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Research Article

Melatonin mediated high-temperature tolerance at seedling stage in green gram (*Vigna radiata* L.)

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Abstract
Global warming is predicted to have a generally negative effect on food grain production. The emergence of seedlings, blooming, pod-filling stages and yield of the mung bean are affected by high-temperature stress. Melatonin is a multifunctional signaling molecule with antioxidant properties that plays a vital role in plant stress defense mechanism. With this knowledge, the experiment was conducted to identify the optimum melatonin concentration to mitigate the adverse effects of high temperature in green gram var CO 8 with a completely randomized design (CRD). The treatments consisted of soaking seeds with different melatonin concentrations, *viz.,* 20, 40, 60, 80 and 100 µM. Seeds were sown in a pertidish and allowed to germinate. After 5 days, the seedlings were exposed to two different high-temperature stress following the temperature induction response (TIR) protocol in the growth chamber *viz.,* Ambient + 2°C (40°C) and Ambient + 4°C (42°C). After stress period, the seedlings were allowed to recover at room temperature for 2 days. At the end of the recovery period, observations on temperature tolerance-related traits *viz.,* survival percentage, per cent reduction of shoot and root growth, cell viability, mortality per cent, malondialdehyde content, superoxide dismutase and catalase activity of green gram seedlings were assessed. Seeds pre-treated with melatonin of 100 and 80 µM exhibited higher survival percentage, shoot and root growth, cell viability and antioxidant enzyme activity (like superoxide dismutase and catalase) with reduced mortality per cent and malondialdehyde content under high-temperature stress at both 40°C and 42°C. The results revealed that seeds treated with different melatonin concentrations significantly improved green gram germination and seedling health.

Keywords: Green gram, High-temperature stress, Melatonin, Seedlings survival

INTRODUCTION

Greengram (Mung bean) is an imperative grain legume with high economic status and an excellent dietary protein source with nutritional health benefits. It increases soil fertility and plays a crucial role in major cropping systems due to its short life span (Parihar *et al.,* 2017). Several abiotic factors like heat, drought, salt and water -logging negatively impact greengram production and adaptation (Kaur *et al.,* 2015). Abiotic stresses affect crop growth and development by modifying physiological processes and the plant-water connection

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(Zandalinas *et al.,* 2017). Mung bean production is altered by adverse environmental conditions, particularly by the rise in temperature due to climate change. The global air temperature is expected to reach 0.2°C every decade, raising temperatures from 1.8 to 4.0°C above the current level (IPCC, 2022). The optimum temperature ideal for the cultivation of greengram ranges from 30°C to 40°C (Zinn *et al.,* 2010). The maximum temperature during the summer month continually exceeds 39° C to 40ºC in some places of Tamil Nadu, which is beyond the tolerance limit of the mung bean. Therefore, a rise in temperature beyond 40°C will severely affect the growth and yield of mung bean cultivation in summer (Karande *et al.,* 2018).

Moreover, most of the area under pulses is in the rainfed ecosystem, which often encounters high temperatures during the reproductive stage of the crop. During the reproductive phase, extreme temperature causes flower drop, induces male sterility, impaired anthesis and shortens the grain-filling period in green gram (Basu *et al.,* 2019). The plant growth is severely reduced under heat stress by altering shoot net assimilation rates and the plant's total dry weight production (Fahad *et al.,* 2017). Several studies have found that high-temperature stress reduces crop growth and development of mung beans (Hanumantha Rao *et al.,* 2016; Sharma *et al.,* 2016; Sita *et al.,* 2017; Priya *et al.,* 2020).

Abiotic stress negatively impacts plant growth, photosynthetic pigments, water and nitrogen usage efficiency, cell structural changes and essential enzyme activities (Singh and Thakur, 2018). Extreme temperature shows impact on photosynthetic processes such as altered enzyme activity, photochemical reactions and disruption of the entire PSII protein complex due to increased membrane flexibility (Yamamoto *et al.,* 2016). High-temperature stress induces the production of reactive oxygen species that damages the membrane lipids and increases the membrane fluidity; therefore, metabolic activities are hindered (Yamamoto *et al.,* 2016). The coincidence of high-temperature stress at crucial growth phases of mung bean is one of the causes of decreased growth traits. Additionally, future means temperature trends in the areas where mung beans are grown are expected to vary significantly. Recently, the growth regulator hormone known as melatonin has been well recognized for its essential role in determining plant growth and development under adverse environmental conditions.

Melatonin (N-acetyl-5-methoxytryptamine) is an indolic substance synthesized from serotonin (5-hydroxytryptamine) and acts as a pleiotropic signaling molecule against various abiotic and biotic stresses (Zeng *et al.,* 2022). In higher plants, tryptophan, the precursor of indole-3-acetic acid (IAA), also serves as a common precursor for the production of both serotonin and melatonin (Back *et al.,* 2016). Melatonin act as a promoter of seed germination (Cao *et al.,* 2019), lateral roots formation (Liang *et al.,* 2017), regulates blooming time (Sun *et al.,* 2021) and delays leaf senescence (Liang *et al.,* 2018) to manage and control plant growth and development under challenging environments. Hossain *et al.* (2020) suggested that exogenous melatonin improves plant growth by enhancing the enzymatic antioxidants like superoxide dismutase, peroxidase, catalase and ascorbate peroxidase and reduces the oxidative damage induced by ROS. Under stress, melatonin application reduces cell membrane lipids peroxidation and maintains higher plasma membrane integrity (Khan *et al.,* 2020). Buttar *et al.* (2020) reported that melatonin is a multifunctional signaling molecule that improves plants heat tolerance by modulating its antioxidant defense system. Exogenous melatonin can stimulate the biosynthesis of endogenous melatonin and reduce the generation of H_2O_2, $O_2^{\bullet-}$, and malondialdehyde (MDA) (Chen *et al.,* 2021) under various abiotic stress, reducing cell membrane damage and enhances photosynthesis (Imran *et al.,* 2021). With this background, the present study thus examined the melatonin concentrations capacity on the enhancement of biochemical characteristics and development of green gram grown in high-temperature-stressed conditions.

MATERIALS AND METHODS

Plant growth conditions and treatments

A laboratory experiment was conducted in the Department of Crop Physiology at Tamil Nadu Agricultural University, Coimbatore, to standardize the optimum concentration of melatonin for mitigating the ill effects of high-temperature stress. Temperature induction response (TIR) is a promising tool for determining a seedlings' thermo-tolerance level based on its growth and recovery during the seedling stage. This approach involved exposing germinated greengram seedlings to an induced high temperature in a growth chamber for a short period to identify the optimum induction temperature (OIT) and challenging lethal temperature. The seeds of green gram variety CO 8 were used as source material. The uniform and healthy seeds were taken and the seeds were surface sterilized with 3% sodium hypochlorite for two mins and washed thrice with distilled water followed by the seeds were soaked in different concentrations of melatonin about 20, 40, 60, 80 and 100 µM for 6 h. The seeds treated with varying concentrations of melatonin were placed in petri plates (20 seeds per petri plate) separately for the imposition of high-temperature stress. About five days old, uniform seedlings were taken and subjected to two different high-temperature stress, *viz.,* Ambient + 2°C and Ambi-

ent + 4°C for 3 h without prior induction. The ambient temperature was recorded as 38°C. The treatment details consisted of T_1: Absolute control (no stress and melatonin), T_2: Control (exposure to high-temperature stress without melatonin), T_3: 20 µM of melatonin, T_4: 40 µM of melatonin, T_5: 60 µM of melatonin, T_6: 80 µM of melatonin and T_7: 100 µM of melatonin. All these treatments were subjected to two different high-temperature treatments, including 40°C (38°C + 2°C) and 42°C (38°C + 4°C). Three replications were maintained for each treatment. After the stress induction period, these seedlings were immediately allowed to recover in an incubator with the following conditions at 30ºC and 60% relative humidity (RH) for 2 days. After the recovery period, various observations on seedling related traits were measured.

Measurement of seedling growth parameters

After the seedlings had recovered from the high-temperature stress for two days, observations were made. The temperature tolerance-related traits of green gram seedlings were assessed by the following methods

Survival percentage and shoot and root growth reduction percentage were calculated by the formula described by Rekha *et al.* (2016).

Percent survival of seedlings = (Number of seedlings survived at the end of recovery/ Total number of seeds sown) x 100 ……Eq. 1

Percent reduction in shoot and root growth = (C-T/C) x 100 …...Eq. 2

Where, C – Shoot and root growth of control seedlings

T – Shoot and root growth of treated seedlings

Mortality percentage = Number of dead seedlings / Total number of seeds sown) X 100 ……Eq. 3

Cell viability was determined according to the method described by Kheir *et al.* (2012). The green gram seedlings exposed to high-temperature stress were allowed to recover @ 30ºC and 60% RH. After 3 h of recovery, the seedlings were incubated in 0.01% Evans blue dye solution for 2 h. After that, the excess dye was removed by washing it with distilled water. The stain from the seedlings was extracted in absolute alcohol and maintained at 50°C for 15 min, and the absorbance was measured at 600 nm using a UV visible spectrophotometer. The cell viability was calculated by the formula given below:

Cell viability = (T/C) x 100 ….. Eq. 4

Where, T – Absorbance @ 600 of dye extracted from induced seedlings.

C – Absorbance @ 600 of dye extracted from absolute control seedlings.

The malondialdehyde (MDA) content was assessed by the thiobarbituric acid (TBA) reaction according to the method illustrated by Karabal *et al.* (2003). The leaf tissue of 0.5 g was homogenized with 5 mL of 0.1% trichloroacetic acid (TCA) and centrifuged at 10,000 rpm for 5 min. About 4 mL of 20% trichloroacetic acid (TCA) containing 0.5% thiobarbituric acid (TBA) was added to 1 mL of aliquot and heated at 95°C for 30 min. Immediately the tubes were cooled and centrifuged at 10,000 rpm for 10 min. The supernatant was collected and absorbance was measured at 532 and 600 nm and expressed as µmol g^{-1} of fresh weight.

To estimate the antioxidant enzyme activity like catalase (CAT) and superoxide dismutase (SOD), the enzyme extract was prepared by weighing 0.5 g of leaf sample and ground into powder using liquid nitrogen. Enzyme extract was prepared by homogenizing the leaf powder with 0.1 M of phosphate buffer (pH 6.8) containing 0.1mM EDTA and 1% Polyvinylpyrrolidone (PVP) in a pre-chilled pestle and mortar. Homogenate was centrifuged at 10,000 rpm for 30 min at 4°C. Collected supernatant was used to estimate antioxidants enzyme activity *viz.,* CAT and SOD.

The CAT activity was analyzed using a method described by Aebi (1984). About 0.5 mL of 75 mM H_2O_2, 1.5 mL of 0.1 M phosphate buffer (pH 7) and 50 µL of enzyme extract were added; finally, the total reaction mixture volume was made up to 3 mL by adding distilled water. The addition of H_2O_2 started the reaction. The decrease in absorbance at 240 nm was recorded for 1 min for every 15 sec time intervals and enzyme activity was computed by calculating the amount of H_2O_2 decomposed. For catalase activity, the extinction coefficient is 39.4 $mM^{-1}cm^{-1}$ and expressed in terms of µg of H_2O_2 reduced mg $protein^{-1}$ min^{-1}.

The SOD activity was examined according to the method of Dhindsa *et al.* (1981). The reaction mixture consisted of 1.3µM riboflavin,13 mM methionine, 63 µM nitro blue tetrazolium chloride (NBT), 0.05 M sodium carbonate, 1% Triton X-100, 50 mM sodium phosphate buffer (pH 7.8), enzyme extract and the final volume was made up to 3 mL by using distilled water. Test tubes were kept under illumination for colour development whereas the non-illuminated reaction mixture without enzyme extract served as a blank. The SOD activity was determined as the amount of enzyme required to cause 50% inhibition of the reduction of NBT and expressed as units mg $protein^{-1}$ min^{-1}.

Statistical analysis

The design of the experiment was a completely randomized design (CRD) with three replications and the data collected from various traits were statistically analyzed by using R software (version 4.1.2) with the analysis of variance (ANOVA). The least significant difference (LSD) test was used to compare the differences among group means, and the critical difference (CD) was computed at a five percent probability ($P \leq 0.05$).

Figures were generated using Originpro 2019 software (Originlab Corp., USA).

RESULTS

A significant difference ($p \leq 0.05$) was recorded between the treatments of green gram seedlings exposed to two different high-temperature stress. The results revealed that absolute control (AC) showed 100 % survival of seedlings compared to control (C) treatment. While comparing the two temperature treatments, the seedlings exposed to 42°C exhibited a more reduced seedling survival percentage than 40°C (Fig. 1). Among the melatonin treatments, the seeds treated with 100 (77.67 %) and 80 (76.33 %) µM of melatonin concentration observed a higher survival percentage of green gram seedlings at 40°C, over the control (C).

The shoot and root growth were drastically reduced in control (C) under high-temperature stress conditions at both 40°C (28.74% and 37.29%) and 42°C (35.11% and 49.57%). Irrespective of the melatonin treatments, the maximum percent of the shoot (27.05% and 33.43%) and root growth (36.19% and 44.16%) reduction were noticed in seeds treated with 20 µM of melatonin concentration exposed to 40°C and 42°C, respectively (Fig. 2a and 2b). In contrast, the minimum percent reduction in shoot and root growth were noticed in 100 µM of melatonin-treated seeds subjected to 40°C (4.20 % and 9.73%) and 42°C (6.30% and 19.18%) than the control treatment.

High-temperature stress significantly affects the cell viability ratio and mortality percent of green gram seedlings. The mortality percent of seedlings exposed to 42° C was found to be higher than that of 40°C. Seedlings subject to high-temperature stress at 40°C and 42°C (51.00% and 60.00%) without any melatonin pre-treatment (C) showed higher mortality percent than the melatonin-treated seeds (Fig. 3a). A significant difference ($p \leq 0.05$) was observed between the melatonin treatments, melatonin @ 100 and 80 µM recorded the minimum mortality percent at both 40°C (22.33% and 23.67%) and 42°C (25.00% and 26.67%) over the control (C). The maximum mortality percent was observed in 20 µM of melatonin pre-treated seeds exposed to 40°C (32.67%) and 42°C (35.33%) when compared to other melatonin treatments. In contrast, the cell viability percent decreased significantly at 42°C than the seedlings exposed to 40°C. Under high-temperature stress conditions, a higher cell viability percent was recorded in seeds treated with 100 µM (87.67% and 80.00%) and 80 µM (85.67% and 76.67%) of melatonin concentration. In contrast, a lower percentage of cell viability was observed in 20 µM (74.00 % and 68.33 %) compared to control (C) treatment (70.00 % and 64.67 %) at both 40°C and 42°C, respectively (Fig. 3b).

The seedlings exposed to high-temperature stress recorded a significant ($p \leq 0.05$) variation between the control and melatonin treatments. The higher MDA content was observed in control (C) seedlings (1.28 µmol g^{-1} and 1.38 µmol g^{-1}) around 80 % over absolute control (AC) at both 40°C and 42°C (Fig. 4a). Irrespective of the melatonin treatments, seedlings exposed to 40°C showed more malondialdehyde content than 42°C. Among the melatonin treatments, 100 µM (0.73 µmol g^{-1}) and 80 µM (0.76 µmol g^{-1}) of melatonin treatment produced significantly lower malondialdehyde content at 40°C than the control. The higher malondialdehyde content was observed in seeds pre-treated melatonin of 20 µM (0.89 µmol g^{-1}) at 40°C. Among the melatonin treatments, at both 40°C and 42°C temperature stress, the seeds treated with 100 µM melatonin showed a significantly increased production of the antioxidant enzyme CAT (6.89 and 6.79 µg of H_2O_2 reduced mg protein^{-1} min^{-1}) and SOD (1.89 and 1.93 units mg protein^{-1} min^{-1}) than the control (C) (Fig. 4b & 4c). In contrast, the lower antioxidant enzyme activity of CAT (5.38 and 5.68 µg of H_2O_2 reduced mg protein^{-1} min^{-1}) and SOD (1.73 and 1.75 units mg protein^{-1} min^{-1}) were recorded in 20 µM of melatonin pre-treated seeds exposed to 40°C and 42°C high-temperature stress. The production of the antioxidant enzyme like CAT (5.40 and 5.50 µg of H_2O_2 reduced mg protein^{-1} min^{-1}) and SOD (1.51 and 1.53 units mg protein^{-1} min^{-1}) was lower under high-temperature stress at both 40°C and 42°C compared to the melatonin treatments.

Principal component analysis

Principal component analysis was used to determine the impact of melatonin pre-treatment on the ability of seedlings to withstand high temperatures. (Fig. 5). The principal component analysis consists of two principal

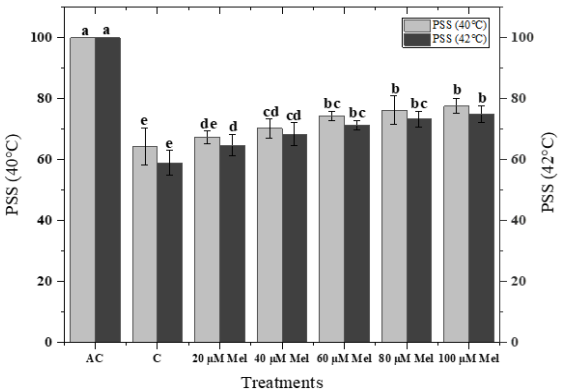

Fig. 1. *Effect of melatonin on percent survival of seedlings (PSS) of greengram under two different (@ 40°C and 42° C) high-temperature stresses. AC: Absolute Control, C: Control, Mel: Melatonin (Different alphabet letters indicates that treatments are significantly different from each other)*

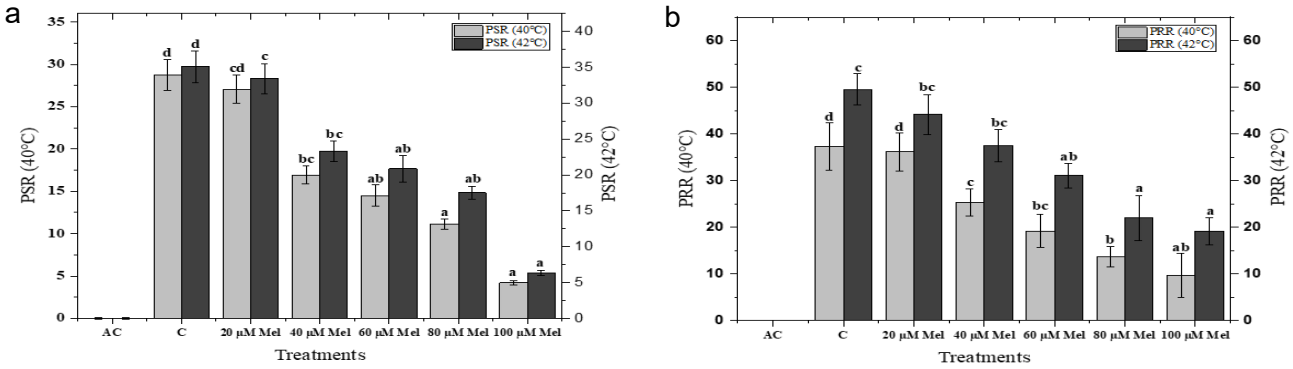

Fig. 2. *Effect of melatonin on percent (a) shoot growth reduction (PSR) and (b) root growth reduction (PRR) of green gram seedlings under two different (@ 40°C and 42°C) high-temperature stresses. AC: Absolute Control, C: Control, Mel: Melatoni (Different alphabet letters indicates that treatments are significantly different from each other)*

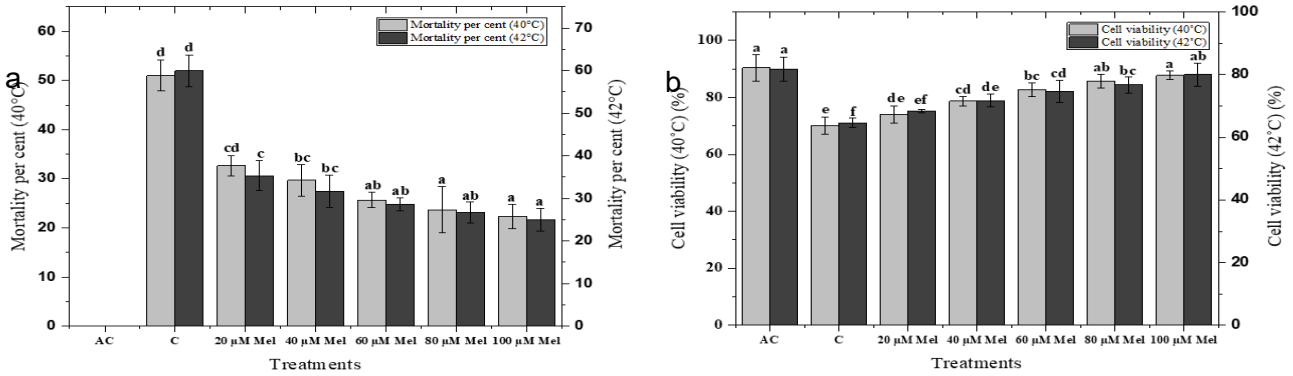

Fig. 3. *Effect of melatonin on mortality percent (a) and cell viability (b) of greengram seedlings under two different (@ 40°C and 42°C) high-temperature stresses. AC: Absolute Control, C: Control, Mel: Melatonin(Different alphabet letters indicates that treatments are significantly different from each other)*

components and the indices of different melatonin treatments were represented by PC1 and PC2, contributing 93.11 % of the total variations. Principal component 1 (PC1, X-axis) accounted for 68.70% of the variation and principal component 2 (PC2, Y-axis) explained 24.41% of the variation. From PCA analysis, it was observed that the indices of mortality per cent (MP), per cent survival of seedlings (PSS), per cent shoot growth reduction (PSR) and malondialdehyde (MDA) were grouped together and positively correlated, whereas cell viability (CV) and per cent survival of seedlings (PSS) were inversely correlated, meaning when CV and PSS increased the opposite MP, PSS, PSR and MDA were get decreased and vice versa. CAT and SOD were likely to be correlated with other parameters. The variation between absolute control (AC) and 100 µM of melatonin-treated seedlings showed 24.41% in response to high-temperature stress. Similarly, the variation between absolute control (AC) and control (C) treatment was explained by about 68.70%. Among the melatonin treatments, 20, 40, 60 and 80 µM of melatonin concentration were found close to the plot origin and showed no effect on seedlings tolerance to high-temperature stress. However, 100 µM melatonin treatment showed the greatest deviation from the mean value, indicating that seedlings treated with 100 µM melatonin were significantly tolerant to high-temperature stress.

DISCUSSION

Plants are periodically exposed to various environmental factors. The plant metabolism, cellular homeostasis and major key enzymes involved in physiological and biochemical processes are altered by temperature as it increases over the optimal threshold (Hemantaranjan *et al.,* 2014). High-temperature stress affects the germination process (Essemine *et al.,* 2010), shoot and root growth (Luo *et al.,* 2020), membrane integrity (Narayanan, 2018), and antioxidant enzyme activity (Song *et al.,* 2014). The present study demonstrated the impact of melatonin on seedling tolerance to high-temperature stress.

The current study observed that seedlings exposed to high-temperature stress affected the seedling survival percentage, shoot and root growth, cell viability and

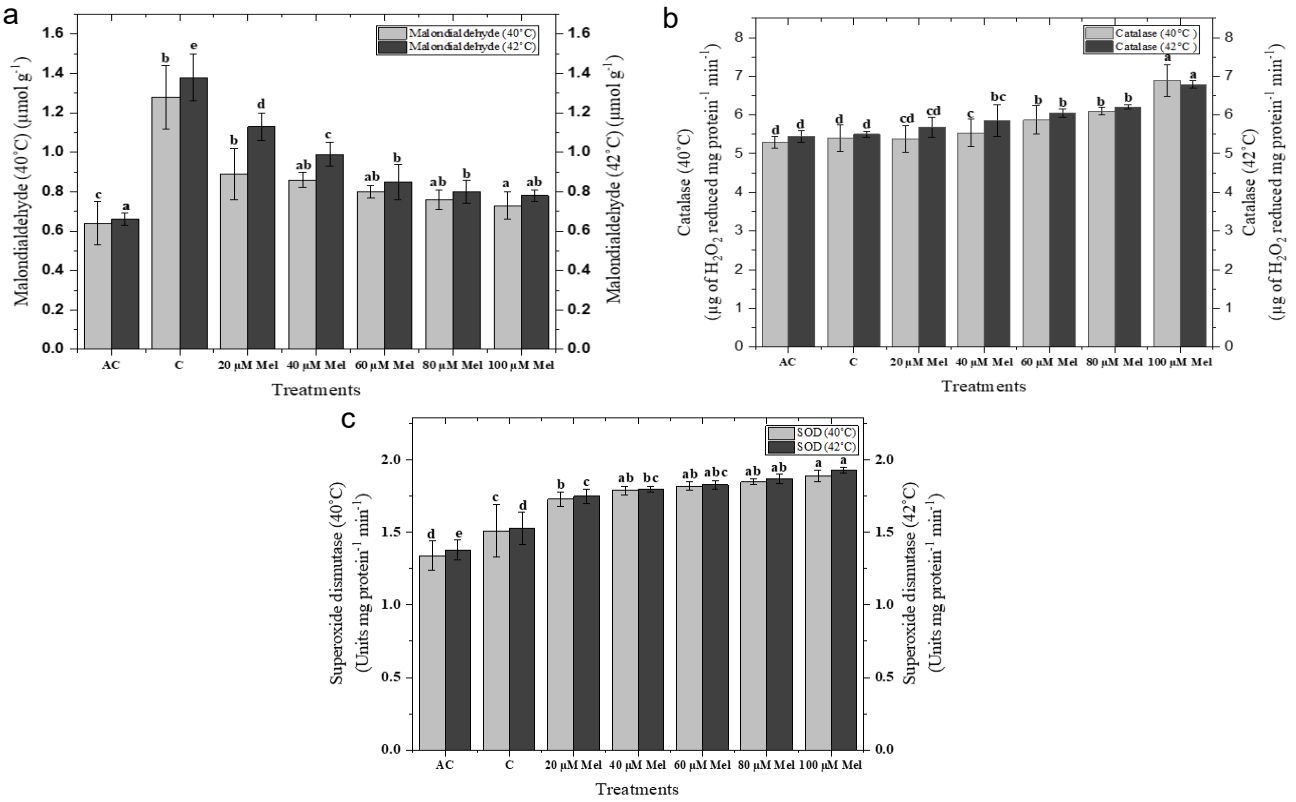

Fig. 4. *Effect of melatonin on MDA (a), CAT activity (b) and SOD activity (c) of greengram seedlings under two different (@ 40°C and 42°C) high temperature stresses. AC: Absolute Control, C: Control, Mel: Melatoni n(Different alphabet letters indicates that treatments are significantly different from each other)*

antioxidant enzyme activity. The seeds treated with 100 and 80 µM of melatonin recorded nearly 21% and 19% enhanced survival percentage (Fig.1), 80% and 73% improved shoot and root growth (Fig.2a and 2b) and 28% and 16% higher cell viability ratio (Fig.3b) than the control treatment. Elevated temperature lowers the seeds' ability to germinate, which leads to poor germination and stands establishment (Fahad *et al.,* 2017). The application of melatonin counteracts these effects and improves the tolerance of seedlings to heat stress (Rajora *et al.,* 2022). Exogenous melatonin application enhances reserve mobilization (Lei *et al.,* 2021), upregulates the transcription of heat shock proteins (HSP) and activity of numerous antioxidant enzymes, which reduces the formation of reactive oxygen species (ROS) (Khan *et al.,* 2020). In addition, the level of other endogenous growth factors like IAA was increased by melatonin treatment, resulting in the formation of a denser root system (Zeng *et al.,* 2018). A similar effect was found in other crops like rice (Yu *et al.,* 2022), maize (Jiang *et al.,* 2016), cucumber (Zhang *et al.,* 2014), cherry (Sarropoulou *et al.,* 2012) and soybean (Imran *et al.,* 2021) that seeds pre-treated with melatonin had a positive effect on germination, seedling growth and establishment.

Cell membrane damage is the first phenomenon that occurs under conditions of extreme temperature stress (Moradpour *et al.,* 2021). More membrane damage was observed under high-temperature stress and present results were corroborated with the previous finding of Sachdev *et al.* (2021), who articulated that elevated temperature stress leads to generation and accumulation of ROS like hydrogen peroxide (H_2O_2) and superoxide radical ($O_2^{\bullet-}$) within the cell (Fig.3a) and create oxidative damage such as lipid peroxidation, which result in increased malondialdehyde (MDA) content. Heat stress tolerance is closely related to sustaining membrane stability and integrity of the cell (Bita and Gerats, 2013). The present study observed a positive effect of melatonin on membrane integrity when the seedlings were exposed to high-temperature stress. Seeds pretreated with 100 and 80 µM of melatonin reduced the membrane damage by 12 % and 15 % to the control (Fig.4a). Huang *et al.* (2019) reported that melatonin has amphiphilic properties that can quickly diffuse and distribute in cytoplasm and lipid membranes. Yasmeen *et al.* (2022) observed that the hydrophilic side of the lipid bilayer was bounded with melatonin and protected the membrane against lipid peroxidation by directly neutralizing the harmful substances generated during stress conditions. The results of the current investigation concur with those indicated previously.

The antioxidant enzyme activity like SOD and CAT was remarkably reduced under high-temperature stress

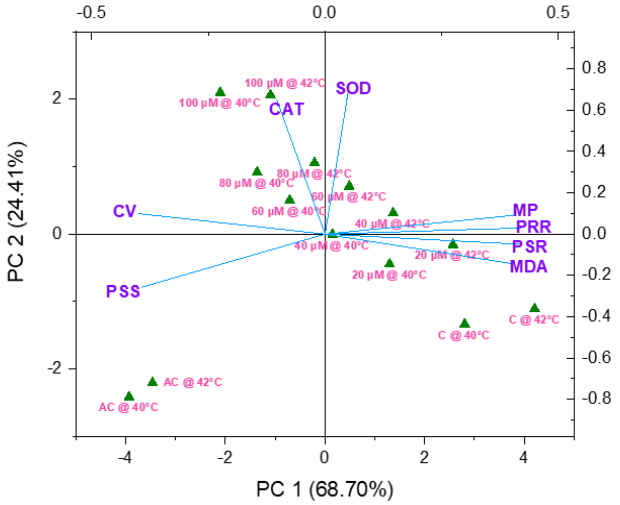

Fig. 5. *Principal component analysis of various seedling growth parameters of greengram seedlings in response to high-temperature stress. Absolute control (AC), Control (C), Percent survival of seedlings (PSS), Percent shoot growth reduction (PSR), percent root growth reduction (PRR), Mortality percent (MP), cell viability (CV), Malondialdehyde (MDA), Catalase (CAT), Superoxide dismutase (SOD)*

conditions. Similarly, in *Brassica oleracea,* Soengas *et al.* (2018), found that plants' antioxidant defense systems are significantly altered by heat stress. Experimental results of the present study demonstrated that seeds treated with 100 and 80 µM of melatonin significantly reduced ROS production through enhanced antioxidant enzymatic activities like CAT of nearly 28% and 23% (Fig. 4b) and SOD with 25% and 26% (Fig. 4c) than the seedlings subjected to high-temperature stress without melatonin treatment. The primary role of melatonin is to act as an antioxidant. It scavenges the reactive oxygen and nitrogen species produced during stressful conditions by enhancing the antioxidant enzyme activity, thereby maintaining cellular redox homeostasis (Arnao and Hernandez-Ruiz, 2019). ROS and RNS produced in response to stress conditions are detoxified by antioxidant enzymes like SOD and CAT (Di Meo *et al.,* 2016). The first line of defense and a key player in the plants' ability to detoxify ROS is the enzyme SOD, which removes O_2^- from ROS and transforms it into H_2O and O_2. Further, the intermediary product H_2O_2 was detoxified by the enzyme POX and CAT, which converts H_2O_2 into O_2 and H_2O and protects the plant from oxidative damage (Hu *et al.,* 2016). The increased antioxidant enzyme activity and defense system by the exogenous application of melatonin under stress conditions have also been reported in rice (Yu *et al.,* 2022), wheat (Buttar *et al.,* 2020), tomato (Jahan *et al.,* 2019) and cabbage (Lee *et al.,* 2021).

Conclusion

In conclusion, high-temperature stress affected the germination of seedlings and other seedling growth parameters like survival percentage, shoot and root growth, cell viability and antioxidant enzyme activity like superoxide dismutase and catalase in green gram. Pretreatment of green gram seeds with different concentrations of melatonin promoted seedling growth and enhanced the thermo-tolerance capacity by reducing oxidative damage. Among the different concentrations of melatonin treatment, 100 µM of melatonin showed the most significant impact on the germination of green gram seedlings. It improved shoot length, root length, cell viability and antioxidant enzyme activity with reduced malondialdehyde content, thereby alleviating the high-temperature stress inhibitory effect on green gram seedlings. Hence, melatonin can be used to enhance stress tolerance in plants. Further detailed studies on the molecular mechanism are needed to understand the interaction with other metabolites and growth-regulating hormones concerning plant tolerance to abiotic stress conditions.

Conflict of interest

The authors declare that they have no conflict of interest.

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