Silicon mitigates drought stress in lentil through enhancing photosynthetic activity and yield related traits

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Abstract

Drought stress is one of the major constraints leading to significant production losses in lentil. Silicon (Si) application has been shown to be a promising management strategy in improvement of drought tolerance in crops. Consequently, the present study aims to investigate the role of Si in mitigating drought stress in lentil. Measurements of chlorophyll fluorescence, photosynthetic pigments, infrared thermal canopy temperature (IRTc), gas exchange parameters and yield traits explained the possible role of Si in alleviation of drought stress effects in lentil. Experiments were conducted in field conditions with selected drought tolerant and sensitive lentil genotypes, which were subjected to severe drought stress at the onset of the flowering stage. Results showed that Si attenuated drought stress-mediated effects on light absorption of photosystem II (PSII) by increasing the effective quantum yield of PSII photochemistry and concentration of photosynthetic pigments along with maintenance of cooler canopies. Additionally, negative effects induced by drought stress on gas exchange were also mitigated by Si application. Increased growth and grain yield of Si-treated drought stressed plants could be related to the increased photosynthetic activity. Overall, Si supplementation could be used as a potential drought stress mitigation strategy in lentil plants.

Key Words

Canopy temperature, chlorophyll fluorescence, gas exchange, photochemistry, pigments, quantum yield

Introduction

Lentil (*Lens culinaris*, Medik.) is one of the most important and nutritious legume crops grown in semi-arid regions of the world including Australia. Among many biotic and abiotic constraints affecting lentil productivity, drought stress is one of the major abiotic stresses. Drought can negatively affect the production and accumulation of assimilates due to degradation of photosynthetic pigments, stomatal closure, reduction in photosynthetic efficiency and yield components (Anjum *et al*. 2011). Si is regarded as an important plant nutrient considering its beneficial effects on biotic and abiotic stress resistance/tolerance in several plant species (Zargar *et al*. 2019). Supplementation of Si to lentil seedlings under drought stress has improved their drought tolerance levels (Biju *et al.* 2017). This paper focuses on the effects of Si supplementation on photosynthetic activity and grain yield and yield traits of lentil grown under drought-stress conditions. This may further help to elucidate the underlying physiological mechanisms of Si mediating drought tolerance of plants.

Methods

Plant materials

Seeds of lentil genotypes (ILL 6002, drought-tolerant; PBA Jumbo 2-moderatelty tolerant; ILL 7537-drought susceptible) used in this study were selected based on non-destructive (an infrared thermal imaging) and destructive physiological screening methods in lentil genotypes (Biju *et al*. 2018).

Field experiment

A field experiment was conducted during May -December 2018 at Dookie farm, The University of Melbourne (36.378S, 145.708E, 185 m above sea level) in Victoria, Australia, using a total area of 308 m^2 (14m*22m). The experiment was laid out as a randomized block design with three replicates in split plot arrangement of three blocks. Buffer zones of 2 m in between the blocks and 0.5 m between the plots were maintained to minimize potential Si contamination via lateral movements. The three genotypes were randomized within each plot and planted in five rows spaced 50 cm apart with a spacing of 25 cm between the plants in each plot. The soil at the experimental site was red brown clay with pH 6.5. Sodium meta silicate was applied to the treatment plots one week before seed sowing (Biju *et al.* 2018). The trial was fertilized as per standard lentil growing practices. Inoculated seeds (Group F® *Rhizobium leguminosarum*) were hand sown. The treatments were as control (C-well irrigated), drought stress (D), drought stress with supplemented Si (DSi), and Si alone (Si).

Plants were subjected to drought stress by withholding irrigation at flowering stage for 14 days. Estimation of photosynthetic pigments, chlorophyll fluorescence, gas exchange parameters using a portable photosynthesis system (Li-6400, Li-COR, Lincoln, NE, USA) equipped with a 6 cm^2 chamber, and canopy temperature (IRTc) using infrared camera (Biju *et al*. 2018) were carried out after 28 days of drought stress treatment. Above ground biomass and other yield traits were measured after drying samples at 40^{0}C for 72 hours.

Statistical analysis

Statistical analysis of the data was done using analysis of variance (ANOVA), followed by a Tukey pairwise comparison test for mean comparison between genotypes and treatments using Minitab®v17 (Minitab Inc., Pennsylvania, USA).

Results and Discussion

Si application increased PS II efficiency and photosynthetic pigments in lentil plants

The photosynthetic pigments of lentil genotypes decreased significantly (P<0.05) under drought stress. However, the exogeneous application of Si mitigated the effect of drought stress with significant increase in photosynthetic pigments (Figure 1b-d). The photosynthetic pigments content in plants has a positive relationship with photosynthetic rate (Anjum *et al*. 2011) and the increase in these pigments may enhance photosynthesis activity. This explains increase in the *Fv/Fm* ratio, which in turn alleviated the harmful effects of drought on the photochemical reactions in response to Si.

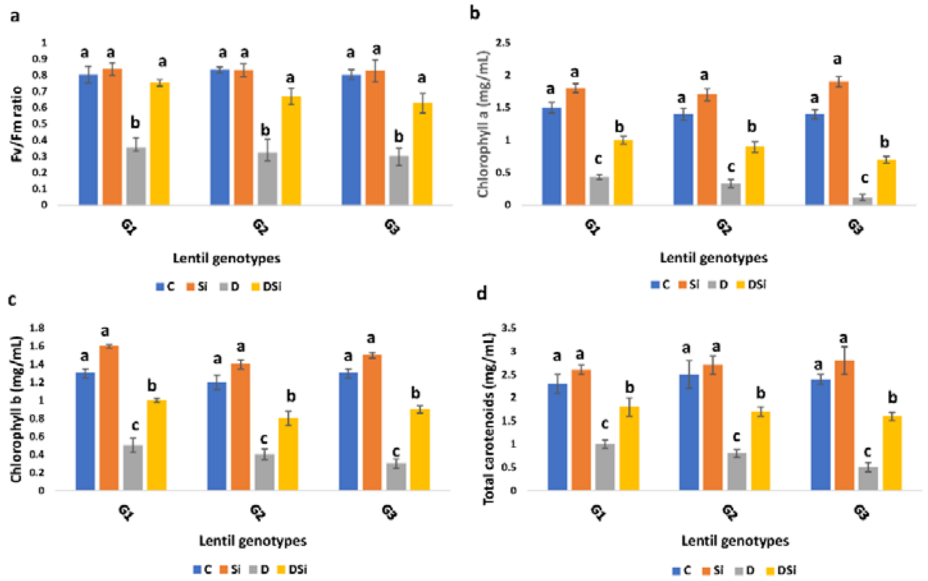
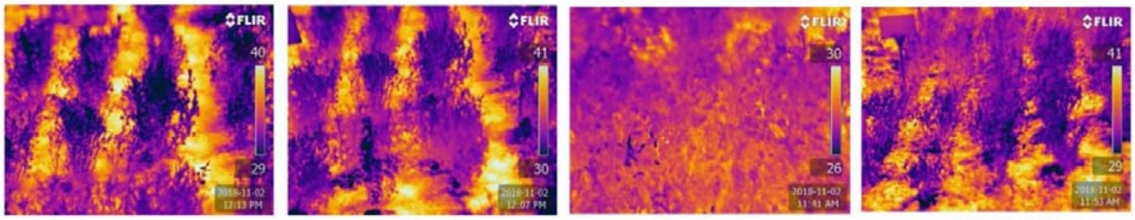


Figure 1. (a) *Fv/Fm* ratio, (b) Chlorophyll a (c) chlorophyll b and (c) total carotenoids in lentil genotypes (G1- ILL 6002, G2- PBA Jumbo 2, G3- ILL 7537) under different drought stress treatments (C- control, D- drought stress, DSi- drought stress + Si and Si- Si alone). Mean values with error bars represent the standard deviation and different letters represent statistical significances within the genotypes (Turkey test; $p < 0.05$).

Si application decreased the canopy temperature (IRTc) and crop water stress index (CWSI) values of drought stressed lentil plants

Plants with high stomatal conductance transpire more and thus maintain a cooler IRTc. Drought stress increased IRTc for all the genotypes and Si significantly decreased IRTc under drought stress further giving evidence of Si augmenting lentil drought tolerance (Figure 2; Figure 3a). Lower IRTc is associated with better lentil crop performance through increased transpiration (Biju *et al*. 2018). The crop water stress index (CWSI) has been recognized as an indicator of plant water status based on It, ambient air temperature and relative humidity. Control and Si alone treated plants had the CWSI value of zero, and drought stressed plants had the CWSI values close to one. Drought susceptible genotype G3 had the highest mean CWSI under drought, followed by G2 and G1 (Figure 3b).



Control (C) Silicon (Si) Drought (D) Drought+Si (DSi)

Figure 2. Thermal images from different treatment plots

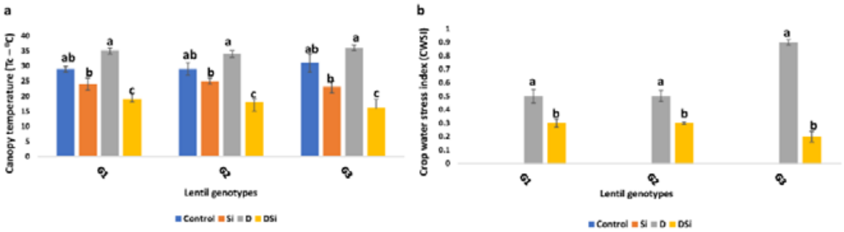


Figure 3. (a) Canopy temperature (It) and (b) crop water stress index (CWSI) in lentil genotypes (G1- ILL 6002, G2- PBA Jumbo 2, G3- ILL 7537) under different drought stress treatments (C- control, D- drought stress, DSi- drought stress + Si and Si- Si alone). Mean values with error bars represent the standard deviation and different letters represent statistical significances within the genotypes (Turkey test; $p < 0.05$).

Si regulated gas exchange, photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (Tr) and internal CO_2 concentration (Ci) in drought stressed lentil plants

The photosynthetic activity of lentil genotypes was negatively affected by drought stress (Table 1). However, the interactions between drought stress and Si treatment showed an increase in *Pn, gs, Tr* and *Ci* values when compared with the control. The enhancing effect of Si on photosynthetic rate could be attributed to the increase in chlorophyll pigments under Si supplementation. Si also alleviated the drought stress-induced inhibition of photosynthesis due to stomatal conductance limitations. Increased stomatal conductance contributed to higher internal CO_2 concentration in the cellular spaces of the leaf and higher transpiration rates. Desired mass flow of water and transportation of substances to the leaf surface led to optimal photosynthesis in leaves.

Table 1. Photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (Tr) and internal CO_2 concentration (Ci) of lentil genotypes (G1- ILL 6002, G2- PBA Jumbo 2, G3- ILL 7537) under different drought stress treatments (C- control, D- drought stress, DSi- drought stress + Si and Si- Si alone). Mean values are provided with standard deviation and different letters represent statistical significances within the genotypes (Turkey test; $p < 0.05$).

Genotype	Treatment	Pn (µmol CO_2 m^{-2} s^{-1})	gs (mol H_2O m^{-2} s^{-1})	Tr (mmol H_2O m^{-2} s^{-1})	Ci (µmol CO_2 mol^{-1})
G1	C	10.35 ± 0.38b	150.02 ± 2.35b	3.31 ± 0.34d	478.36 ± 3.35a
	Si	12.35 ± 0.66a	165.07 ± 2.33a	5.35 ± 0.25c	486.89 ± 3.65a
	D	06.35 ± 0.33c	75.96 ± 3.23d	7.36 ± 0.24b	305.36 ± 5.36b
	DSi	8.98 ± 0.67ab	125.63 ± 2.55c	9.35 ± 0.28a	491.36 ± 3.37a
G2	C	9.68 ± 1.23b	135.36 ± 1.25b	3.16 ± 0.98d	476.32 ± 2.35b
	Si	12.25 ± 1.12a	153.36 ± 2.54a	5.16 ± 0.35c	487.22 ± 0.68b
	D	6.01 ± 0.25c	64.35 ± 2.55d	7.05 ± 0.65b	298.36 ± 5.32c
	DSi	8.36 ± 0.98b	123.35 ± 4.69c	9.23 ± 0.55a	501.72 ± 4.96a
G3	C	11.23 ± 1.02a	147.38 ± 4.02b	3.23 ± 0.87d	468.38 ± 2.37b
	Si	12.36 ± 1.01a	166.32 ± 3.34a	6.11 ± 0.52c	513.98 ± 3.54a
	D	3.25 ± 0.85c	35.63 ± 1.25d	8.07 ± 0.56b	189.36 ± 2.35c
	DSi	7.65 ± 0.02b	102.36 ± 3.35c	11.23± 0.99a	552.03 ± 4.92a

Si enhanced the biomass and yield traits in lentil

The above-ground biomass of all genotypes was enhanced significantly by added Si under drought stress and non-stress conditions, agreeing with previous results on lentil seedlings (Biju *et al*. 2017). The higher values of yield traits from Si aided drought stressed lentil genotypes can be attributed to the increased biomass and photosynthetic rates, which in turn lead to the synthesis and translocation of more assimilates from source to sink.

Table 2. Above ground biomass and yield related traits of lentil genotypes (G1- ILL 6002, G2- PBA Jumbo 2, G3-ILL 7537) under different drought stress treatments (C- control, D- drought stress, DSi- drought stress + Si and Si- Si alone). Mean values are provided with standard errors and different letters represent statistical significances within the genotypes (Turkey test; p < 0.05).

Genotype	Treatment	Above ground biomass/plant (g)	Pod number/plant	Pod weight/plant (g)	Seed number/ plant	Seed weight per plant (g)	Seed yield/plot (tonnes/ha)
G1	C	5.79 ± 0.33a	39.75 ±1.23a	2.96 ± 0.01a	301.25±1.02b	2.65 ±0.12a	0.39±0.02a
	Si	6.58± 0.04a	43.35±2.36a	3.11 ± 0.23a	475.32 ±2.11a	2.89±0.02a	0.43±0.33a
	D	3.27 ± 0.01c	19.25±2.24c	1.65 ± 0.12b	156.25±3.21c	1.35±0.13b	0.17±0.16c
	DSi	4.63± 0.23ab	26.7±0.27b	2.14 ± 0.87ab	335.65±2.33b	1.78±0.01b	0.26±0.11b
G2	C	5.87± 0.02a	35.25±1.02b	2.68 ± 0.27b	324.56±2.37b	2.35±0.34b	0.35±0.21b
	Si	6.65± 0.23a	44.72±1.25a	3.45 ± 0.22a	432.32±2.87a	2.98±0.01b	0.44±0.32a
	D	2.15 ± 0.01c	15.33±0.97d	1.65 ± 0.88b	112.86±3.65d	1.02±0.07b	0.15±0.11d
	DSi	4.67 ± 0.21ab	23.27±1.77c	2.12 ± 0.32ab	220.36±2.93c	1.78±0.21ab	0.26±0.01c
G3	C	5.87 ± 0.03a	41.25± 0.88a	3.12± 0.23a	254.78±4.23b	2.75±0.16a	0.41±0.07a
	Si	6.69 ± 0.98a	45.15±1.85a	3.44 ± 0.27a	389.36±2.37a	3.01±0.66a	0.45±0.02a
	D	1.02 ± 0.05c	13.33 ± 0.32c	1.94 ± 0.11b	57.66±4.83d	0.22±0.75c	0.03±0.23c
	DSi	2.35 ± 0.44b	29.75 ± 0.65b	0.99 ± 0.23c	148.36±1.32c	0.65±0.33b	0.19±0.02b

Conclusion

Si application to drought stressed lentil genotypes induced benefits on photosynthetic metabolism along with enhancement in yield related traits and thus alleviated the negative effects of drought stress. Si application to plants can be considered as a sustainable management strategy to enhance the yield and productivity under drought stressed environments.

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