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ROLE OF EXOGENOUS APPLICATION OF ALPHA-TOCOPHEROL IN REDUCING LOW TEMPERATURE STRESS IN BELL PEPPER

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ABSTRACT

Changing climatic conditions have an impact on the commercial harvest and production of *Capsicum annuum* L. across the world. It is a summer crop that grows best at 21°C (low) to 37 °C (high) temperature. Changes in normal growth, poor shoot and root length, increased antioxidant activity, low sugar content, high proline content, and poor yield were observed in bell pepper at low temperature stress. A research trial was conducted on bell peppers in the Department of Plant Pathology at University of Agriculture, Faisalabad. Bell peppers were cultivated hydroponically and alpha-tocopherol control (0ppm), 25ppm, 50ppm, and 100ppm were applied in foliar application. At the reproductive period, a low temperature stress of 18 °C day and 15 °C night was used given. After seven days of foliar spray, plants were exposed to cold temperatures during the day and night. After seven days of stress, the plants were harvested and morphological, physiological, and biochemical data were examined. Plant growth, leaf area, number of leaves, buds, and flowers, photosynthetic pigments, relative water content, cell membrane permeability, total soluble sugar, total reducing sugar, protein contents, and total free amino acid levels were all reduced when exposed to high temperatures. When the stress of low temperature was applied, there was a rise in proline, phenolic, flavonoid, H₂O₂, MDA, enzymatic antioxidants SOD, CAT, POD, and in APX. Under temperature stress, foliar application of alpha-tocopherol significantly improved CAT, POD, APX activity, decreased MDA, H₂O₂, and improved proline content. Exogenously administered alpha-tocopherol was found to be effective in boosting capsicum growth and antioxidant capability under low temperature stress.

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INTRODUCTION

Capsicum annuum L. belongs to the family *solanacea*, genus capsicum, locally known as bell pepper, Shimla Mirch or sweet pepper, used as a food worldwide. It contains vitamins A, B, C, E, B₆, thiamine, beta-carotene, proteins, iron, and Ca²⁺, which are good for human health. It is a large-sized fruit which is cultivated almost around

the world (Shrestha *et al.*, 2014; Ali *et al.*, 2016; Kantar *et al.*, 2016; Khan *et al.*, 2017). Capsicum in Pakistan is an economically important cash crop and is cultivated on 19% area available for vegetable cultivation (Shah *et al.*, 2009). The economic survey of Pakistan during 2013-2014 found that the area available for cultivation was 62.7 thousand ha, with 145.8 thousand tonnes of production

annually (Qureshi *et al.*, 2015).

Environmental stress causes damage to the plants and poses a major threat to food production. It alters the plant morphology, physiology, biochemistry, rate of metabolism, and photosynthesis in C3 and C4 plants (Liu *et al.*, 2001; Wang *et al.*, 2003; Jing *et al.*, 2016). Low temperatures enhance photorespiration, leaf senescence, alter gene function, retard growth, reduce productivity, biological mechanisms, plant height, biomass, and yield. Under low temperatures, reactive oxygen species (ROS) increase in plants that damage the cell membranes, and plants die due to oxidative stress (Li *et al.*, 2004; Wang and Liu, 2010; Zhai *et al.*, 2016).

Capsicum is highly temperature sensitive crop and low temperature (14°C) severely disturbs its physiology that results in decreased growth of leaves, buds, and flower, reduced metabolism and cell function, irregular shedding of vegetative and reproductive parts, accumulation of ROS that lead to lipid and protein degradation, abnormal sex organ and feasible pollen grain, swollen and enlarged ovaries, parthenocarpic and abnormal fruit size and poor yield (Mateos *et al.*, 2013; Pyshnaya *et al.*, 2016). Application of antioxidants is one of the leading remedies to reduce stress, improve quality, growth, and yield. Vitamins are antioxidants, natural bio-regulators, essential organic compounds, part of enzymatic reaction as cofactors. A small amount is effective as well as essential for living organism's metabolisms and their deficiency leads to poor yield (Oertli, 1987; Sadak, 2014).

Vitamins (folic acid, vitamin A, B12, B6, B2, B1, C, D, E, K, H, pantothenic acid) are applied as foliar, priming agents, rooting medium and to eliminate stress, protect the plant, scavenge reactive oxygen species and initiate root and flower development (Sadiq *et al.*, 2017). PSII is protected from photo-inactivation by alpha-tocopherol (vitamin E), an antioxidant and chloroplast membrane bounded stress sensitive hormone that prevents peroxidation of lipids and polyunsaturated fatty acids, photo-oxidation of chloroplast, and free radical scavenger (Havaux *et al.*, 2005; Farouk, 2011; Szarka *et al.*, 2012).

Under stress, when the immense amount of reactive oxygen species accumulates in the plant, the concentration of membrane-bound α -tocopherol drops, and the production of SOD, POD, CAT, proline, and phenolic compounds is severely affected, resulting in reduced growth and yield (Sadiq *et al.*, 2016). This experiment was conducted with the aim of

understanding the plant's morpho-physiological responses under low temperature stress and evaluating the effectiveness of Alpha-tocopherol foliar application to control the accumulation of antioxidants in bell peppers under stress.

MATERIALS AND METHODS

A research trial was conducted to check whether exogenously applied alpha-tocopherol acts as an effective foliar agent. The bell pepper plants were grown following hydroponic techniques in a plant growth chamber (Model MLR-351H). The experiment was conducted under complete randomized design (CRD) with three replications. Seedlings of *Capsicum annum* cv. *aristotle* were transplanted and grown at 25 °C (daytime temperature) and 20 °C (night temperature). Exogenous application of alpha-tocopherol control (0), 25, 50, and 100 ppm was applied with the help of an atomizer after 30 days of transplantation. After one week, treated plants were subjected to chilling stress of 18 °C (day) and 15 °C (night). After seven days of low temperature stress application, plants were harvested for morphological, physiological, and biochemical study.

Morphological parameters

The length of the shoot and root of plants was measured in centimeters (cm) using a measuring scale. An electronic weight balance (Model PX/MA 1003) was used to determine the fresh weight of the plant shoot and root in grams (g). For dry weight, shoots and roots were kept in a heating oven (Model Xu058) for 24 hours at 70°C, and the dry weight of the shoots was measured. The formula was used to calculate the leaf area (cm²);

$$\text{Area of leaf (cm}^2\text{)} = \text{Leaf length in cm} \times \text{Leaf Width in cm}$$

All the leaves, flowers and buds of plants were manually counted at the time of harvest.

Physiological parameters

The amounts of chlorophyll (a, b, and total chlorophyll) and carotenoid from plant leaves were estimated using a technique described by (Arnon, 1949). The plant anthocyanin concentration was determined using 5 ml of phosphate buffer (pH 7.8) and 0.25 g of plant material. Then centrifuged and spectrophotometrically absorbance at 600 nm was measured by using Model Hitachi U-1800. The technique of Barrs and Weatherley (1962) was used to determine the relative water content of the leaf, by following the given formula;

$$\text{RWC} = \left(\frac{\text{Fresh weight of leaf} - \text{Dry weight of leaf}}{\text{Turgid weight of leaf} - \text{Dry weight of leaf}} \right) \times 100$$

To determine cell membrane permeability, 0.1 g fresh plant leaf was placed in 10 ml H₂O in a test tube and gently stirred for 5 seconds, following the ECo value which was determined using an EC meter (Model CD98304). To determine the EC1, the filtrate was kept at 4°C for 24 hours. To determine the EC2, the filtrate was autoclaved for 15 minutes, and EC2 was measured by using EC meter (Model CD98304), and the CMP was calculated using the following formula;

$$\text{CMP (\%)} = \frac{\text{EC}_1 - \text{EC}_0}{\text{EC}_2 - \text{EC}_0} \times 100$$

Biochemical parameters

To determine total soluble sugars, leaves were ground in methanol solution (5 mL, 80%), centrifuged, 1 ml sulfuric acid and 2 ml phenol (5%) were added, vortexed, and after 30 minutes absorbance was measured at 480 nanometers (nm) on a spectrophotometer. Dinitrosalicylic acid reagent was used to detect reducing sugars (DNSA reagent). The mixture was prepared by adding 1 ml dH₂O and 1 ml DNSA reagent in plant extract. That mixture was placed in a water bath at 100°C for 15 minutes, then cool to room temperature. A spectrophotometer was used to measure the absorbance at 540 nm. The AlCl₃ colorimetric approach was used to discover flavonoids in plants. The plant extract, 0.3 ml NaNO₂ (5%), and 0.3 m Aluminium chloride (10%) was added in a test tube and gently shaken for a few minutes. Then 2 ml of sodium hydroxide (1 M) was added, and after 5 minutes the absorbance was measured on a spectrophotometer at 510 nm. Folin-Ciocateu reagent was used to determine the phenolic content of the bell pepper plant. Folin reagent (1 ml) and Na₂CO₃ (1 ml) were added to 0.5 ml plant extract. At 40°C, the mixture was placed in a water bath until the colour emergence, then absorbance was measured at 765 nm. The Bradford technique was used to determine total soluble protein (1976). Plant extract (0.1 ml) was combined with 2 ml Bradford reagent and absorbance was measured at 590 nm on spectrophotometer. The total free amino acid in bell pepper plants was determined using the Yemm *et al.* (1955) technique. The plant material (1 g) was ground in 10 ml of phosphate buffer (pH 7.1) and centrifuged to get the extract. 0.5 ml centrifuged material was added to 0.5 ml of 10% pyrimidine, 0.5 ml 2% ninhydrin, and the

solution was water bathed for 30 minutes before checking the absorbance at 570 nm. 0.1 ml plant extract, add 2 ml phosphate buffer, 0.1 ml H₂O₂ (5.9 mM) was taken to determine the activity of the CAT (catalase) enzyme. The absorbance of the mixture was measured at 240 nm. To test the activity of Peroxidase enzyme (POD) in plants, mixture of 0.1 ml plant extract, 1.5 ml potassium buffer, 0.5 ml guaiacol, and 1 ml H₂O₂ was prepared and measured the absorbance at 470 nm using a spectrophotometer. To determine SOD enzyme activity in plants, the mixture was prepared by adding plant extract with phosphate buffer (0.5 ml), 0.1 ml 100 mM methionine, 0.1 ml 2 mM riboflavin, 0.1 ml plant extract, and 0.1 ml NBT (1 mM). After exposing the combination to light for 15 minutes, the absorbance was measured at 560 nm. To test the activity of the ascorbate peroxidase (APX) enzyme in plants, 100 liters of plant extract with 1 liter of distilled water, 100 liters of EDTA, 100 liters of ascorbic acid, 600 liters of H₂O₂ was used to prepare the mixture, readings of the absorbance at 290 nm was calculated by using spectrophotometer. Velikova *et al.* (2000) used a technique to determine the H₂O₂ content in plants, by following that technique the mixture was prepared by adding 1 ml plant extract, 1 ml KI at 1 M concentration, 100 L phosphate buffer, kept at room temperature for half an hour and absorbance was measured using a spectrophotometer at 390 nm wavelength. The quantity of MDA in the sample was determined using Heath and Packer (1968) technique of 0.5 % TCA in 20% TBA. The Bates *et al.* (1973) technique was used to determine the content of proline in the plant. 1 ml of 3% sulfosalicylic acid, 1 ml glacial acetic acid (100%), and 1 ml ninhydrin were added to 1 ml plant extract, and the mixture was immersed in a water bath at 100 °C for 30 minutes. Then 4 mL of toluene was added and the mixture was shaken carefully until the two layers formed. The top layer was taken to measure the absorbance at 520 nm with the help of spectrophotometer.

RESULTS

Morphological parameters

Fresh and dried weight of shoots reduced considerably when exposed to high temperatures. When alpha-tocopherol was administered exogenously, stress was not as much effective; however, the foliar treatment decreased stress and resulted in an increase in shoot length. The effects of foliar alpha-tocopherol

concentrations (25, 50, and 100 ppm) on stress-induced damage were substantial. When compared to control plants, 100ppm alpha-tocopherol was the most effective in minimizing stress effects and increasing shoot length in bell pepper (Figure 1). Under low temperature stress, bell pepper root length, fresh and dried weight were all reduced due to stress. Plants given alpha-tocopherol as a foliar spray demonstrated tolerance to the stress. Alpha-tocopherol concentrations of 100ppm were shown to be effective in lowering stress effects and improving root length, fresh and dry weight (Figure 1). Plants under stress showed a decrease in leaf area. In comparison to control plants, alpha-tocopherol treated plants had more

leaf area. Alpha-tocopherol was shown to be beneficial in lowering stress, and plants treated with 100ppm alpha-tocopherol had more leaf area than non-treated plants of bell pepper (Figure 2). Temperature stress reduced the amount of leaves, buds, and flowers per plant substantially. When compared to plants grown under control conditions, alpha-tocopherol treatment (25, 50, and 100ppm) proved effective in eliminating stress-induced effects. When comparing plants treated with 100ppm alpha-tocopherol to control and various levels of treatment, a clear increase in the number of leaves, buds, and flowers per plant was observed (Figure 2).

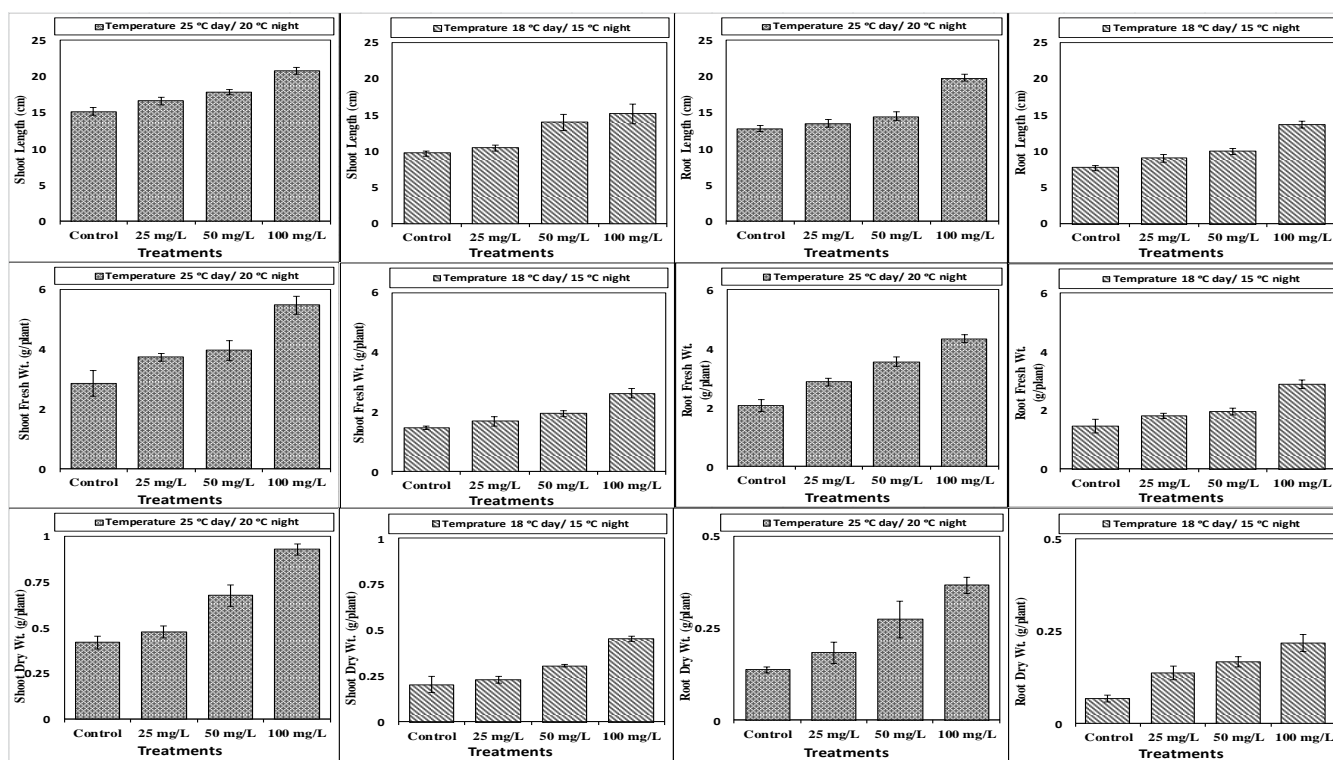


Figure 1. Shoot length, fresh and dry weight, root length, fresh and dry weight of bell pepper (*Capicum annuum* L.) treated with different levels of alpha-tocopherol (control, 25, 50, 100 mg/L) as foliar agent under temperature stress.

Physiological parameters

Reduced chlorophyll content was observed in the fresh leaves of a bell pepper plant when temperature stress was applied. Stress-induced effects were reduced by alpha-tocopherol application. Plants treated with alpha-tocopherol showed increased chlorophyll a content as compared to control plants under low temperature stress. Foliar application of -tocopherol at

100 ppm levels showed better results in reducing stress (Figure 2). In the fresh leaves of bell pepper, chlorophyll b content decreased significantly when stress was applied. When a plant is subjected to low temperature stress, its chlorophyll content decreases. Exogenously applied alpha-tocopherol at all levels were found beneficial in reducing the stress effect caused by temperature stress (Figure 2).

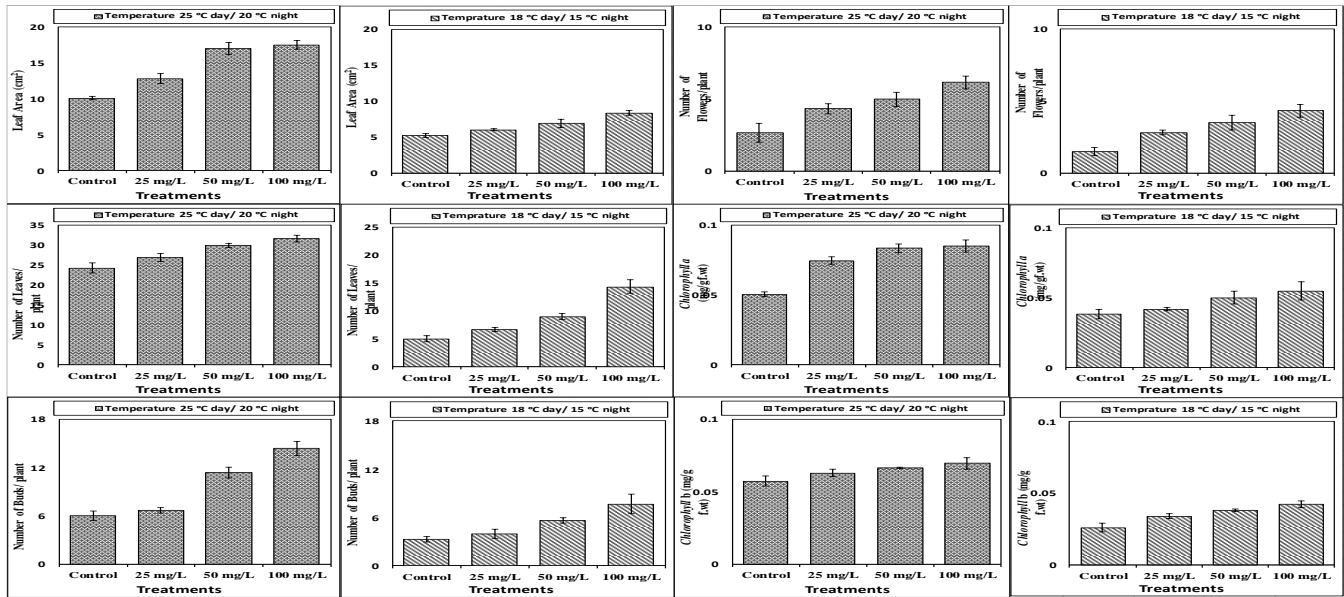


Figure 2. Leaf area, number. of leave, number of buds, number of flower, *chlorophyll a* and *chlorophyll b* of bell pepper (*Capcicum annum* L.) treated with varying levels of alpha-tocopherol (control, 25, 50, 100 mg/L) as foliar agent under temperature stress.

Biochemical Parameters

The foliar application was effective and increased the chlorophyll a/b ratio in the plants treated with alpha-tocopherol foliar under low temperature stress (Figure 3). Carotenoid content in fresh leaves of a bell pepper plant was reduced significantly when low temperature

stress was applied. Alpha-tocopherol was effective in enhancing carotenoid content. Of various alpha-tocopherol levels, 25 and 50 ppm increased carotenoid content as compared to the others under stress conditions (Figure 3).

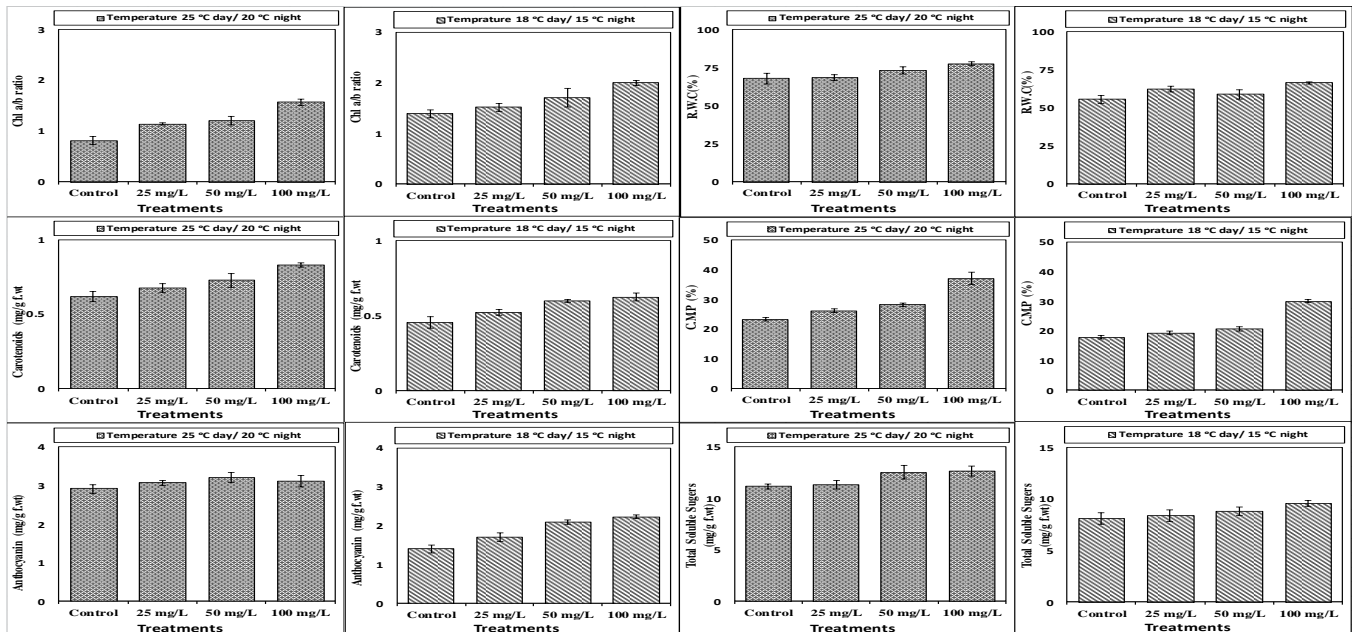


Figure 3. *Chl a/b* ratio, carotenoids, anthocyanin, R.W.C, C.M.P and total soluble sugars of bell pepper (*Capcicum annum* L.) treated with different levels of alpha-tocopherol (control, 25, 50, 100 mg/L) as foliar agent under temperature stress.

Anthocyanin content was reduced under temperature stress significantly. Application of alpha-tocopherol caused a significant increase in the plant carotenoid content under temperature stress when compared to the plants not treated with alpha-tocopherol. When plants were treated with 100ppm alpha-tocopherol exogenously, their anthocyanin content was significantly higher than in control plants (Figure 3). Relative water content is significantly reduced under temperature stress. When temperature stress is applied (Figure 3), the relative water content of bell peppers increased when treated with alpha-tocopherol in comparison to plants that were not treated with α -tocopherol. 100ppm of alpha-tocopherol improves the relative water content of the bell pepper plant. Cell membrane permeability (CMP) in the fresh leaves of a bell pepper plant is reduced under temperature stress. Exogenous application of alpha-tocopherol improved CMP as observed in plants treated with α -tocopherol in comparison to plants not treated with the exogenous application. Among different levels, 100ppm improved more CMP than other levels of alpha-tocopherol treatment under stress (Figure 3). The total soluble sugar content in the fresh leaves of bell pepper plants was reduced significantly when temperature stress was applied. Increased soluble sugar content was observed in plants treated with the alpha-tocopherol exogenous application. Under low temperature stress, 100ppm exogenous

application eliminates stress-induced effects and increased the content of soluble sugars (Figure 3). Under temperature stress, the total reducing sugar content in fresh leaves of bell pepper plants was significantly reduced. Among the levels of α -tocopherol applied as a foliar spray, plants treated with 100 ppm alpha-tocopherol showed increased total reducing sugar content as compared to control plants under stress (Figure 4).

An increase in flavonoid content was observed when temperature stress was applied. Used as a foliar spray, it reduced the low temperature stress effect. Exogenous application of 100ppm alpha-tocopherol resulted in a significant increase in the flavonoids content of the stressed plant (Figure 4). Phenolic contents in fresh leaves of bell pepper plants increased under temperature stress. Plants treated with 100ppm alpha-tocopherol had lower phenolic content when compared to other levels of foliar and plants grown under temperature stress (Figure 4). Total soluble protein decreased under temperature stress in fresh leaves of bell pepper plants. Plant total soluble protein concentration was significantly reduced under low temperature stress. Foliar application of alpha-tocopherol reduced the temperature stress effect and increased the content of total soluble protein observed in plants treated with 100 ppm alpha-tocopherol as compared to plants grown under control conditions under stress (Figure 4).

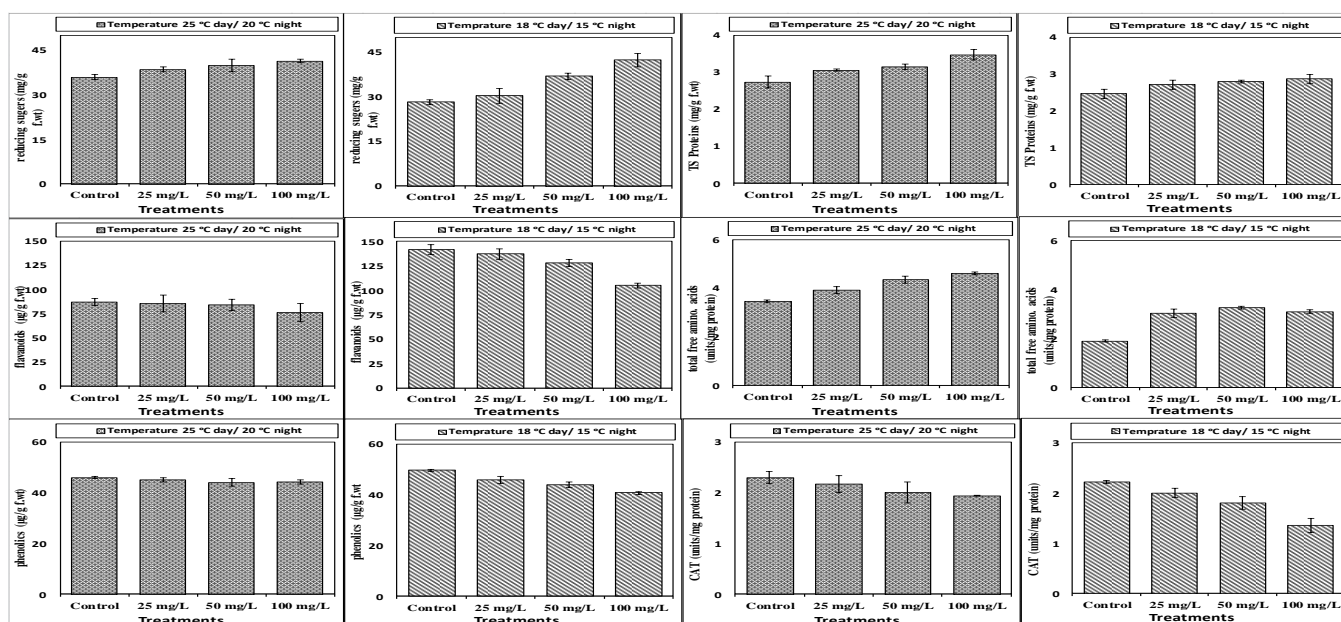


Figure 4. Total reducing sugars, flavonoids, phenolics, total soluble proteins and CAT activity (catalase per oxidase) of bell pepper (*Capicum annuum* L.) treated with different levels of alpha-tocopherol (control, 25, 50, 100 mg/L) as foliar agent under temperature stress.

Under low temperature stress, total free amino acid decreased in the fresh leaves of bell pepper plants. An increase in total free amino acid content was observed in 100ppm alpha-tocopherol treated plants under stress as compared to other levels of treatments (Figure 4). The activity of catalase (CAT) increased with temperature in bell pepper plants. The catalase enzyme is produced in response to an increase in reactive oxygen species (ROS) in a stressed plant. It was observed that foliar application of alpha-tocopherol reduced temperature stress effects and plants treated with 100ppm alpha-tocopherol had improved catalase activity (Figure 4). The activity of POD increased with the temperature in bell pepper plants. Foliar application of alpha-tocopherol improved the POD activity. Plants treated with 50 and

100 ppm alpha-tocopherol showed high peroxidase activity as compared to the others (Figure 5).

The activity of the SOD enzyme increased when temperature stress was applied. Foliar application of alpha-tocopherol was effective and reduced stress-induced effects in bell pepper plants. It was observed that plants treated with 100ppm alpha-tocopherol improved SOD activity as compared to other levels under temperature stress (Figure 5). The activity of the APX (Ascorbate peroxidase) enzyme increased under temperature stress in bell pepper plants. Temperature stress increased APX activity observed in plants. Plants treated with 100ppm alpha-tocopherol showed a decrease in the activity of the APX in comparison to the control (Figure 5).

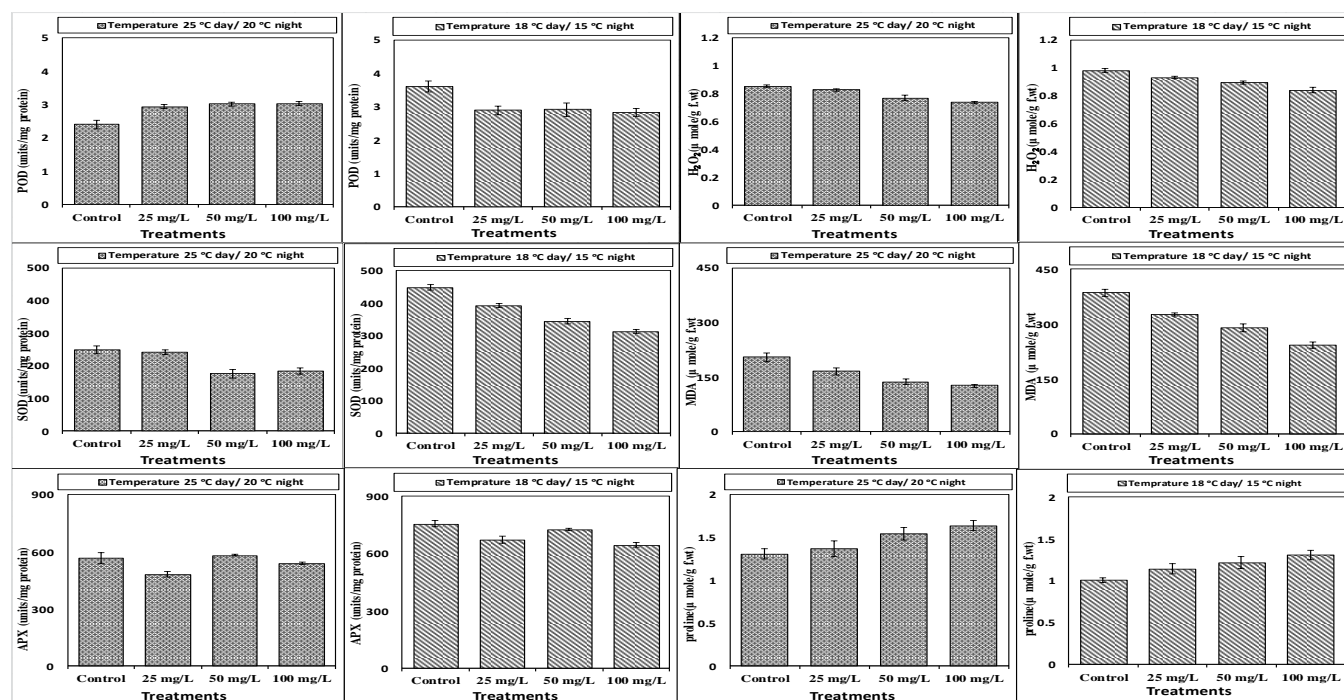


Figure 5. POD, SOD, APX, H₂O₂, MDA and proline of bell pepper (*Capicum annuum* L.) treated with different levels of alpha-tocopherol (control, 25, 50, 100 mg/L) as foliar agent under temperature stress.

The H₂O₂ concentration increased under temperature stress in bell pepper plants. Foliar application of alpha-tocopherol lowered the H₂O₂ concentration in bell pepper plants (Figure 5). The malondialdehyde concentration in plants increased under temperature stress. Plants treated with alpha-tocopherol reduced stress effects. Plants treated with 100ppm alpha-tocopherol foliar application have a reduced concentration of MDA under stress (Figure 5). In bell pepper plants, proline content increased when

temperature stress was applied. Foliar application of alpha-tocopherol played a significant role in reducing temperature stress effects. Proline, a stress indicator, is reduced in 100ppm alpha-tocopherol treated plants as compared to plants under control conditions when temperature stress is applied (Figure 5). Stress affected the metabolites in plants, ion leakage decreased, and antioxidants hunted the reactive oxygen species (ROS). Under stress, the production of antioxidants increases due to increased oxidative stress. Foliar application of

alpha-tocopherol improved the plant growth, sugar, protein, and amino acid contents by reducing oxidative stress.

DISCUSSION

During the life cycle of crops, they are exposed to different environmental stresses. Stress adversely affects the development and growth of plants. Plants under stress have a disturbed metabolic rate and produce less biomass (Wei *et al.*, 2014). alpha-tocopherol is a membrane-bound antioxidant of plants and is present in the chloroplast (Orabi and Abdelhamid, 2016). When plants are under stress, alpha-tocopherol controls redox reactions in the chloroplast and prevents the membrane from degradation (Munné-Bosch, 2005). In the present study, low temperature stress negatively affects the shoot length, fresh and dry weight of the shoot and root length, as well as the fresh and dry weight of the root. Under stress, a reduction in the number of leaves, buds, and flowers in bell pepper plants is clearly observed. Alpha-tocopherol has a significant effect and improves root and shoot length. The fresh and dry mass of root and shoot increased in alpha-tocopherol treated plants. In stress conditions, upgradation in growth is related to the higher protein content available to the plant under tocopherol treatment. Similarly, alpha-tocopherol prompted growth was reported in faba beans (Semida *et al.*, 2014). Applying alpha-tocopherol levels of 25 ppm, 50 ppm, and 100 ppm as foliar was effective in improving growth. In the present study, reduced RWC, CMP, chlorophyll a, b, and carotenoid were observed. Temperature stress has severe effects on plant water relations. Membrane deformation and ion gradient imbalance caused by ion leakage have been observed in stressed plants. It was reported that in bell peppers, under low temperature stress, reduced chlorophyll content was present. Carotenoids and chlorophyll degrade under low temperature stress (León-Chan *et al.*, 2017). Chilling has a destructive effect on cucumber seedlings and lower chlorophyll contents, CMP, and RWC were observed in cucumber seedlings (Seydpour and Sayyari, 2016). In tomato seedlings, chilling stress leads to higher solute leakage and the eventual death of plant leaves (Senaratna *et al.*, 1988). Foliar application of alpha-tocopherol reduced the temperature stress in bell pepper plants and higher chlorophyll content, improved CMP and RWC were observed in plants under treatment

in comparison to those grown in a controlled environment. Similar results of alpha-tocopherol foliar application in reducing stress were observed in *Vigna radiata* (Sadiq *et al.*, 2017). The chlorophyll content of flag leaf wheat grown under stress conditions decreased significantly, and the application of alpha-tocopherol improved the chlorophyll content (Farouk, 2011). Alpha-tocopherol improves the growth rate, chlorophyll, RWC, and antioxidant activity by inhibiting the reactive oxygen species accumulation in bell pepper plants. In the present study, under low temperature stress in bell pepper plants, total sugar, reducing sugar, and total soluble proteins decreased. It was reported that carbohydrate contents decrease in plant parts under low night temperatures in bell peppers (Shaked *et al.*, 2004). In the present experimental study, alpha-tocopherol exogenous application lessens the temperature stress effects in bell pepper plants and a higher content of sugars and protein is observed in plants treated with alpha-tocopherol when compared to plants under control. Similarly, in *Linum usitatissimum* plants, an increase in total carbohydrate and total protein content treated with alpha-tocopherol foliar application was reported (Sadak, 2014). Increased proline, flavonoid, and phenolic content were observed in the present study. Under low temperatures, oxidative stress increases and the plant increases its osmolytes to protect the plant from oxidation. Foliar application of alpha-tocopherol improved the plant's proline, flavonoid, and phenolic content. Exogenous application of soy bean-tocopherol improved the concentrations of proline, soluble sugars, and free amino acids under stress conditions (Mostafa *et al.*, 2015). In two cultivars of *Vicia faba*, an increased proline content was observed under stress, and foliar application of alpha-tocopherol lowered stress-induced effects and improved the proline content (Orabi and Abdelhamid, 2016). In the present study, an increase in H₂O₂, MDA, SOD, CAT, POD, and APX enzymatic antioxidants under temperature stress was observed. Whereas alpha-tocopherol foliar application improved the activity of catalase, POD, and APX enzymes and reduced MDA and H₂O₂ under temperature stress, CAT, POD, and APX enzymatic antioxidants are effective biomolecules that prevent the plant from cellular damage. In cucumbers, increased H₂O₂ content, CAT, POD, SOD, and APX activity were reported under chilling stress (Yang *et al.*, 2011). Similarly, under low temperature stress, ROS (reactive

oxygen species) accumulate in sweet pepper plants, and a higher content of H₂O₂ and increased activity of APX reported (Airaki *et al.*, 2012). Increased lipid peroxidation, activity of CAT and POD were reported in three flax cultivars under stress. The application of alpha-tocopherol to the skin reduces the effects of stress and increases the activity of the antioxidants CAT and POD (El-Bassiouny and Sadak, 2015). In bell peppers, chilling stress produces oxidative stress and an increased H₂O₂ content, CAT, POD, SOD, and APX activity were reported. Antioxidants control the accumulation of ROS. Their chelation with metal ions lowers the formation of excessive ROS by reducing their catalytic activity. Foliar application of hormones reduces the H₂O₂ content and improves the activity of CAT, POD, SOD, and APX (Li *et al.*, 2015).

It was concluded from the results of the current experiment that low temperature stress reduced the growth and high oxidative stress produced under stress. Foliar application of alpha-tocopherol was beneficial in regulating growth and improving the antioxidant potential of the bell pepper plants under low temperature stress.

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CONFLICT OF INTEREST

The authors have not declared any conflict of interests.

AUTHORS CONTRIBUTIONS

All the authors equally contributed in research as well as helped in manuscript drafting and analyzing the data

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