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The Role of α-Tocopherol in Mitigating the Effect of Elevated CO_2 Concentrations Emitted from the AL-Hunay Power Plant Main Station on *Glycine max* L. Plants

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Soybean (*Glycine max* L.), belonging to Leguminosae, is an essential food in Asian countries. It has become a necessity to study the long-term effects of elevated concentrations of CO_2 on plant growth and development. Climate change may be affected by the increment of CO_2 and higher temperatures on crops. Elevated concentrations of atmospheric CO_2 can negatively affect the yield as well as the quality of the field crops. Alpha-tocopherol is the major vitamin E compound found in leaf chloroplasts. This antioxidant deactivates photosynthesis-derived reactive oxygen species and prevents the propagation of lipid peroxidation by scavenging lipid peroxyl radicals in thylakoid membranes. AL-Hunay is an electrical power plant main station located in the Al-Hofuf agricultural area in Saudi Arabia. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay on the morphological and physiological traits of soybean has been investigated in this study by selecting a site of 100 meters apart from the station. The results revealed a negative effect of elevated concentrations of CO_2 on the morphological traits of soybean such as plant height, leaf area, and number of leaves. Furthermore, it also negatively affected the physiological traits such as the contents of P and K, mono- and disaccharides, chlorophyll a and b, and the activity of catalase, and superoxide dismutase. The results showed an obvious role of α-Tocopherol in mitigating the effect of elevated CO_2 on soybean plants through regulating the growth, stimulating photosynthesis, protecting the cell membrane and chloroplasts, and tolerating oxidative stress. The current study provides proof for the positive role of α-Tocopherol in mitigating the effect of elevated CO_2 emitted by the AL-Hunay power plant main station on the morphological and physiological traits of *Glycine max* L. plants.

Keywords: α-Tocopherol, CO_2, AL-Hunay power plant main station, morphological and physiological traits, *Glycine max*

Abbreviations: RuBP—ribulose-1,5-bisphosphate, Rubisco—ribulose 1,5-bisphosphate carboxylase/oxygenase, CAT—catalase, SOD—superoxide dismutase, GPX—guaiacol peroxidase, APX—ascorbate peroxidase, ROS—reactive Oxygen Species, and POD—peroxidase

INTRODUCTION

Soybean (*Glycine max* L.), a subtropical leguminous plant native to Southeast Asia, has been an essential food in Asian countries for over 5,000 years (Badole and Bodhankar 2013). Soybean has been widely consumed worldwide as a source of protein-rich food and beverages (Naresh et al. 2019; Hashiguchi and Komatsu 2017).

The concentration of carbon dioxide (CO_2) has been increasing in the atmosphere for more than a century (Allen Jr. et al. 1988). It has become a necessity to study the long-term effects of CO_2 concentration on plant growth, because the intense burning of fossil fuels and the destruction of forests promise to continue the rise of CO_2 in the atmosphere during the next century (Rogers et al. 1983). The concentration of CO_2 in the earth's atmosphere may double by the end of the 21st century. Oftentimes the response of plants to double CO_2 causes a decrease in nitrogen content, but the reasons for this decrease have been uncertain (Bloom et al. 2010). Climate change due to increased CO_2 and rising of temperature may affect the formation of crop seeds (Thomas et al. 2003). It is important to study and understand crop responses to projected changes in climate (Zhao et al. 2003). Increases in the atmospheric CO_2 concentration have stimulated the response of agricultural crops to high levels of CO_2 (Kleemola et al. 1994). The high CO_2 in the atmosphere enhances the production of vegetables and can also affect their nutritional quality (Dong et al. 2018). It is important to uncover the possible effects of high CO_2 on the quality of important food crops such as wheat (*Triticum aestivum* L.) as it is one of the most important food sources in the world. CO_2 also has profound effects on the nutritional value of wheat products as well as on many industrial sectors (Wu et al. 2004). High CO_2 concentration enhances vegetative growth but reduces the quality of the wheat grain due to the reduction in protein content (Blumenthal et al. 1996; Dong et al. 2018). Some plants grown under high concentrations of CO_2 also show significant changes in the chemical composition of their leaves and other plant parts. The rise of CO_2 leads to a decrease in the concentration of nitrogen which may have serious consequences on the quality of the crops (Weigel and Manderscheid 2005).

There is a very little information about the effects of elevated concentration of CO_2 on the basic cereals such as rice (*Oryza sativa* L.). It is expected that increases in CO_2 levels in the global atmosphere could lead to increase the yield of the crops, but major changes can potentially effect the food needs of the population, as the rice crop provides a large proportion of the nutritional needs, and data indicates that a high CO_2 can cause a decrease in the rice yield (Lieffering et al. 2004). The high concentration of CO_2 in the atmosphere may have an impact on the growth and production of the rice crop. Rice plants were cultivated at elevated concentrations of CO_2 of up to 700 μL in the growth chamber. The total above-ground biomass and grain yield were greater at elevated concentrations of CO_2 (Seneweera et al. 1997). Higher atmospheric CO_2 also affected protein concentrations in major food crops. In this regard, a study was conducted on barley, rice, wheat, soybean, and potato, grown at a CO_2 concentration of 540–958 $\mu mol\ mol^{-1}$. The protein concentration in the grains decreased by approximately 10-15% compared by the atmospheric CO_2 (315–400 $\mu mol\ mol^{-1}$) (Taub et al. 2008). High levels of CO_2 in the atmosphere are likely to increase biomass production for C3 plant species in the natural ecosystems because of the higher rates of photosynthesis (Conroy 1992). Environmental stresses also lead to a variety of plant responses that lead to changes in cellular metabolism, growth, and genetic expression (Munné-Bosch 2005).

It is widely known that α-Tocopherol is necessary for human and animal health and is synthesized only in photosynthetic organisms in the membranes of chloroplasts (Trebst et al. 2002). α-Tocopherol is an antioxidant compound found in chloroplasts and the plants depend on it to protect themselves against oxygen toxicity (Munné-Bosch and Alegre 2002; Munné-Bosch 2005). It is also a fat-soluble antioxidant and is manufactured in most plants by oxygen-evolving phototrophs including some bacteria and all algae and plants (Abbasi et al. 2007; Sakuragi et al. 2006). So far, little is known about the specific roles of α-Tocopherol in various plant tissues (Abbasi et al. 2007). Foliar-application of α-tocopherol enhanced the growth of maize and is associated with improvements in photosynthetic pigment, antioxidative mechanism, water relations, and better nutrient acquisition in root and shoot along with tocopherol contents, and a decrease in lipid peroxidation. Furthermore, the increase of tocopherol levels in roots after α-Toc foliar application confers its basipetal translocation. (Ali et al. 2020).

Thompson et al. (2017) discussed the effects of elevated carbon dioxide on photosynthesis and carbon partitioning. Increased photosynthesis under elevated CO_2 mainly occurs due to an increase in ribulose-1,5-bisphosphate (RuBP) carboxylase/oxygenase (Rubisco) activity. Rubisco catalyzes the carboxylation of RuBP which is required for CO_2 fixation, but also uses O_2 as a substrate to oxygenate RuBP in a process called photorespiration (Makino and Mae 1999). The carboxylation reaction of RuBP is not saturated at the current atmospheric CO_2, therefore, as the availability of CO_2 increases under elevated CO_2 conditions so too will the rate of carboxylation (Drake et al. 1997). The other process, photorespiration, is wasteful in terms of energy, as it costs the plant more energy and does not lead to any gains in energy or carbon (Peterhansel et al. 2010). However, increasing the atmospheric CO_2 levels increases the [CO_2] surrounding Rubisco, shifting the ratio of CO_2:O_2 and thereby increasing the rate of carboxylation while decreasing the rate of oxygenation (Makino and Mae 1999). Low availability of soil nitrate increases the severity of photosynthetic acclimation and also seems to be associated with an inhibition of leaf nitrate assimilation (Vicente et al. 2016). Inhibition of leaf nitrate assimilation also occurs under elevated CO_2 (Bloom et al. 2014). It is not known whether the reduction of Rubisco synthesis at elevated CO_2 is directly related to lower N assimilation or if Rubisco is just regulated to balance the source and sink activity. The concentration of sucrose, the main product of photosynthesis, increases in all organs of pea plants exposed to elevated CO_2 in growth chambers; however, glucose concentrations are largely unaltered (Aranjuelo et al. 2013). In shorter periods of light, carbon partitioning shifts toward starch synthesis, while sucrose synthesis and consumption are decreased (Pokhilko et al. 2014). The plant's circadian clock prevents the total depletion of starch at night by setting limits on starch degradation based on the length of the night period (Martins et al. 2013).

This study aims to identify the role of α-Tocopherol in mitigating the effect of elevated concentrations of CO_2 emitted from the AL-Hunay Power Plant Main Station on the morphological and physiological traits of soybean (*Glycine max* L.).

MATERIALS AND METHODS

Planting

Seeds of soybean (*Glycine max* L. var. Giza 111) were planted in the botanical garden of the Faculty of Sciences, Shaqra University in 20 cm plastic pots containing 1:1 loamy sandy soil and sterilized with fungicides to prevent fungal infection. Each treatment has three pots with five seeds for each pot. The same soil was used for all treatments as well as the control.

Treatments

The plants of the control were kept in the botany garden and were allowed to continue its growth without any treatment until the morphological and physiological measurements were taken. The control plants were exposed to normal concentrations of CO_2 coming from fresh air in the botany garden.

The remaining four treatments were also put in the botany garden until the plants had fully emerged cotyledon leaves, then transferred to the location of the study which is 100 m from the AL-Hunay Power Plant Main Station in the Al-Hofuf agricultural area in Saudi Arabia.

The α-Tocopherol ≥ 95.5% (Sigma-Aldrich) was used to prepare the concentrations of the treatments. Three concentrations of α-Tocopherol were prepared by dissolving the required quantity of each concentration (100, 200, and 300 mg/L) in distilled water. Then, the plants were irrigated with four concentrations of α-Tocopherol (0, 100, 200, and 300 mg/L) every 15 days and were simultaneously exposed to the pollution of CO_2 emitted from the power station.

The atmospheric CO_2 concentration was measured during the three months of the trial (May, June, and July) in the first location (the botany garden where the control was put) as well as in the second location (100 m from the AL-Hunay Power Plant Main Station where the α-Tocopherol treatments were applied). The difference between 0 α-tocopherol and control plants is thet 0 α-tocopherol plants exposed to high elevated CO_2. Whereas control plants were far away and exposed to normal CO_2 concentration.

Measurements

Leaf samples were collected from *Glycine max* plants at the end of vegetative growth but before flowering.

The concentration of CO_2 was measured daily at the botanical garden as well as at the AL-Hunay Power Plant Main Station using Stack Gas Level device model ECOM J2KN Pro Easy. The monthly average of CO_2 concentration was calculated.

Plant pigments were estimated using the method of Metzner (1965).

Protein content was estimated depending on the methods of Micro-Kjeldahlby (Benton Jones Jr. et al. 1991) and Bradford (1976).

Lipids were assessed according to the Soxhlet method (Luque de Castro et al. 1998).

Sugars were estimated using the Thayumanavan method (Feteris 1965; van Handel 1968; Thayumanavan and Sadasivam 1984).

The mineral elements content was measured according to Allen (1974) methods.

The activity of antioxidant enzymes was estimated according to the methods of Egley (1983), Aebi (1984), Giannopolitis (1977), Maria Sgherri (1994), and Asada (1984).

Statistical analysis

Statistical analysis was done according to randomized complete block design (RCBD) and analysis of variance using SAS software according to Steel and Torie (1996).

RESULTS

The CO_2 Concentrations Emitted from the AL-Hunay Power Plant Main Station in the Kingdom of Saudi Arabia

The results showed that the concentration of atmospheric CO_2 in the botanical garden at the Faculty of Science, Shaqra University is in the normal accepted limits (Table 1). They reached 345, 341, 347 ppm during the studied period of May, June, and July, respectively. However, the

Table 1. The recorded concentrations of CO_2 emitted from the AL-Hunay Power Plant Main Station during the studied period.

Location	Month	CO_2 Concentration (ppm)
Botany garden (Control)	May	345
	June	341
	July	347
AL-Hunay Power Plant Main Station	May	3340
	June	3385
	July	3565
Accepted limit CO_2 air pollution		350

*Description of bioclimatic variables were adopted from O'Donnell and Ignizio (2012).

concentration of CO_2 emitted from the AL-Hunay Power Plant Main Station and measured at a distance of 100 m from the station was constantly increasing during the study period. An average of 3340, 3385, and 3565 ppm was recorded during May, June, and July, respectively, representing a 10 times increment compared with the concentration at the botanical garden. It is obvious that the concentration exceeded the accepted limit for air pollution with CO_2 (350 ppm).

The Role of α-Tocopherol in Mitigating the Effect of Elevated Concentration of CO_2 on the Morphological Traits of Soybean

The results shown in Table 2 revealed the effect of α-Tocopherol in mitigating the elevated concentration of CO_2 emitted from the station on the plant height, leaf area, and leaf number of the *Glycine max* plants. The results indicated that α-Tocopherol concentrations (100, 200, 300 mg/L) played a role in mitigating the effect of CO_2 on the plant height which reached 49.6, 49.9, and 52.8 cm, respectively as compared to the plant height in untreated plants with α-Tocopherol which reached 46.8 m. The results also indicated that there was an effect on the average leaf area with significant differences between plants treated with different concentrations of α-Tocopherol compared to the control. There were also significant differences in the average number of leaves between treated plants with different concentrations of α-Tocopherol compared to the control. A decrement in the number of leaves was observed in untreated plants compared to the control. Treating the plants with α-Tocopherol mitigated the effect of CO_2 on the number of leaves (14.2,14.9, and 17.8) compared to the number of leaves in untreated plants (13.4).

The results shown in Table 3 revealed the role of α-Tocopherol in mitigating the effect of CO_2 emitted by the station on average wet and dry weight of root, stem, and leaf in soybean plants. A decrement in the wet weight of the root was observed in untreated plants compared to the control. The results also indicated that the concentrations of α-Tocopherol (100, 200, 300 mg/L) played a role in mitigating the effect of CO_2 on wet root weight compared to untreated plants. There was also a positive effect of treating the soybean plants with α-Tocopherol.

The Role of α-Tocopherol in Mitigating the Effect of Elevated Concentration of CO_2 on the Physiological Traits of Soybean

The results showed the role of α-Tocopherol in mitigating the negative effect of CO_2 emitted by the station on the leaf content of some mineral elements (Table 4). A decrement in the leaf content of Zn was observed in

Table 2. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the plant height, leaf area, and leaf number of *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Plant height (cm)	59.2a ±17.1	46.8b ±12.2	49.6c ±12.2	49.9b ±12.9	52.8a ±17.2	3.2
Leaf area (cm^2)	911.2a ±309.9	507.8c ±140.5	537.4c ±151.5	570.6c ±165.1	675.3b ±221.2	28.9
Number of leaves	22.2a ±5.9	13.4c ±5.1	14.2c ±2.2	14.9c ±2.3	17.8b ±4.2	0.94

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

Table 3. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the wet and dry weight of the root, stem and leaf of *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Root wet weight (g)	31.1a ±6.1	22.1b ±2.9	22.8cd ±4.2	25.6c ±3.2	28.8b ±5.2	2.32
Stem wet weight (g)	53.1a ±17.1	34.8c ±12.1	39.6b ±12.2	44.1b ±12.9	49.2a ±17.2	2.94
Leaf wet weight (g)	84.3a ±29.9	39.8d ±7.6	43.4d ±8.5	47.6c ±7.1	68.6b ±28.2	4.61
Root dry weight (g)	20.4a ±6.1	16.1c ±4.2	18.0bc ±2.9	18.2bc ±3.2	18.8b ±5.2	1.82
Stem dry weight (g)	24.7a ±5.6	12.5d ±4.3	17.4b ±4.1	17.8c ±2.9	19.8a ±5.2	1.45
Leaf dry weight (g)	51.1a ±13.1	18.2d ±5.5	20.8d ±3.5	21.1c ±4.1	35.8b ±7.2	1.96

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

Table 4. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the mineral content of the leaves of *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Zn (ppm)	0.21a ±0.1	0.12c ±0.08	0.13c ±0.15	0.14c ±0.08	0.15bc ±0.07	0.02
Mn (ppm)	39.6a ±2.4	14.3d ±6.3	15.1d ±10.3	20.1c ±5.8	23.1b ±6.9	2.7
P (ppm)	2.7b ±0.3	1.3c ±0.8	1.7b ±1.4	2.1a ±0.7	2.3a ±1.4	0.19
Ca (ppm)	18.8b ±7.2	12.5d ±10.6	15.9cd ±8.1	16.2a ±12.2	16.1bc ±15.6	2.3
K (ppm)	105.4a ±8.4	53.2d ±17.3	73.3bc ±12.3	74.5c ±19.1	82.1b±8.9	4.8
Copper (ppm)	0.24a ±0.14	0.13bc ±0.09	0.14c ±0.09	0.15c ±0.08	0.16c ±0.18	0.03
Iron (ppm)	4.23a ±1.01	2.01d ±0.32	2.14d ±0.33	3.25c ±0.23	4.13b ±0.57	0.31

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

untreated plants compared to the control. It was observed that α-Tocopherol has a role in mitigating the effect of CO_2 of Zn, which reached 0.15 ppm at a concentration of 300 mg/L α-Tocopherol compared to untreated plants (0.12 ppm). A decrement in the leaf content of Cu was observed in untreated plants (0.13 ppm) compared to the control. It was also observed that the concentration of 100, 200, and 300 mg/L of α-Tocopherol had a role in mitigating the effect of CO_2 on the content of Cu, as it reached 0.14, 0.15, and 0.16 ppm, respectively, compared with the content in untreated plants.

The results in Table 5 indicated that there is a positive role for α-Tocopherol in mitigating the effect of CO_2 on the activity of some antioxidant enzymes in the soybean plants. A decrement in the activity of antioxidant enzymes was observed in plants not treated with α-Tocopherol compared to the control. it was observed that α-Tocopherol has a positive role in mitigating the effect of CO_2 on the activity of antioxidant enzymes catalase (CAT) and superoxide dismutase (SOD) at concentrations of 100, 200, and 300 mg/L. Moreover, guaiacol peroxidase (GPX) activity increased at 300 mg/L whereas ascorbate peroxidase (APX) activity was not affected by the three concentrations of α-Tocopherol.

The results presented in Table 6 showed the role of α-Tocopherol in mitigating the effect of CO_2 emitted from the power station on the leaf content of chlorophyll a, chlorophyll b, and carotenoids in the soybean plants. A reduction in the leaf content of chlorophyll a was observed in non-treated plants compared to the control. The results indicated that the concentrations of α-Tocopherol (100, 200, 300 mg/L) played a role in mitigating the effect of CO_2 on the leaf content of chlorophyll a which reached 0.19, 0.21, and 0,37 μg /g, respectively, compared with untreated plants (0.18 μg /g).

The results shown in Table 7 indicated the positive role of α-Tocopherol in mitigating the effect of CO_2

Table 5. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the activity of some antioxidant enzymes in *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Guaiacol peroxidase (GPX) (µmol/min/mg protein)	2.70ab ±0.23	1.84b ±0.07	1.89b ±0.06	2.11ab ±0.20	2.18a ±0.06	0.19
Catalase(CAT) (µmol/ min/mg protein)	58.12a ±1.44	43.35e ±1.39	47.25d ±1.39	49.11c ±1.01	49.82b ±0.71	0.12
Superoxide dismutase (SOD) (µmol/min/mg protein)	49.02a ±2.44	41.63d ±4.51	43.13c ±3.21	46.16c ±3.29	46.67b ±1.06	1.17
Ascorbate peroxidase (APX) (µmol/min/mg protein)	2.51a ±0.09	1.92b ±0.05	1.86b ±0.06	2.02b ±0.25	2.13b ±0.27	0.16

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

Table 6. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the content of pigments in the leaves of *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Chlorophyll *a* (µg/g)	0.58a ±0.14	0.28c ±0.15	0.36c ±0.16	0.41c ±0.14	0.45b± 0.13	0.03
Chlorophyll *b* (µg/g)	0.39a ±0.13	0.15d ±0.06	0.16d ±0.07	0.16c ±0.03	0.21b ±0.05	0.02
Carotenoids (µg/g)	0.034a ±0.02	0.023b ±0.02	0.025b ±0.02	0.025a ±0.01	0.030a ±0.02	0.09

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

emitted from the station on the leaf content of mono-, di-, and polysaccharides in the soybean plants. There are significant differences between plants treated with different concentrations of α-Tocopherol compared to the control. A decrement in the leaf content of disaccharides was observed in non-treated plants compared to the control. The results also indicated that the concentrations of α-Tocopherol (100, 200, and 300 mg/L) have a helpful role in mitigating the effect of CO_2 on disaccharides compared to non-treated plants.

The results in Table 8 showed elucidate the helpful role of α-Tocopherol in mitigating the effect of CO_2 emitted from the power station on the leaf content of lipids, total proteins, and soluble proteins in the *Glycine max* plants. A reduction in the leaf content of lipids, total proteins, and soluble proteins was observed in non-treated plants compared to the control. It was noticed that α-Tocopherol had a role in mitigating the effect of CO_2 on the leaf content of lipids, total proteins, and soluble proteins at concentrations of 100, 200, 300 mg/L.

DISCUSSION

In this study, the role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station in Soybean (*Glycine max* L.) was studied.

Much is still unknown about how a high CO_2 concentration will decrease photosynthesis when CO_2 is the primary substrate. Plants will react to elevated CO_2, the primary substrate of photosynthesis. In plants grown under elevated CO_2, carbohydrate production is increased due to an increase in photosynthesis. It is possible to use these carbohydrates, especially glucose and sucrose signaling pathways, to regulate many root functions. The acquisition of nutrients appears to be regulated by sugars, as evidenced by the regulation of the expression of different ion transporters and the ability of sugars to influence root development. The biosynthesis of some plant hormones may influence both elevated CO_2 and sugars, which may mean that sugars act as an intermediate in elevated CO_2 hormone regulation. (Jayawardena et al. 2017; Broberg et al. 2017; Thompson et al. 2017).

The results showed that the CO_2 emitted from the plant influences the morphological traits. It was observed that there was growth inhibition in the root and stems, leaf area, and number of leaves compared to the control. This decrease in plant growth may be due to the decrease in photosynthesis because of high concentration of CO_2. These findings are consistent with many previous investigations (Ainsworth et al. 2007; Bloom et al. 2010; Leakey et al. 2009). Changes in plant growth response to high CO_2 concentrations depend on the growth potential or growth conditions of a species (Reich et al. 2014; Lopes et al. 2018), as well as the species' developmental strategy, such as the creation of new sinks for extra C (Ceulemans and Mousseau 1994). Several studies have suggested that growth under elevated CO_2 concentrations leads to shifts in the root system architecture, which could affect the nutrient uptake capacity (Bloom et al. 2014; Cha et al. 2017).

The exposure of the plants to high concentrations of CO_2 resulted in a decrease in the plant height and a decrease in the leaf area. These results are in alignment with those in the studies of Debin (Zhao et al. 2003) and Sanchez (2000). However, they are in contrast with the

Table 7. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the content of sugars in the leaves of *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Monosaccharides (mg/g)	7.33a ±1.01	4.14d ±0.33	4.74d ±0.33	5.25c ±0.23	6.13b ±0.77	0.36
Disaccharide (mg/g)	23.2a ±5.3	13.4d ±4.1	17.4b ±3.9	19.1c ±2.8	19.9a ±4.8	1.53
Polysaccharides (mg/g)	38.2a ±5.9	27.2b ±3.4	27.6cd ±4.4	30.6c ±3.6	32.4b ±5.6	2.6

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

Table 8. The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay Power Plant Main Station on the lipids, total protein, and soluble protein in *Glycine max* L.

Treatments/ Parameters	Control	α-Tocopherol (mg/L)				LSD 0.05
		0	100	200	300	
Lipids (%)	4.21a ±1.05	2.24c ±0.43	3.02b ±0.43	3.25a ±0.24	3.42a ±0.67	0.21
Total protein (%)	18.4a ±3.1	11.6d ±3.4	13.1c ±4.4	13.7c ±5.4	15.7b ±3.2	0.89
Soluble protein (mg/g)	8.7a ±0.13	7.2d ±0.07	7.6b ±0.15	8.3c ±0.15	8.4b ±0.10	0.09

Values represent mean ± standard deviation. The averages followed by the same letter within the same row do not differ significantly from each other.

results of Acock (1990) who indicated that the high concentration of CO_2 has led to an increase in the rate of photosynthesis and increase the growth of stems and sizes of most vegetative parts of the plant. They are also inconsistent with the reports of Rogers (1983) and Conroy (1992) who reported that the increase in CO_2 above the accepted limit led to an increase in the growth of plant parts and an increase in the area of plant leaves.

The results also showed that there is an effect of CO_2 emitted from the power station on the physiological traits. It was observed that the content of soybean leaves of the elements (Zn, Mg, P, Ca, K, Cu, and Fe) decreases in plants growing at the power station compared to the control in the botanical garden. This decrement in mineral elements may be attributed to their exposure to high concentrations of CO_2, and thus may affect the signals inside plant cells through interaction with the main components. These results are in alignment with many previous investigations. For instance, Munné-Bosch and Alegre (2002) and Fangmeier (1996) pointed out that all mineral elements except P and Fe decreased. Fangmeier (2002) also indicated that the plant exposed to high concentrations of CO_2 led to a decrease in all mineral elements. Chaudhuri (1986) and Wu (2004) reported that the high CO_2 concentration led to a decrease in the elements of P, K, and Zn. Loladze (2002) found that the rise in CO_2 led to a decrease in important mineral elements such as Fe, I, and Zn. Fangmeier (1997) indicated that the increase in the concentration of CO_2 affected the elements of Mg and Zn in green tissues, while the P was not affected by the high concentration of CO_2. Manderscheid (1995) who discovered that the rise in CO_2 causes a decrease in the Mg and K. Dong et al. (2018) found that high CO_2 reduced the concentration of Mg, Fe, and Zn.

The average leaf content of chlorophylls and carotenoids decreased in response to the high concentration of CO_2 in the plants grown near the power station compared to the control grown in the botanical garden. This deficiency may be due to the high concentration of CO_2, which may affect the efficiency of the chloroplasts in the leaves and thus reduce the content of chlorophyll and carotenoids. Our findings of this study agree with Munné-Bosch and Alegre (2002) but contrasted with Dong (2018) who indicated that the leaf content of chlorophyll and carotenoids was not affected by the high concentration of CO_2.

A decrease in the leaf content of all sugars was also observed. This finding agrees with Thomas (2003) who indicated that the plant exposure to elevated concentrations of CO_2 up to 700 μmol mol^{-1} resulted in a decrease in the sugar content in the *Glycine max* L. plants. It also agrees with Chaudhuri (1986) who observed that exposing the plant to a high concentration of CO_2 leads to a decrease in carbohydrates. In contrast, it is inconsistent with many previous studies. For instance, Conroy (1994) indicated that the high concentration of atmospheric CO_2 improves plants' tolerance to heat stress due to its facilitation of maintaining cell size and photosynthesis function in the leaves, and leads to increased carbohydrate storage in the stems. Rogers (1996) found that the sugars content increased when the plants were exposed to elevated concentrations of CO_2 (900 μmol mol^{-1}). Wu (2004) exposed wheat (*Triticum aestivum* L.) plants to two concentrations of CO_2 (350 and 700 μmol mol^{-1}), respectively. He observed that there was a significant increase in carbohydrates. Dong (2018) reported that elevated atmospheric CO_2 enhanced the concentrations of fructose, glucose, and soluble sugar.

In our experiment, the negative effect of elevated CO_2 on the leaf content of lipids and proteins was also observed. Our results are inconsistent with the results of Taub (2008) on barley, rice, wheat, soybean, and potato grown at CO_2 concentration of 540–958 μmol mol^{-1}. He noticed a reduction in grain proteins with ~10-15%. Other studies also reported no negative effect of elevated CO_2 on the leaf protein content (Bencze et al. 2004; Kimball et al. 2001). However, our results agree with the findings of Sæbø (1996) who recorded a negative effect of high concentration of CO_2 on the growth, productivity, and quality of barley (*Hordeum vulgare*, cv. Thule), and the protein content decreased by 8%. Pleijel (2000) also found that the exposure of the spring wheat (*Triticum aestivum* L. cv. Dragon) resulted in a high concentration of CO_2 leading to a negative decrease in the protein content with 13%. Our results are also in parallel with many previous studies (Blumenthal et al. 1996; Chaudhuri et al. 1986; Conroy et al. 1994; Conroy 1992; Rogers et al. 1998; Rogers et al. 1996; Rogers et al. 1984; Terao et al. 2005; Wu et al. 2004; Ziska et al. 2004) which indicated that high concentrations of CO_2 lead to reduction in the protein content.

An increase in the levels of ROS under stressful environments is a general phenomenon. These overly produced ROS directly affect different cellular membranes through lipid peroxidation. As a defense for the protection of the cellular membranes and other components from the deleterious and damaging effects of overproduced ROS, plants have evolved well-developed mechanisms for the antioxidation of ROS composed of non-enzymatic (AsA, phenolics, carotenoids, flavonoids, tocopherol, etc.) and enzymatic (SOD, POD, CAT, APX) components (Ali et al. 2018). Reports state that

α-Tocopherol is also an excellent quencher and scavenger of singlet oxygen by controlling the lifetime of ROS. By resonance energy transfer, one α-Tocopherol molecule can neutralize up to 120 molecules of singlet oxygen. The activities of antioxidants such as SOD, POD, and CAT were found to be higher in leaves and roots of maize plants after α-Toc treatment, which suggested their antioxidative role to be stimulated in the presence of α-Toc (Ali et al. 2020).

The elevated CO_2 also affected negatively the leaf content of antioxidant enzymes (guaiacol peroxidase, catalase, superoxide dismutase, and ascorbate peroxidase) and plant systems inside the cell that control the growth and development of plants and the action of enzymes. These findings are consistent with many previous studies (Conroy et al. 1994; Fangmeier et al. 1999; Fangmeier et al. 1996) that indicated that the rise in CO_2 leads to partial disruption of enzymes.

In this investigation, the second group of plants were located 100 m from the AL-Hunay Power Plant Main Station and were spontaneously exposed to elevated concentrations of CO_2 emitted from the power station (Table 1). These soybean plants were treated with four levels of α-Tocopherol (0, 100, 200, and 300 mg/L) to mitigate the effect of elevated CO_2 on their morphological and physiological traits. α-Tocopherol may have a role in regulating plant growth, activating of photosynthesis, protection of the cell membrane, protection of chloroplasts, and helping the plant to withstand oxidative stress resulting from the exposure to elevated concentration of CO_2. The results revealed a helpful and positive effect of α-Tocopherol on all studied morphophysiological traits of soybean. The study are harmonious with the findings of Munné-Bosch and Alegre (2002) who indicated that α-Tocopherol protects the components of the cell membrane, regulates the plant's response to stress, and provides protection for chloroplasts. α-Tocopherol may also have a role against the oxidative stress caused by plant exposure to high concentration of CO_2 through degradation of free radicals and reactive oxygen species (ROS) (Munné-Bosch and Alegre 2002; Munné-Bosch 2005; Sakuragi et al. 2006). The use of different concentrations of α-Tocopherol may lead to a variety of plant responses that lead to changes in cellular metabolism and contribute to plant tolerance to stress (Munné-Bosch 2005).

CONCLUSION

The role of α-Tocopherol in mitigating the effect of CO_2 emitted from the AL-Hunay on the morphological and physiological traits of soybean has been investigated in this study. The results revealed a negative effect of elevated concentrations of CO_2 on the morphological and physiological traits of soybean. The current study provides proof for the positive role of α-Tocopherol in mitigating the effect of elevated CO_2 the morphological and physiological traits of *Glycine max* L. plants. Thus, this study recommends using 300 mg/L α-Tocopherol as a soil application for soybean plants to enhance its tolerance to elevated CO_2.

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