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Enhancement of Heat Stress Tolerance in Common Bean Plants by Trehalose, Hydrogen Peroxide and Salicylic Acid Treatments

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Abstract: This work was conducted at a private vegetable farm in El-Taweila, near El-Mansoura City, Dakahlia Governorate, Egypt during the two successive summer seasons of 2020 and 2021. The study examined the effect of exogenous foliar treatments of trehalose (200, 300 and 400 ppm), hydrogen peroxide (20, 30 and 40 ppm) and salicylic acid (150, 200 and 250 ppm) on heat stress tolerance of common bean plants cv. Giza 6. The results showed that the highest concentrations of trehalose, hydrogen peroxide and salicylic acid recorded the maximum values of plant height, leaves number per plant, fresh and dry weight per plant, total chlorophyll, antioxidant activities (catalase and peroxidase), seed yield and seed quality compared to the lowest ones and control. Overall, the obtained results indicate the potential of trehalose at 400 ppm for alleviating the effect of heat stress on common bean by improving vegetative growth, antioxidant activity and finally seed yield and quality compared to other treatments.

Key words: Trehalose, hydrogen peroxide, salicylic acid, common bean, heat stress.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of the most important legume crops allover the world grown for its mature seeds (dry bean), seeds at the physiological maturity (shell beans), and green pods **(Lone *et al.*, 2021)**. It plays a significant role in human diets, as it is rich in protein, fiber, carbohydrates, vitamins and minerals.

Global warming has an adverse effect on agriculture and food security around the world, as the average earth temperature is predicted to rise about 1.8 – 4 °C by 2100 **(Kumari *et al.*, 2020).** This rise in the earth's average temperature has become a major concern for crop production worldwide due to its greatly impacts on plant growth and productivity **(Debnath *et al.*, 2022).** High temperature stress causes a number of morphological, physiological and biochemical changes in plants, which leading to severe reductions in crop yield **(Surabhi and**

Seth, 2020). These changes include reduction in seed germination percentage, high transpiration rate, reduction in respiration and pollen viability, damaged photosynthetic machinery, reduction in photosynthesis **(Hassan *et al*., 2021; Sajid *et al*., 2021)** and generation of reactive oxygen species (ROS) which induce oxidative stress by altering membrane properties and degradation of proteins and enzymes inactivation **(Kumari *et al*., 2021; Debnath *et al*., 2022).** Common bean is highly sensitive to heat stress, which may limit its adaptation and consequently its yield **(Suárez *et al*., 2022; Muñoz *et al*., 2021).** The optimum mean temperature for its better growth and productivity ranges from 20 ºC to 25 ºC **(Dhakal *et al*., 2020)** and temperature above 30 °C during the day and more than 20 °C during the night led to yield reduction **(Rainey and Griffiths, 2005; Muñoz *et al*., 2021).**

Flowering and pods formation are highly sensitive to heat stress and high temperatures (above 30°C) during the flowering stage **(Machado *et al*., 2022)** cause losses in pollen grain formation, reduction in size and number of pollen grains and abortion of flowers, thereby fewer pods formation and severe reduction in bean seed yield **(Silva *et al*., 2020).** Hence, it is necessary to improve heat tolerance in legume crops, in particular common bean crop, due to its contributing in food security **(Tokyol and Turhan, 2019).**

Among the exogenous substances used for improving heat stress tolerance, trehalose, one of the compatible solutes accumulated in plants under biotic and abiotic stresses. Trehalose (Tre) is a non-reducing disaccharide consist of two units of glucose and found in bacteria, yeasts, animals and higher plants, where it acts as osmo-protectant **(Hassan *et al*., 2022)**. Trehalose considered an energy source **(Rehman *et al*., 2022)** as well as plays a direct role as a signaling molecule **(Abdi *et al*., 2022)** against several abiotic stresses. In addition, Tre acting as an important membrane stabilizer **(Kosar *et al*., 2020)** can protect cellular membranes and proteins from inactivation and denaturation caused by different stresses **(Maheswari *et al*., 2023).** Under heat stress, Tre can induce high temperature tolerant-related gene expressions, enhance antioxidant systems and activate photosynthesis **(Zhao *et al*., 2019)** as well as up-regulate the expression of salicylic acid (SA)- dependent genes **(Hassan *et al*., 2022).** The amount of trehalose exists in plants is very low **(Feng *et al*., 2019)** and its production is not sufficient to alleviate the adverse effects of different stresses **(Hassan *et al*., 2022)**, thereby supplemental exogenous application is a promise practice for improving plant stress tolerance.

Recently, signaling molecules like hydrogen peroxide (H_2O_2), nitric oxide (NO) and hydrogen sulfide (H_2S) have been used as an effective application to overcome abiotic stress conditions **(Güler and Pehlivan, 2020).** Among signaling molecules, H_2O_2, a type of reactive oxygen species (ROS) which accumulates when the plants are exposed to different levels of stress factors **(Sharma *et al*., 2020; Singh *et al*., 2021)**. H_2O_2 plays a dual role in plants, at low concentration acts as a messenger that involved in signaling and trigger the tolerance against different stresses **(Bagheri *et al*., 2019; Asgher *et al*., 2021)** while at high concentration induces oxidative damage to biomolecules, leading to cell death **(Černý *et al*., 2018)**. Also, H_2O_2 regulates many physiological processes, such growth and development, under normal and stressed conditions **(Basal and Szabó, 2020)**. Under different stress conditions, it can involve in the regulation of different stress-responsive transcription factors (TFs), increase the activity of antioxidant enzymes, proline metabolism, glutathione-related oxidant defense system, photosynthesis **(Chen and Ko, 2021; Asgher *et al*., 2021)**, osmolytes accumulation and ABA regulating **(Iqbal *et al*., 2018)**. Meanwhile, it can enhance heat tolerance through the activation of stress signaling components, heat shock proteins **(Zhang *et al*., 2020a),** antioxidant defense systems and improving chlorophyll content **(Shalaby *et al*., 2021).**

Likewise, salicylic acid (SA) is a phenolic compound considers a plant hormone, acts a signal molecule for the development of various plant stress resistance mechanisms **(Beigzadeh *et al*., 2018; Soni *et al*., 2022)**. It regulates numerous physiological processes such as seed germination, stomatal closure, nutrient uptake, photosynthesis and flower formation and enhances the plant tolerance to various abiotic stresses, i.e., drought, heat, chilling, heavy metal and osmotic stress **(Salem *et al*., 2021; Çetinbaş-Genç and Vardar, 2021)**. SA application can induce heat stress tolerance in plants by inducing the genes responsible for coding heat shock proteins, antioxidants and metabolites accumulation **(Sharma *et al*., 2021),** protecting the reproductive system, increasing photosynthetic efficiency and maintaining Ca^{2+} homeostasis **(Sangwan *et al*., 2022).**

Therefore, the aim of this study is to evaluate the effects of several concentrations of trehalose, hydrogen peroxide and salicylic acid as foliar treatments on common bean tolerance to high temperature stress.

MATERIALS AND METHODS

Description of the study site

The present study was carried out at a private vegetable farm in El-Taweila, near El-Mansoura City, Dakahlia Governorate, Egypt (31.114824 N, 31.409729 E) during the two summer seasons of 2020 and 2021. Meteorological data (the average of both air temperature ºC and relative humidity %) at the experimental site are shown in Table 1.

Table 1. Average maximum and minimum air temperature (ºC) and average relative humidity (RH, %) at the site of the experiment during 2020 and 2021 seasons

Months	2020			2021		
	Air Temp. (°C)		RH (%)	Air Temp. (°C)		RH (%)
	max	min		max	min	
April	27.05	12.56	62.93	29.84	12.08	56.21
May	32.72	15.70	58.87	37.14	17.86	46.36
June	36.86	19.15	49.51	36.92	19.78	50.06
July	39.05	21.79	52.91	39.65	22.82	50.95

Experimental design and tested treatments

The experiment was designed as complete randomized blocks system with three replicates and consists of ten treatments, i.e., trehalose at 200, 300 and 400 ppm, H_2O_2 at 20, 30 and 40 ppm and salicylic acid at 150, 200 and 250 ppm in addition to control (untreated plants). The experimental unit area was 11.2 m^2, contained 4 ridges, with 4 m in length and 70 cm in width for each ridge. Common bean seeds cv. Giza 6 were sown on the 15th and 20th April in the first and the second seasons of the study, respectively, at 10 cm apart on one side of the ridge. The plants were sprayed three times, at 25, 35 and 45 days from sowing. Normal farming practices like fertilization, irrigation etc. were conducted according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation.

Data recorded

Vegetative growth

At 50 days after sowing, five plants were randomly taken from each experimental unit to estimate plant height (cm) and leaves number, fresh weight (g) and dry weight (g) per plant.

Biochemical constituents

Random samples of fresh leaves were taken from each experimental unit to determine antioxidant activity. Catalase and peroxidase activities were determined according to **Sairam and Srivastava (2001)** and **Hernandez *et al*. (2000)**, respectively. Total chlorophyll values were recorded using a handheld chlorophyll meter (SPAD-502 plus meter, Konica Minolta, Inc., Japan).

Dry seed yield and its components

At harvesting time, the plants of each experimental unit were harvested to record yield characters, i.e., 100-seed weight per plant (g) and seed yield per plant (g) and per feddan (kg).

Seeds chemical constituents

Crude protein (%), total carbohydrates (%) and total phenols were determined in seeds according to **AACC (2000)**, **Hodge and Hofreiter (1962)** and **McDonald *et al*. (2001)**, respectively.

Statistical analysis

According to **Snedecor and Cochran (1990)**, the obtained data were subjected to statistical analysis of variance and means separation was done according to **Duncan** multiple test at the 5 % level of probability. The statistical analysis was performed using CoStat software (version 6.400).

RESULTS AND DISCUSSION

Vegetative growth

Table 2 shows the impact of different rates of trehalose, hydrogen peroxide and salicylic acid on vegetative growth traits of common bean under high temperature conditions. In the current study, common bean plants grown under high temperatures over than 30 °C (Table 1) which caused heat stress in particular during the reproductive development stage. Untreated plants recorded the minimum values of vegetative growth traits in compare with the different rates of foliar treatments in both seasons. The highest rates of trehalose, hydrogen peroxide and salicylic acid exhibited the best results of plant height, leaves number per plant and fresh and dry weight per plant compared to the lowest ones.

The improvement of common bean vegetative growth under treahalose treatment may be due to its role in stabilizing membrane integrity **(Kosar *et al*., 2020)**, increasing photosynthesis and upregulating stress-responsive genes under heat stress **(Zhao *et al*., 2019; Ali *et al*., 2019).** In addition, trehalose can protect membrane and protein structure from dehydration under stress conditions by creating an amorphous glass structure around polar phospholipids groups or by amino acids through hydrogen bonding **(Zulfiqar *et al*., 2020; Sarkar and Sadhukhan, 2022).** Moreover, **Luo *et al*. (2021a)** found that trehalose pretreatment reduced damage caused by high temperature in maize by protecting cellular membranes, photosynthetic apparatus, and increasing antioxidant activities. Recently in common bean, **Dawa *et al*. (2022)** showed that trehalose improved vegetative growth traits and increased plant tolerance to high temperature stress.

Concerning hydrogen peroxide, it improves vegetative growth through increasing pectin synthesis in root tips **(Dikilitas *et al*., 2020)** and promoting adventitious rooting ability (ARF) **(Gong *et al*., 2022)**, leading to increased surface area of mineral absorption **(Hasan *et al*., 2016),** which resulted in improving growth and development of plants under abiotic stress. Additionally, it was reported that H_2O_2 had a significant role in ABA-induced stomatal closure, compatible solutes accumulation **(Dikilitas *et al*., 2020),** improving chloroplast ultrastructure, photosynthetic efficiency and antioxidant system **(Nazir *et al*., 2021)**. **Zhang *et al*. (2020a)** reported that H_2O_2 application enhanced the tolerance of fescue plants to heat stress through activation of stress signaling components and heat shock proteins as well as improved photochemical efficiency and cellular membrane stability.

Likewise, salicylic acid affects the vegetative growth via increasing cell division in meristem areas **(Beigzadeh *et al*., 2018)**, cell stabilizing, cellular integrity **(Ayub *et al*., 2022)** and the synthesis of heat shock proteins (HSPs) responsible for defense against heat stress **(Liu *et al*., 2022)**. Also, it was noticed that salicylic acid improved stomatal conductance and net photosynthesis, increased CO_2 concentration between cells in heat-stressed plants **(Sangwan *et al*., 2022)** and enhanced the activity of various antioxidant enzymes **(Preet *et al*., 2023).**

Table 2. Effect of trehalose (Tre), hydrogen peroxide (H_2O_2) and salicylic acid (SA) concentrations on common bean vegetative growth in 2020 and 2021 seasons

Treatments (ppm)	Plant height (cm)		Leaves number/ plant		Fresh weight/ plant (g)		Dry weight/ Plant (g)	
	2020	2021	2020	2021	2020	2021	2020	2021
Tre 200	72.00 c	71.66 cd	22.33 bcd	19.66 abc	80.67 cd	79.42 cd	16.29 c	16.18 c
Tre 300	77.33 a	75.66 ab	25.66 ab	24.00 ab	83.99 b	82.70 b	17.92 b	17.44 b
Tre 400	79.33 a	78.66 a	26.66 a	24.66 a	92.13 a	86.73 a	18.69 a	17.96 a
SA 150	66.33 d	65.66 ef	19.66 d	19.00 bc	69.65 h	66.63 g	14.05 g	13.66 e
SA 200	67.33 d	67.66 e	22.33 bcd	21.66 abc	72.27 g	70.23 f	15.21 e	14.97 d
SA 250	75.00 b	68.00 e	24.00 abc	21.66 abc	79.21 de	77.10 d	15.73 d	15.35 d
H_2O_2 20	67.00 d	68.66 de	20.66 cd	18.33 c	76.14 f	73.88 e	14.60 f	13.84 e
H_2O_2 30	75.00 b	74.00 bc	24.00 abc	21.33 abc	78.22 e	76.93 d	15.59 d	15.32 d
H_2O_2 40	78.66 a	77.00 ab	25.66 ab	23.66 abc	82.23 c	81.10 bc	16.39 c	16.28 c
Control	64.00 e	63.00 f	14.33 e	13.00 d	64.18 i	61.44 h	12.67 h	12.49 f

Means followed by the same letter within a column are not significantly different ($p < 0.05$) according to the Duncan's multiple range test.

Biochemical constituents

In Table 3, the results show that exogenous application of trehalose, hydrogen peroxide and salicylic acid at various levels increased total chlorophyll content and catalase and peroxidase activity compared to control treatment under the conditions of the study.

Photosynthesis is the most physiological process that is sensitive to high temperatures. **(Fan *et al*., 2022).** Trehalose might protect photosynthetic apparatus from oxidative stress through reducing chlorophyll degrading enzymes activity **(Rehman *et al*., 2022)** and maintaining membrane integrity **(Bian *et al*., 2021).** Moreover, trehalose alleviates the PS II photo-inhibition caused by heat stress through improving photochemical efficiency and the electron transport rate **(Luo *et al*., 2021b).** The results also showed that trehalose increased antioxidant activity (catalase and peroxidase) in common bean leaves compared to control (Table 3). It was reported that Tre can work as an elicitor of genes involved in reactive oxygen species (ROS) detoxification **(Rohman *et al*., 2019; Hassan *et al*., 2022)** and promote antioxidant enzyme activities **(Abdallah *et al*., 2020).** Similar reports were indicated by **Zhao *et al*. (2019), Bian *et al*. (2021) and Rehman *et al*. (2022).**

As to H_2O_2, it increased chlorophyll content and antioxidants activity due to its role in enhancing the activity of chlorophyllase enzymes which protected the chlorophyll from degradation **(Andrade *et al*., 2018; Asgher *et al*., 2021)** and enhanced the activity of superoxide dismutase, catalase and peroxidase antioxidant enzymes under abiotic stress **(Nazir *et al*., 2021)**. Similar effects of H_2O_2 have been detected by **Abbaspour *et al*. (2020) and Basal and Szabó (2020).**

Moreover, salicylic acid can protect chlorophyll contents through decreasing reactive oxygen species (ROS), elevating the antioxidant systems **(El-Taher *et al*., 2022)** and participation in protecting the chloroplast membrane structure **(Fan *et al*., 2022)** which resulted in higher chlorophyll content

(Table 3). However, SA may operate directly as an antioxidant to scavenge the reactive oxygen species and/or indirectly by regulating redox balance by triggering antioxidant responses **(Hediji *et al*., 2021).**

Table 3. Effect of trehalose (Tre), hydrogen peroxide (H_2O_2) and salicylic acid (SA) concentrations on biochemical constituents of common bean in 2020 and 2021 seasons

Treatments (ppm)	Total chlorophyll (SPAD unit)		Catalase (U/mg protein)		Peroxidase (U/mg protein)	
	2020	2021	2020	2021	2020	2021
Tre 200	47.53 bcd	44.33 f	69.40 c	64.25 d	0.94 c	0.92 b
Tre 300	49.03 b	47.86 b	71.22 b	68.74 b	0.98 b	0.96 a
Tre 400	53.10 a	50.66 a	73.41 a	70.18 a	1.02 a	0.98 a
SA 150	43.73 f	42.16 g	57.44 i	56.28 i	0.73 i	0.72 e
SA 200	45.96 de	45.10 ef	58.99 h	56.69 h	0.77 h	0.75 de
SA 250	47.93 bc	46.53 cd	61.04 g	58.63 g	0.80 g	0.76 d
H_2O_2 20	44.96 ef	44.70 ef	63.03 f	60.68 f	0.83 f	0.80 c
H_2O_2 30	46.43 cde	45.80 de	65.17 e	61.88 e	0.87 e	0.81 c
H_2O_2 40	48.03 bc	47.13 bc	67.34 d	65.28 c	0.90 d	0.89 c
Control	40.73 g	39.00 h	55.45 j	52.30 j	0.69 j	0.67 f

Means followed by the same letter within a column are not significantly different ($p < 0.05$) according to the Duncan's multiple range test.

Dry seed yield and its components

The results of this study show that 100-seed weight per plant and dry seed yield per plant and per feddan significantly increased in response to different studied treatments compared to control (Table 4). It was observed that dry seed yield components of common bean were gradually increased with increasing the concentrations of trehalose, peroxide hydrogen and salicylic acid treatments. Overall, the best results were noticed with trehalose at the highest rates (400 and 300 ppm) followed by H_2O_2 treatment at 40 ppm and trehalose at 200 ppm. However, salicylic acid also increased dry seed yield components when applied at the several rates in comparing with the control, but its effect was less than trehalose and hydrogen peroxide applications.

Trehalose might protect photosynthetic system from oxidative stress, thereby increasing photosynthesis efficiency and carbon assimilation **(Kosar *et al*., 2020; Bian *et al*., 2021)** and control of sucrose metabolization to several pathways in plant cells **(Qaid, 2020)** resulting in increased pod set and seed yield of common bean. Similar reports were obtained by **Zaky *et al*. (2021), Dawa *et al*. (2022) and Rehman *et al*. (2022).** The positive effect of H_2O_2 on common bean seed yield may be related to its role in increasing net photosynthetic rate through enhancing energy dissipation process **(Güler and Pehlivan, 2020)** and increasing root volume, stem diameter and biomass accumulation **(Andrade *et al*., 2018).** In this line, **Khan *et al*. (2018)** reported that H_2O_2 increased the photosynthetic efficiency through increasing the carboxylation rate of Rubisco (Vcmax) and initial Rubisco activity. Similar results were obtained by **Basal and Szabó (2020) and Shalaby *et al*. (2021).** Concerning SA, it showed different effects on plant development, including flowering **(Koo *et al*., 2020),** regulating pollen tube growth **(Çetinbaş-Genç and Vardar, 2021)**, prolonging the viability of pollen grains and improving seed-setting **(Sangwan *et al*., 2022).** In addition, it can protect the photosynthetic system by maintaining high Rubisco activity **(Zhang *et al*., 2020b)** resulting in promoting the formation and transport of photosynthetic products **(Fan *et al*., 2022)** and thereby increasing common bean seed yield under heat stress conditions. Similar findings were recorded by **El-Sayed *et al*. (2020), Kumar *et al*. (2020) and Preet *et al*. (2023).**

Table 4. Effect of trehalose (Tre), hydrogen peroxide (H_2O_2) and salicylic acid (SA) concentrations on common bean dry seed yield and its components in 2020 and 2021 seasons.

Treatments (ppm)	Dry seed yield/ plant (g)		100-seed weight (g)		Dry seed yield/ fed (kg)	
	2020	2021	2020	2021	2020	2021
Tre 200	16.22 b	15.51 cd	46.49 c	46.37 c	926.81 b	886.00 cd
Tre 300	16.73 b	16.30 b	47.66 b	47.28 b	955.91 b	931.43 b
Tre 400	17.84 a	17.04 a	48.33 a	48.09 a	1019.40 a	973.37 a
SA 150	12.49 f	12.18 g	42.61 g	42.23 f	713.65 f	696.00 g
SA 200	14.13 e	13.58 f	43.91 f	43.68 e	807.24 e	776.06 f
SA 250	15.20 cd	14.97 de	44.78 e	44.33 de	868.46 cd	855.41 de
H_2O_2 20	15.02 d	14.65 e	45.30 de	44.51 de	858.35 d	836.82 e
H_2O_2 30	15.69 c	14.93de	45.59 d	45.11 d	896.59 c	853.12 de
H_2O_2 40	16.44 b	16.09 bc	47.16 b	46.55 bc	939.24 b	919.51 bc
Control	11.07 g	10.58 h	40.17 h	39.86 g	632.50 g	604.32 h

Means followed by the same letter within a column are not significantly different ($p < 0.05$) according to the Duncan's multiple range test.

Seeds chemical constituents

The results in Table 5 indicate that the several concentrations of trehalose, hydrogen peroxide and salicylic acid applications improved chemical constituents of common bean seeds in comparing with control under high temperature conditions. Highest contents of total phenol, protein and carbohydrates were obtained with 400 and 300 ppm of trehalose followed by 40 ppm of hydrogen peroxide in both seasons. Trehalose considered as an energy source **(Rohman *et al*., 2019)** increased the accumulation of sugars by upregulating the expression of genes involved in starch and soluble sugar metabolism **(John *et al*., 2017; Feng *et al*., 2019).** Moreover, Tre increased total phenolic compounds due its role in activating non-enzymatic antioxidants **(Hassan *et al*., 2022).**

Likewise, H_2O_2 improved the chemical composition of common bean seeds under high stress conditions (Table 5). H_2O_2 may have a role in compatible solutes accumulation such as soluble sugars, polyamine and proline in soybean under drought stress **(Güler and Pehlivan, 2020).** Further, it was reported that H_2O_2 can improve α-amylase activity which decomposes starch into sugar **(Ishibashi *et al*., 2012; Iqbal *et al*., 2018)** and increase total phenols and ascorbate contents under stress conditions **(Bhardwaj *et al*., 2021).**

Also, salicylic acid at the different rates improved the chemical composition of common bean seeds under the study conditions compared to control, but its effect was lesser than the effect of both trehalose and H_2O_2 (Table 5). SA can up-regulate soluble proteins **(Preet *et al*., 2023)** and enhance the biosynthesis of secondary metabolites under abiotic stress conditions **(Koche *et al*., 2021).** Further, SA was shown to activate the genes involved in the shikimic acid pathway, responsible for the phenolic compounds production in plants like flavonoids, tannins and lignin **(Pacheco and Gorni, 2021)** and increase carbohydrate content in stressed plants **(Pandey and Chakraborty, 2023).**

Table 5. Effect of trehalose (Tre), hydrogen peroxide (H_2O_2) and salicylic acid (SA) concentrations on chemical constituents of common bean seeds in 2020 and 2021 seasons

Treatments (ppm)	Total phenols (mg/g)		Protein (%)		Carbohydrates (%)	
	2020	2021	2020	2021	2020	2021
Tre 200	54.54 d	50.49 d	19.61 c	18.02 cde	39.42 c	37.33 cd
Tre 300	57.80 b	55.12 b	20.38 b	18.77 bc	40.29 b	38.20 ab
Tre 400	59.25 a	57.21 a	21 .20 a	20.28 a	41.61 a	38.46 a
SA 150	47.12 i	46.46 g	18.77 g	17.60 de	36.25 g	35.53 e
SA 200	47.60 h	47.16 fg	18.94 f	18.25 bcd	36.74 f	35.80 e
SA 250	48.74 g	47.87 f	19.07 e	18.33 bcd	37.52 e	36.03 e
H_2O_2 20	51.43 f	48.90 e	19.08 e	18.75 bc	39.11 d	37.00 d
H_2O_2 30	52.73 e	50.39 d	19.29 d	18.66 bc	39.24 cd	37.15 d
H_2O_2 40	57.33 c	53.43 c	20.42 b	19.09 b	40.24 b	37.80 bc
Control	46.55 j	45.13 h	18.38 h	17.21 e	36.08 g	34.89 f

Means followed by the same letter within a column are not significantly different ($p < 0.05$) according to the Duncan's multiple range test.

Based on the findings of this study, it can be concluded that spraying common bean plants with trehalose at 400 ppm was the most effective application in improving vegetative growth, activating antioxidant activity and increasing dry seed yield and seed quality under high temperature conditions.

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