ones [14].

Alkaline-stressed plants showed a reduction in growth parameters, leaf relative water content (LRWC), and the contents of photosynthetic pigment and soluble sugars. On the other hand, alkaline stress increased the contents of soluble proteins. Application of Si by seed-priming improved growth of stimulated plants, which was accompanied by the enhancement in LRWC and levels of photosynthetic pigment, soluble sugars and soluble proteins [4].

Plant photosynthesis is accomplished by a series of reactions that occur mainly in the chloroplast. Plant pigment serve a variety of purposes, and are thus critical to the function and health of plants, though the relative concentrations of these pigment vary significantly depending not only on the species but also on the surrounding environmental factors [15]. Both the chlorophyll Chl a and Chl b are prone to soil drying. However, carotenoids have additional roles and partially help the plants to withstand adversaries of drought [13].

Leaf pigment content is an important trait involved in environmental interactions. It is well established that water stress exerts its deleterious effects on plants

through its induction to the reduction in Chl a, Chl b and total pigment. In this context, there were significant decreases in Chl a, Chl b and total Chl content in water-stressed common bean plants [16-18].

It is intensively documented that the total protein content of plant cells is an important indicator of their physiological state but under stress conditions, total protein content is usually decreased. This change in protein synthesis and/or degradation is one of the main metabolic mechanisms which may substantially affect drought tolerance of plants [19,20].

On water stress, it was found that protein content decreased in different plant species. In relation to control values, withholding water induced massive decrease in the total protein content of *Bacopa monnieri* plants [21, 22]. Obvious decrease in total protein content under water stress was also noted in two maize cultivars by Anjum *et al.* [21].

Plant growth, being an integral of cell division and cell elongation, is well established to be negatively affected by water stress by reducing the cellular content of nucleic acids required for various metabolic processes [23]. Because water stress could affect the cellular gene-expression machinery, it should be evident that both biosynthesis and degradation of nucleic acids are likely to be affected as well [24]. In this respect, Hui *et al.* [25] found that DNA and RNA content decreased in the leaves of two *Malus* varieties compared with their unstressed relatives.

Carbohydrates that represent one of the main organic constituents of the dry matter of plant cells were found to be affected by water stress. When plants suffer from water deficit, more water-soluble carbohydrates are generally accumulated for protecting membrane integrity and preventing protein degradation. Meanwhile, polysaccharides and total carbohydrates usually decline under drought conditions [26-28]. Water stress led to marked decreases in the polysaccharides and total carbohydrates in flag leaves of the two wheat cultivars [26]. It has been observed that sucrose concentration in water stressed maize and rice plants was comparatively higher than that in their unstressed relatives [29].

Exogenous application of Si formed the silica-cuticle double layer on leaf epidermal tissue and improves the water status of the crop plants Applying Si to wheat cultivars, chlorophyll pigment increased under normal conditions as well as under salinity stress conditions. Silicon accelerates disease resistance in plants, imparts turgidity to the cell walls and has a fantastic role in alleviating the metal toxicities [30-32]. However,

information on types of silicate fertilizer, extent and time of their usage, their effect on growth and yield of maize is very limited.

Materials and Methods

Plant material and experimental design

A homogenous lot of Sorghum bicolor L. (i.e. either alkalinity sensitive cultivar Giza 15 or alkalinity tolerant cultivar ICSR 92003) grains were selected. The grains were separately surface sterilized by soaking in 0.01 M HgCl₂ solution for three minutes, then washed thoroughly with distilled water. The sterilized grains from each cultivar were divided into two sets (\approx 300 g per set for each cultivar). Grains of the 1st set were soaked in distilled water to serve as control, while those of the 2nd were soaked in 1.5 mM of freshly prepared Si (as sodium meta-silicate Na₂O₃Si.5H₂O) solution for 6 hrs, thereafter air-dried. The grains of both groups were sown in plastic pots (ten seeds/pot) filled with 5.5 kg of dried soil (clay/sand 2/1, v/v). The pots were arranged in completely randomized design in factorial arrangement. At the time of sowing, the grains were irrigated at field capacity with various alkaline salt concentrations of 0 (control), 25, 50, and 75 mM Na₂CO₃. The Na₂CO₃ concentrations used were equivalent to 0 (control), 0.528, 1.056, and 1.584 g Na₂CO₃ kg⁻¹ soil, respectively. Leaching was avoided by maintaining soil water below field capacity at all times. The Si and Na₂CO₃ concentrations were selected according to our preliminary tests. The pots were then irrigated at field capacity with normal water through the whole experimental period. The pot of the 1st set was allocated to eight groups (64 pots per each group) as follows: control (Cont.), control silicon, 25% Na₂CO₃, silicon + 25% Na₂CO₃, 50% Na₂CO₃, silicon + 50% Na₂CO₃, 75% Na₂CO₃, silicon + 75% Na₂CO₃ (for sensitive cultivar). The 2nd set groups were allocated to eight groups as follows: control (Cont.), control silicon, 25% Na₂CO₃, silicon + 25% Na₂CO₃, silicon + 50% Na₂CO₃, silicon + 75% Na₂CO₃ (for tolerant cultivar). After thinning and at heading, the plants received 36 kg N ha⁻¹ as urea and 25 kg P ha⁻¹ as superphosphate.

Moreover, triplicates samples were taken from each treatment for the biochemical analyses. Data were obtained and the mean values were computed for each treatment.

Determination of relative water content (RWC)

For measuring relative water content, the method of Weatherly and its modification by Weatherly and Barrs was adopted [33,34].

Determination of saturation water deficit (SWD)

Saturation water deficit was calculated according to Weatherly and Barrs [34] from the following equation: SWD (%) = 100 - RWC (%).

Estimation of protein

The method of protein extraction was adopted by Scarponi and Perucci. Protein content was determined spectrophotometrically according to the method adopted by Bradford [35,36].

Estimation of DNA and RNA

Nucleic acids (DNA and RNA) content were determined according to the method adopted by Sadasivam and Manickam [37] as described by Devi [38].

Estimation of polysaccharides

The method used for estimation of polysaccharides in the present study was that of Thayermanavan and Sadasivam [39].

Estimation of glucose

Glucose content was estimated using O-toluidine procedure of Feteris [40] as modified by Riazi *et al.* [41].

Estimation of sucrose

Sucrose content was determined using modification of Handel [42].

Statistical analysis

It should be mentioned that the sample numbers which were taken for investigation were as follows: ten for growth parameters, ten for agronomic traits and three for all chemical analyses and only the mean values were represented in the respective figures. The data were subjected to one-way analysis of variance (ANOVA), and different letters indicate significant differences between treatments at $p \leq 0.05$, according to CoHort/CoStat software, Version 6.311.

Results

Changes in relative water content (RWC %)

The data presented in figure 1.a reflected that, as compared to control plants, alkalinity stress caused marked reduction ($p \leq 0.05$) in RWC % of sorghum flag leaf during grain filling in both cultivars with more reduction in alkalinity sensitive cultivar in comparing to alkalinity tolerant one. Furthermore, the application of silicon alleviated the deleterious effects of alkalinity stress by improving leaf turgidity comparing with the stressed plants except with high alkalinity concentration at 75%.

Changes in saturation water deficit (SWD %)

The data in figure 1.b showed that, alkalinity stress increased significantly ($p \leq 0.05$) SWD % in flag leaf of both cultivars during grain filling. Comparing both cultivars higher SWD % was observed in alkalinity sensitive cultivar than alkaline tolerant one under

alkaline stress conditions. Application of silicon caused a non-significant decrease ($p \leq 0.05$) in SWD as compared with alkalinity stressed plants. Silicon was effective in decreasing the values of SWD in flag leaf of sorghum plants which caused a marked decrease at all treatments comparing with alkalinity stressed plants.

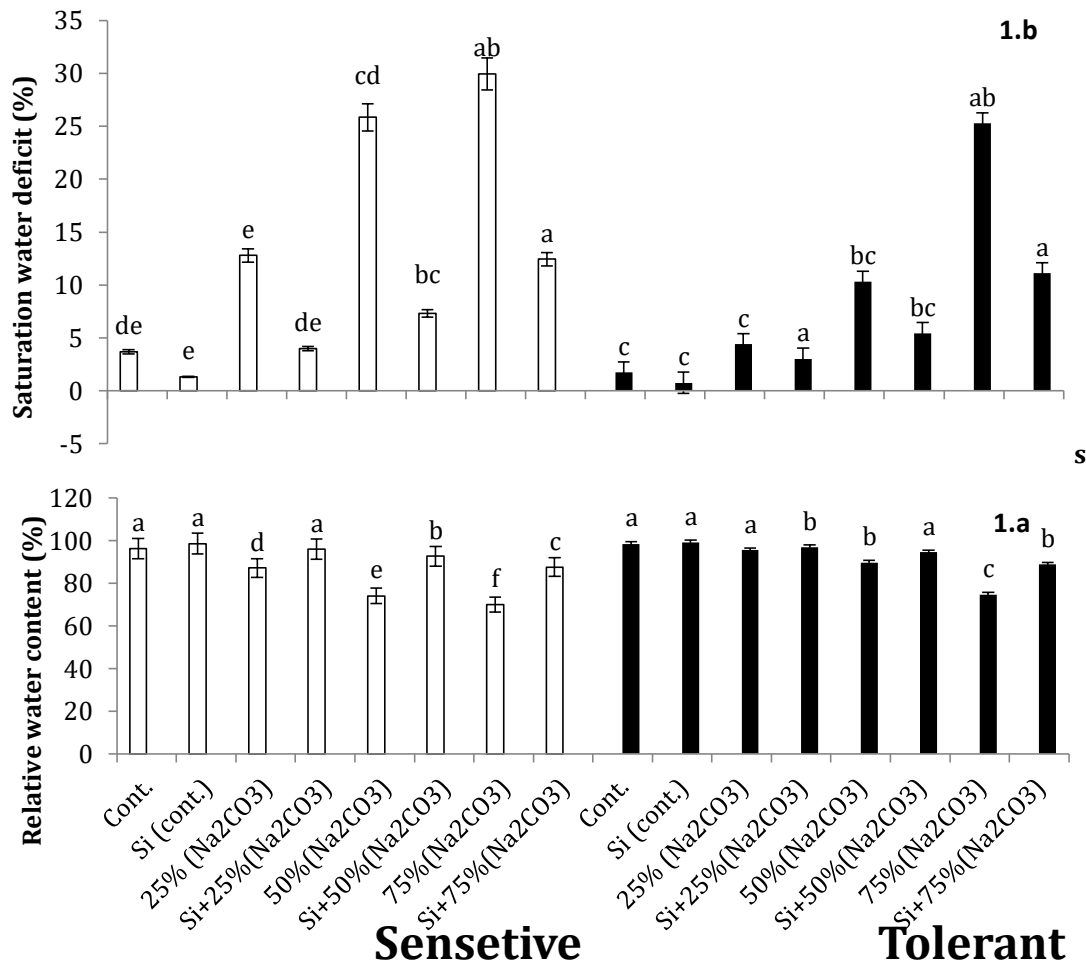


Figure 1: Effect of sodium meta-silicate on relative water content (%) 1.a. and saturation water deficit (%) 1.b. Of flag leaf of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean ($n=3$). Different letters indicate significant differences between treatments at $p \leq 0.05$, according to CoHort/ CoStat software, Version 6.311.

Changes in degree of leaf succulence and degree of leaf sclerophylly

The data presented in figure 2.a&b reflected that, as compared to control plants, alkalinity caused noticeable decreases ($P \leq 0.05$) in the degree of succulence and the

degree of leaf sclerophylly. On the other hand, application of silicon (with and/or without alkalinity) leads to increase the degree of succulence and the degree of leaf sclerophylly.

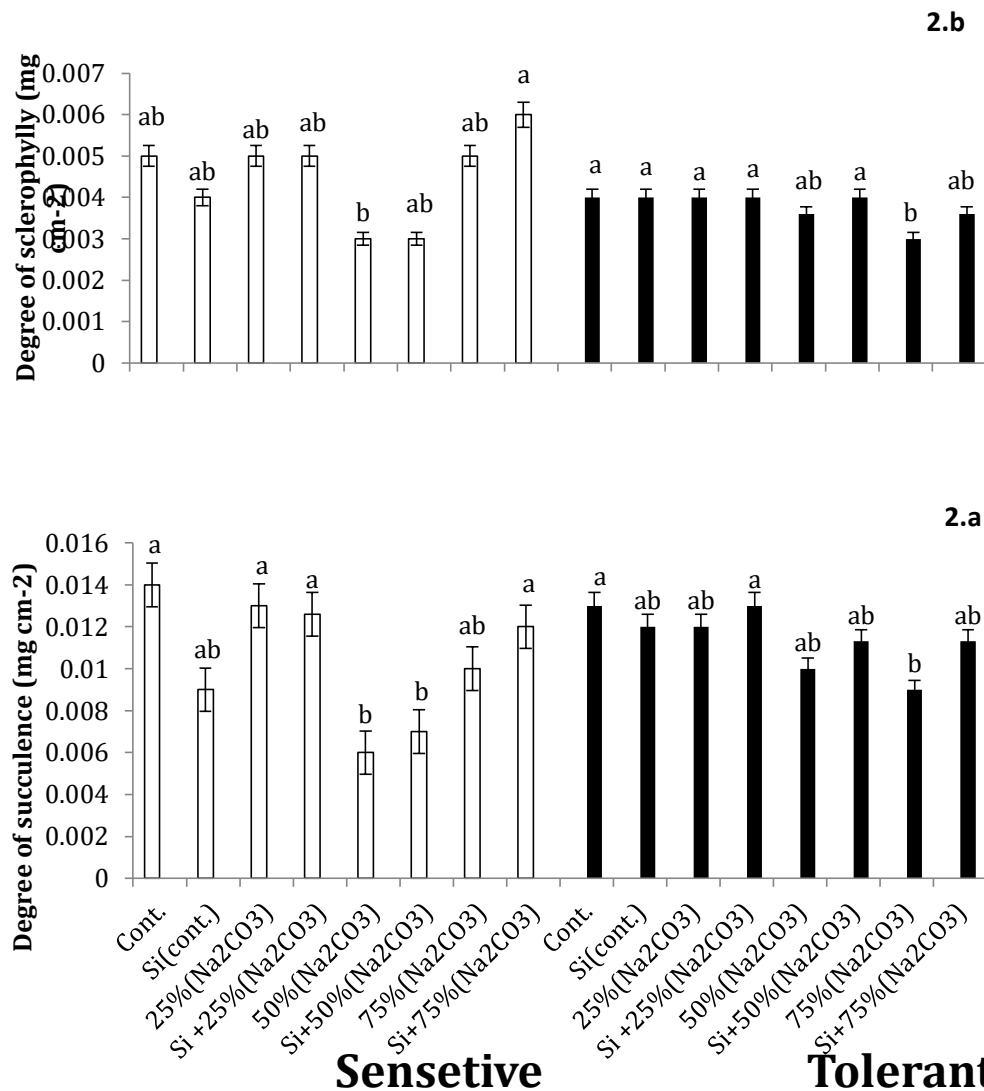


Figure 2: Effect of sodium meta-silicate on growth vigor of flag leaf [degree of succulence (mg cm⁻²) **2.a.** and degree of sclerophylly (mg cm⁻²) **2.b.**] of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean (n=3). Different letters indicate significant differences between treatments at $p \leq 0.05$, according to CoHort/ CoStat software, Version 6.311.

Changes in photosynthetic pigment content

In relation to sorghum cultivars, the flag leaves of the control tolerant plants had higher pigment (chl. a, chl. b, chl. a+b and chl. a/b) contents than the sensitive one (Figures 3.a, 3.b, 3.c, 4.a, 4.b & 4.c). Generally, alkalinity stress resulted in massive decrease ($p \leq 0.05$) in the pigment content of the both sorghum cultivars. Meanwhile, alkalinity enhanced the production of carotenoids of alkalinity sorghum plants in all alkalinity concentrations except 75% of both cultivars. Application

of silicon enhanced pigment production in stressed or unstressed sorghum plants in both cultivars.

Changes in total protein and nucleic acids content

Changes in total protein content of sorghum flag leaf followed the same pattern of the changes in nucleic acids (DNA & RNA) content in response to alkalinity stress were recorded in (Figure 5.a, 5.b & 5.c). As compared to control, alkalinity stress induced drastic reduction ($p \leq 0.05$) in total protein and nucleic acids (DNA & RNA)

contents of the flag leaf during grain filling in both cultivars. Tolerant sorghum cultivars being susceptible to alkalinity induced more protein and nucleic acids contents than sensitive one. Application of silicon markedly increased ($p \leq 0.05$) the concentrations of total

protein and nucleic acids in flag leaf of alkalinity stressed sorghum plants except 75% in both cultivars. Generally, silicon treatment appeared to be effective treatment in counteracting the adverse effects of alkalinity stress on protein, RNA and DNA contents in both cultivars.

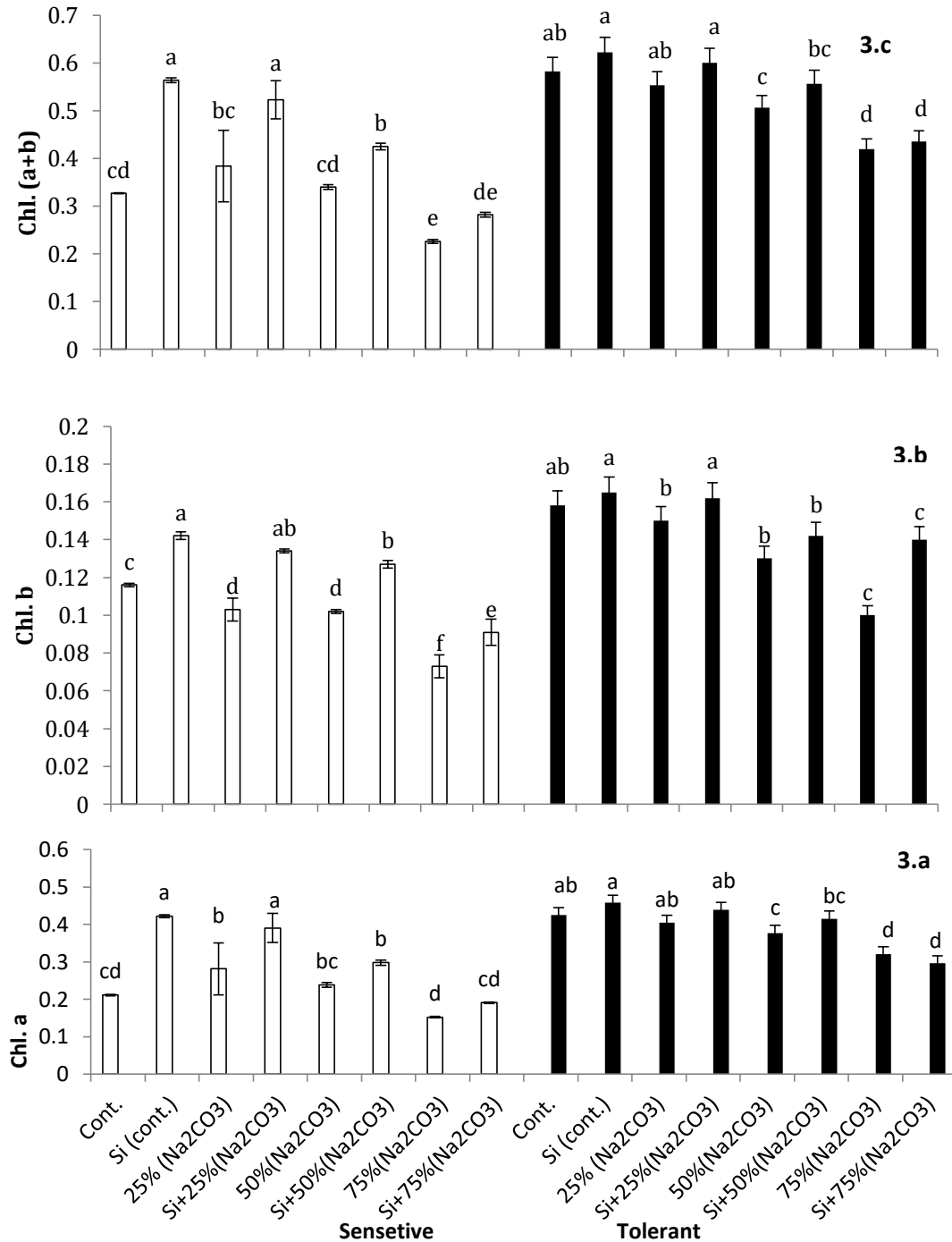


Figure 3: Effect of sodium meta-silicate on pigment contents [Chl.a **3.a.**, Chl. b **3.b.** And Chl. (a + b) **3.c.**] of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean (n=3). Different letters indicate significant differences between treatments at $p \leq 0.05$, according to CoHort/ CoStat software, Version 6.311.

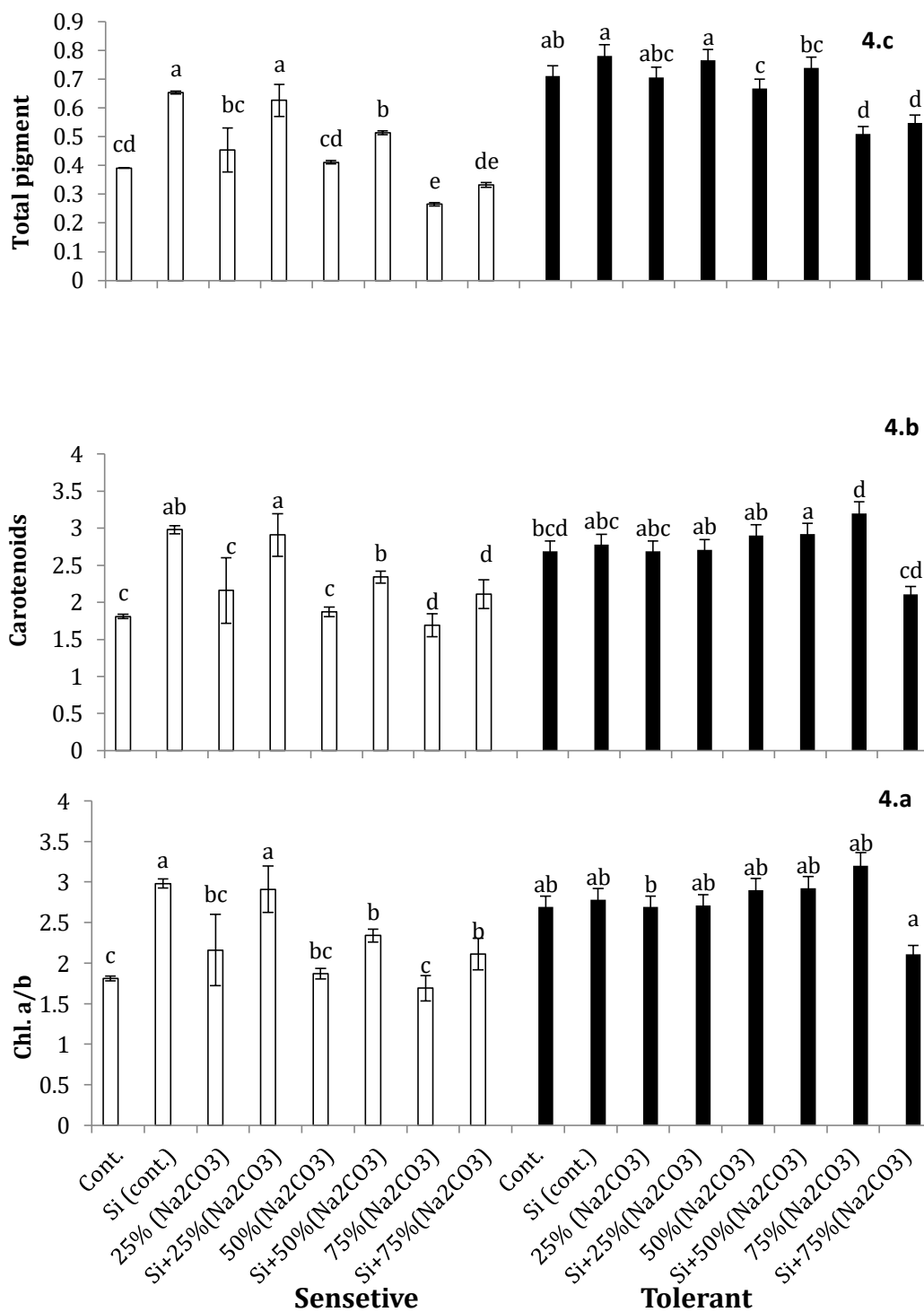


Figure 4: Effect of sodium Meta silicate on pigment content [Ch.a/b 4.a., carotenoids 4.b. And total pigment 4.c. (mg g⁻¹ d wt)] of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean (n=3). Different letters indicate significant differences between treatments at p ≤ 0.05, according to CoHort/ CoStat software, Version 6.311.

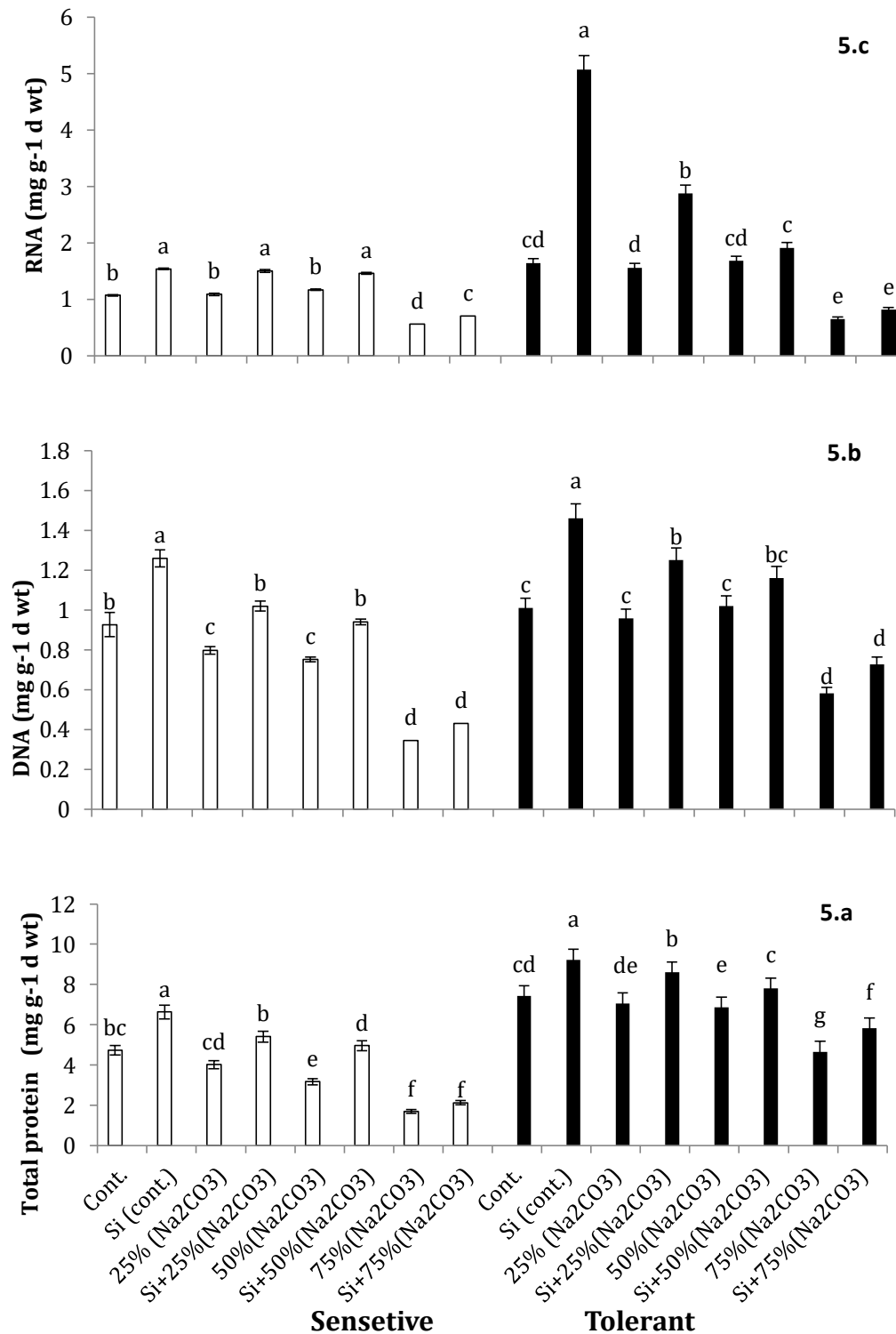
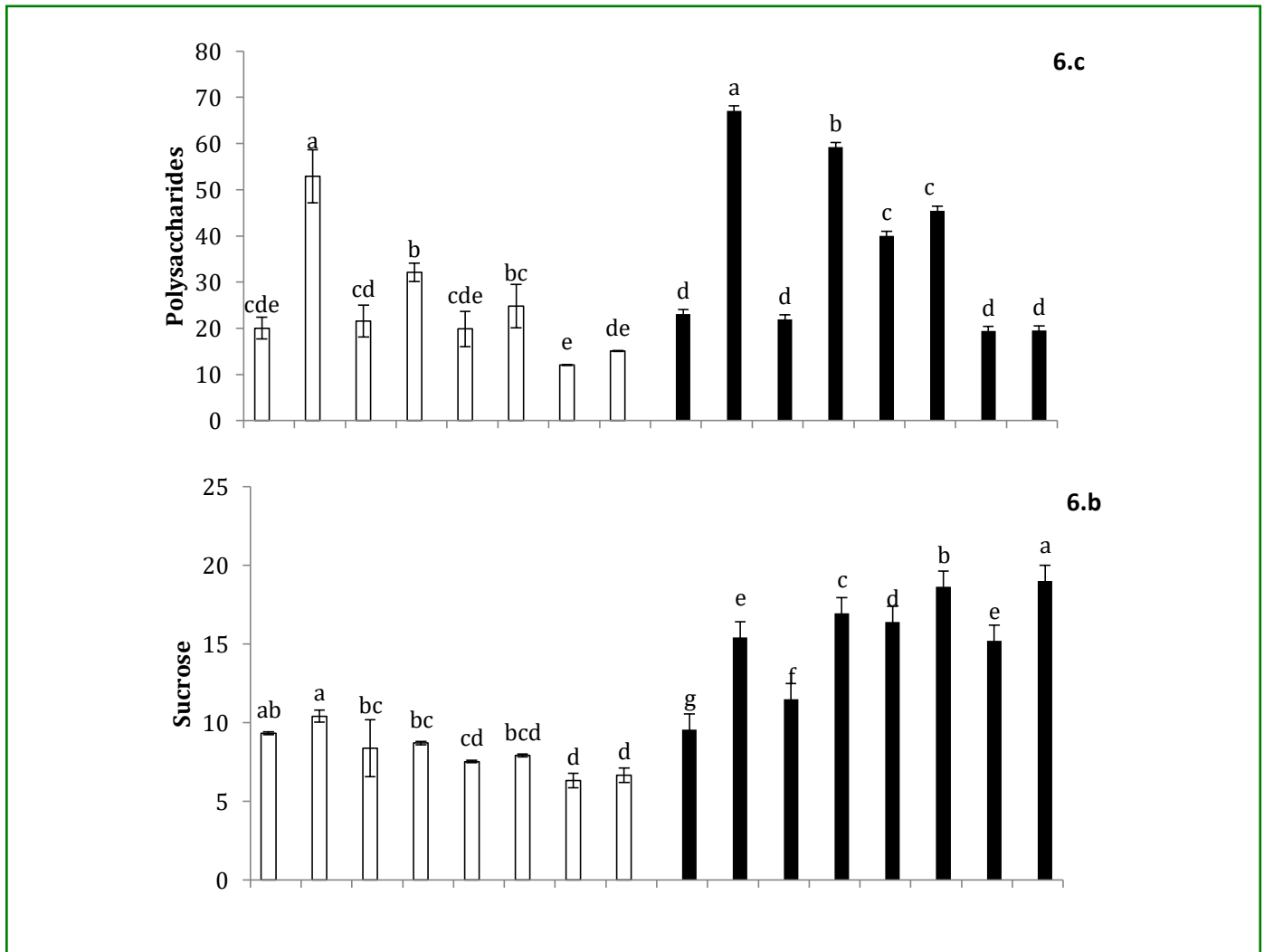


Figure 5: Effect of sodium meta-silicate on [total protein **5.a.** And nucleic acids content (DNA **5.b.** and RNA **5.c.**) (mg g⁻¹ d wt)] In flag leaf of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean (n=3). Different letters indicate significant differences between treatments at p ≤ 0.05, according to CoHort/ CoStat software, Version 6.311.

Changes in carbohydrates content

Changes in soluble sugars and poly saccharides: As compared to control values, the results indicated that, stressed plants showed that the tolerant plants accumulated more soluble sugars (glucose, sucrose) than the sensitive ones (Figures 6.a & 6.b). Alkalinity stress caused noticeable increases ($p \leq 0.05$) in soluble sugars (glucose, sucrose and total soluble sugars) in the flag leaves of sorghum cultivars. Moreover, the applied silicon induced additional increases ($p \leq 0.05$) in soluble sugars in the flag leaves of tolerant sorghum cultivar, while it recorded significant decrease in glucose and sucrose in sensitive sorghum cultivars.

In relation to sorghum cultivar, the developed leaves of tolerant plants had higher polysaccharides than those of the sensitive ones (Figure 6.c). Alkalinity stress led to marked decrease ($p \leq 0.05$) in polysaccharides in the flag leaves of the tolerant sorghum cultivar (except 75%) as compared to control values, while it showed a non-significant decrease in all sensitive treatments. In general, application of silicon induced marked increase ($p \leq 0.05$) in polysaccharides in the flag leaves of the two sorghum cultivars under stressed and controlled conditions with exception high alkalinity concentration (75%) showed a non-significant decreased.



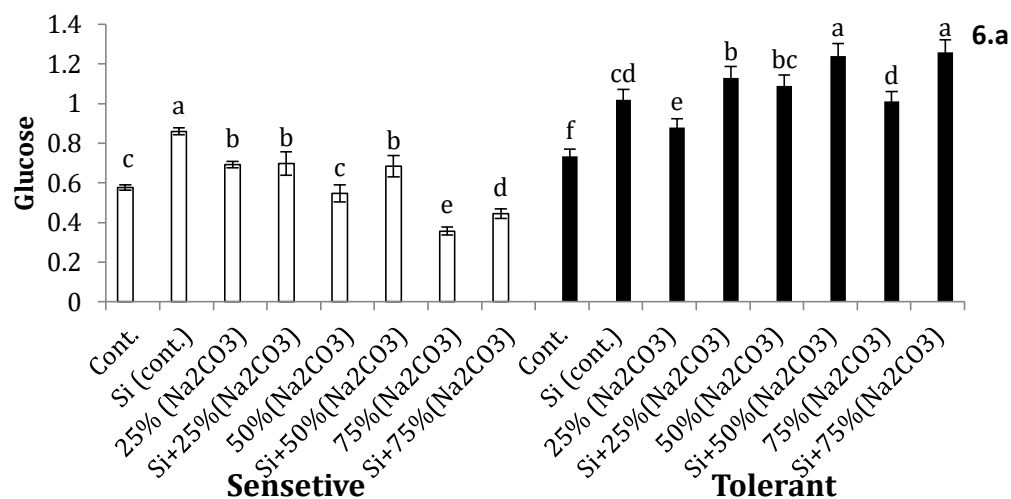


Figure 6: Effect of sodium meta-silicate on carbohydrates content (mg g⁻¹ d wt) [glucose **6.a**, sucrose **6.b**. And polysaccharide **6.c.**] Of flag leaf of alkalinity stressed sorghum plants. Vertical bars represent standard error of the mean (n=3). Different letters indicate significant differences between treatments at $p \leq 0.05$, according to CoHort/CoStat software, Version 6.311.

Discussion

Alkalinity stress has diversified adverse effects on plant water relation and physiological process. Determination of water relations is critical for any study of plant resistance to water stress. Plant water status is important not only for plant growth under favorable environmental conditions but also for their ability to tolerate water deficit. Additionally, the importance of the internal water balance in plant water relations is generally accepted because of the close relationship between the balance and turgidity to the rates of physiological processes that control the quality and quantity of growth [43-45]. Among the common plant-water relations, diurnal changes and mean daily values of relative water content (RWC), saturation water deficit (SWD), degree of leaf succulence and degree of leaf sclerophylly.

Alkalinity stress induces marked decrease in relative water content but led to significant increase in saturation water deficit in flag leaves of treated sorghum plants (Figure 1a&b). The current results were in accordance with [46].

In the present study, the cumulative degree of leaf succulence also decreased under stress conditions (Figure 2a and 2b). These results agree with those obtained by Welch and Rieseberg [7,8] working with three varieties of sunflower plants. Therefore, greater leaf succulence can be recorded as a means of increasing stress tolerance [7, 8].

On contrary to the trend recorded for the degree of leaf succulence, the cumulative degree of leaf sclerophylly was found to increase under stress conditions (Figure 2a and 2b). In accordance with these results, leaf sclerophylly was found to increase by stressing wheat plants [6]. This may be explained on the basis that less absorbed water means less water content of the growing leaves, indicated by less relative water content (Figure 1a), more saturation water deficit (Figure 1b), less succulence (Figure 2a) and more sclerophylly (Figure 2b).

Edwards *et al.* (47) reported that the functional significance of sclerophylly remains controversial, with three main groups of hypotheses proposed to explain its adaptive significance. These centers on sclerophylly as;

- (i) an adaptation to water deficit,
- (ii) An adaptation to, or consequence of, low nutrients in the growing medium
- (iii) Enhancement of leaf longevity by leaf protection, thereby increasing leaf carbon gain.

Thus, the studied wheat plants appeared to induce adaptive feature to increase its tolerance to stress conditions by increasing the degree of its leaf sclerophylly. Grain priming with silicon counteracted the stress induced by alkalinity stress by recovering the turgidity in flag leaf of alkali sorghum plants. Comparing both cultivars, sensitive showed more reduction in relative water content and more increment in saturation water deficit under alkalinity conditions than tolerant

one. A numbers of possible mechanisms are proposed by which Si increase plant resistance against salinity can stress [48]. The Si deposited in the tissues of the plant helps to alleviate water stress induced by salinity by reducing transpiration from the leaves [49].

The reduction of water is due to the deposition of Si that forms a thick layer of silica gel associated with the cellulose in the walls of epidermal cells while epidermal cell wall of silica gel allows water to escape at an accelerated pace [50]. Gong *et al.* [51] also reported that application of Si improved water economy and increased the growth of plants under salt stress conditions. Increased water status in salt-stressed plants may increase salinity tolerance by mitigating specific ion toxicities or by a dilution effect [52].

Plant species and cultivars have different physiological mechanisms in response to water stress [53]. The use of physiological and biochemical criteria has been recommended to achieve a rapid and simple screening of highly drought-tolerant individuals. Leaf pigment content is an important trait involved in environmental interactions [16]. Hence, photosynthetic pigments which constitute mainly of chlorophyll a, chlorophyll b and carotenoids are of vital importance in photosynthesis. In this regard, pigmentation is well reported to reflect the photosynthetic properties of phototrophic organisms as it indicates the size of light-harvesting capacity [54].

Data of the present work clearly showed that alkalinity induced drastic reduction ($p \leq 0.05$) in the pigment content (Chl a, Chl b, Chl (a+b), Chl (a/b) ratio and total pigment) of the both sorghum cultivars. Meanwhile, alkalinity enhanced the production of carotenoids of alkalined sorghum plants (Figures 3 (a, b &c) and 4 (a,b &c)). It is worth noting that, the increase of carotenoid content observed by 25 mM Na_2CO_3 treatment in stressed sorghum plants could improve the amplitudes of this compound to diminish the damage caused by ROS under low level of alkaline salt. Furthermore, Si augmented the Chl and carotenoid contents in maize plants exposed to alkaline stress, which could be resulted from the increase in leaf area, leading to the increase in green pigment and safe guarding of Chl pigment from ROS by reinforcing the level of carotenoids. These results were in accord with those obtained by Hamdia and Shaddad, [55] who reported that Si induced restoration of the levels of photosynthetic pigment in the alkaline-stressed maize seedlings and demonstrated an osmo-protective and membrane-protecting role of Si for maize seedlings subjected to alkaline stress. Meanwhile, Si priming lowered the oxidative damage to the photosynthetic organs in sorghum, thus increasing the accumulation of chlorophyll in leaves.

The decrease in Chl contents under alkaline stress might be due to

- i. Mg^{2+} precipitation that results in the degradation of green pigment [56],
- ii. Enhanced oxidative stress that causes injury to chloroplast structure,
- iii. Increase in the activity of chlorophyllase enzyme that is responsible for the Chl degradation [57].

Additionally, alkaline stress decreased the content of carotenoids in stressed maize plants, which act as effective scavengers of free radicals provoked by reactive oxygen species (ROS) [58].

Stress is known to reduce the life span of plant leaves, resulting in accelerated senescence and, as a consequence, pigment degradation [59]. Continuous water deficit induces early leaf senescence in plants. During this process, chloroplasts are degraded and photosynthesis drastically drops [60].

Si enhanced pigment content ((chl a, chl b, Chl (a+b), Chl (a/b) ratio, carotenoids and total pigment) production in stressed or unstressed sorghum plants. The stimulating effect of Si may be due to the fact that Si increases leaf longevity of alkalized plants by retaining their pigments content, therefore inhibits their senescence.

Water molecules are critical components of the reaction mechanism; they contribute to the stability of proteins, nucleic acids (DNA and RNA) and lipids. Water stress is a detrimental factor which adversely affects the cellular contents of plant cells of different species, such as proteins and nucleic acids [61]. In the present investigation, drastic reduction ($p \leq 0.05$) in total protein and nucleic acids (DNA & RNA) contents of the flag leaf during grain filling in both cultivars. In this respect, a close relation between the changes in total protein and nucleic acids contents under water stress conditions was observed. Since the processes of DNA and RNA synthesis are related to protein synthesis, reductions in RNA synthesis ultimately reduce the enzymatic protein content [62]. In agreement with our results, Debouba *et al.* [63] found that water stress decreased total leaf protein and nucleic acids (DNA and RNA) contents in tomato plants.

Generally, silicon treatment appeared to be effective treatment in counteracting the adverse effects of alkalinity stress on protein, RNA and DNA contents in both cultivars (Figure 5 a, b &c). The increase in soluble protein content in response to Si application may be due to the facts that

- (i) Si has a pivotal role in binding amino acids to form specific proteins [64],

(ii) Si is actively engaged in formation of DNA and functioning of mRNA [65].

The accumulation of soluble carbohydrates in plants has been widely reported as a response to water stress in spite of the significant decrease in the net CO₂ assimilation rate [66]. In the present work, alkalinity caused marked increase in total soluble sugars (glucose, sucrose and total soluble sugars) and a marked decrease in polysaccharides in water extract of sorghum flag leaf when compared with the control plants. Moreover, the applied silicon induced additional increases in soluble sugars and polysaccharides content (Figures 6.a, 6.b & 6.c). In this regard, growth arrest resulted from water deficit was considered as a possibility to preserve carbohydrates for sustained metabolism, prolonged energy supply and better recovery after stress relief [67]. For instance, hexose accumulation was shown to account for a large proportion of osmotic potential in water-stressed maize plants [68].

Plants are continuously challenged by stressful environmental conditions like alkalinity leading to alteration of plant water relation which consequently leads to reduction of plant growth and physiological processes. Hence, measuring the physiological parameters of both sorghum cultivars gave a good indication of the plant status under alkalinity stress and applied Si conditions. In the light of the above mentioned result, we concluded that alkalinity has many adverse impacts on sorghum plants by inhibiting photosynthetic parameters, protein, nucleic acids and carbohydrates contents.

Conclusion

It was concluded from this work that the plant growth is significantly affected by alkalinity stress in both sorghum cultivars (Giza 15 (alkalinity sensitive cultivar) and ICSR 92003 (alkalinity tolerant cultivar)) in comparison to non-alkaline conditions. Moreover, according to these results, silicon appeared to mitigate the negative effect of alkalinity stress on water-relations (i.e. relative water content, saturation water deficit, degree of leaf succulence and degree of leaf sclerophylly) as well as leaf protein, nucleic acids (DNA and RNA) and carbohydrates contents of both sorghum cultivars especially the tolerant one. Finally, silicon (Si) has been verified to play an important role in enhancing plant resistance to alkalinity stress through improving plant water status by reducing the osmotic effect of alkalinity on plant water uptake and plant water storage. This improvement would result from the beneficial effect of silicon on growth and metabolism

of sorghum plants under alkalinity condition. Moreover, key players involved in Si-induced alkalinity tolerance needs to be clarified using proteomic and genomic approaches.

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