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Melatonin’s Potential and Strategies for Reducing Abiotic Stress in Horticultural Plants

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Abstract

Melatonin is a moderated pleiotropic particle in creatures and plants. Numerous developmental processes and stress responses are influenced by melatonin; As a result, the study of its function in plants, particularly horticultural plants, is rapidly expanding. Numerous studies have shown that phytomelatonin is a plant biostimulant that makes the plant more resistant to a variety of abiotic stressors, such as high temperatures, drought, osmotic disturbance, heavy metals, and ultraviolet light (UV). Melatonin appears to play a role in the scavenging of reactive oxygen species (ROS) and other free radicals, influencing the primary and secondary metabolism of plants, regulating the transcripts of stress-related enzymes and transcription factors, and interfering with other hormones in different environments. This pleiotropy makes phytomelatonin an alluring controller to further develop protection from abiotic stress in plants. The new revelation of the potential phytomelatonin receptor CAND2/PMTR1 and the recommendation of putative models connected with the phytomelatonin flagging pathways makes phytomelatonin another plant chemical. This review provides a summary of the biosynthetic and metabolic pathways for phytomelatonin in plants, as well as the most recent advancements in research on phytomelatonin and abiotic stress in horticultural plants, based on relevant studies from our lab. This study will give a reference to clarifying the administrative system of phytomelatonin influencing the protection from abiotic stress in plants.

Keywords: Abiotic tension; Biostimulant; Cultivable plants; Phytomelatonin

Introduction

Melatonin (N-acetyl-5-methoxytryptamine, MT or Mel) is a highly conserved molecule with a structure that is similar to that of auxin as an indole tryptamine. It was at first found in the pineal organ of the cow mind, and was named melatonin since it went about as a skin-lighting specialist in frogs [1]. Melatonin was once thought to only exist in humans and animals and play a role in regulating circadian rhythms, boosting immunity, and delaying aging. The endosperm cells of the Hydrangea lily contained a trace amount of melatonin, which was then discovered. Dubbels and co. 1999 removed melatonin from plants by gas chromatography/mass spectrometry interestingly. Since then, melatonin has been found in numerous grain crops and horticultural plants, including Chinese cabbage (Brassica rapa var.), rice (Oryza sativa), maize (Zea mays), tomato (Solanum lycopersicum), and cucumber (Cucumis sativus). glabra), apple (Malus pumila), banana (Musa nana), and grape (Vitis vinifera), indicating that melatonin is abundant in the plant kingdom [2]. Dark et al. (2004) suggested using the term "phytomelatonin" to differentiate melatonin from other substances found in plants and animals. Plant tissues contain concentrations of phytomelatonin ranging from pico to micrograms per gram, and these concentrations vary between species and within species.

In-depth research on phytomelatonin's function has been carried out by researchers due to the structural similarities it shares with auxin [3]. For the most part viewed as a cell reinforcement controls ROS, responsive nitrogen species (RNS), free revolutionaries, and other destructive oxidative atoms in plants. Studies have shown that phytomelatonin goes about as a plant trigger to direct establish development and resilience to natural circumstances. Albeit the degree of phytomelatonin is exceptionally low, it assumes a critical part in seed germination, root engineering, leave senescence, photosynthesis, stomatal development, circadian rhythms, flower progress, postharvest natural product maturing, and the reactions of plants to unfavorable biotic or abiotic stressors. The discovery of the first putative phytomelatonin receptor, CAND2/PMTR1, in Arabidopsis thaliana suggests that phytomelatonin ought to be a new candidate for a plant hormone. In addition, some hypothetical models of the phytomelatonin signaling pathways have been proposed, supporting the hypothesis that phytomelatonin is a hormone produced by plants [4].

The research that has been conducted over the past seven years on phytomelatonin's role in the abiotic stress response of horticultural plants (such as ornamentals, fruits, and vegetables) is examined and summarized in this review [5]. This study will serve as a reference for elucidating the regulatory mechanism of melatonin against abiotic stressors in horticultural plants. It is more focused on the study of melatonin in horticultural plants.

Phytomelatonin biosynthesis and digestion in plants

Tryptophan decarboxylase (TDC), tryptophan hydroxylase, tryptamine 5-hydroxylase, serotonin N-acetyltransferase (SNAT), N-acetyl-5-hydroxytryptamine methyltransferase (ASMT), and caffeic acid-O-methyltransferase are among the at least six enzymes involved in the biosynthesis of phytomelatonin from tryptophan.

In numerous plants, the gene for melatonin synthetase has been repeatedly identified. SNAT is a vital chemical in melatonin

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biosynthesis and assumes a significant part in the guideline of melatonin biosynthesis [6]. Plant melatonin levels are positively correlated with SNAT expression levels, according to some studies. Zhang et al. Using bioinformatics, they discovered 52 SNAT genes in upland cotton and discovered that GhSNAT3D may regulate melatonin synthesis by interacting with GhSNAT25D and ASMT. Likewise, SNAT knockout in A. thaliana diminished melatonin levels as well as postponed blossoming. Skillet et al. efficiently examined ASMT, which plays a rate-restricting job in melatonin combination in Capsicum. The Capsicum genome contained at least 16 ASMT enzymes, according to the findings. Cadmium has been shown to be the best inducer of melatonin in rice in previous studies, but the specific mechanism is still unknown. confirmed that TDC synthesis is triggered by cadmium. Additionally, cadmium invigorated the record of the COMT1 quality through HsfA1a and incited the collection of melatonin [7]. Other hormones also stimulate melatonin synthesis. Gibberellin (GA) advanced the combination of melatonin in rice by prompting the declaration of the melatonin blend quality TDC.

It's worthwhile to investigate the locations of phytomelatonin biosynthesis. According to some studies, the major sites of phytomelatonin biosynthesis were the mitochondria and chloroplasts. One of the rate-restricting compounds, SNAT, has been confined to chloroplasts, while the other rate-restricting chemical, ASMT, has been limited to the cytoplasm. revealed that apples' primary site of phytomelatonin synthesis is mitochondria.

On the other hand, research on the metabolism of phytomelatonin is still in its infancy. The digestion of phytomelatonin has been primarily concentrated on in model plants like Arabidopsis and rice. The first melatonin metabolite recognized in quite a while was N1-acetyl-N2-formyl-5-methoxykynuramine (AFMK), which was identified in water hyacinth [8]. The indoleamine 2, 3-dioxygenase quality, which encodes the compound that changes over melatonin into AFMK in creatures, has been segregated from rice and moved into a tomato, and the degree of phytomelatonin diminishes essentially, showing that this pathway is preserved among creatures and plants. What's more, hydroxylated melatonin, including 2-, 4-, and 6-hydroxy melatonin, has been distinguished in plants. Rice was found to have a high level of 2-hydroxy melatonin, and its synthetic enzyme, melatonin 2-hydroxylase (M2H), was found and cloned. M2H has a place with the 2-oxoglutarate-subordinate dioxygenase (2-ODD) superfamily and controls the development of 2-hydroxy melatonin. Three of the M2H proteins have been confined to the cytoplasm and one M2H protein has been limited to chloroplasts, showing that melatonin debasement happens in the cytoplasm and chloroplasts. Overexpressing the rice M2H gene led to dwarfism and early senescence of plant leaves, suggesting that 2-OHM is a senescence-inducing factor in plants, as recent research has demonstrated that 2-OHM treatment induced the production of ROS rather than melatonin. In plants, cyclic 3-hydroxy melatonin (c3-OHM) has been identified as an additional metabolite of melatonin hydroxylation [9]. C3-OHM is created by the catalyst melatonin 3-hydroxylase (M3H), which is likewise an individual from the 2-oxoglutarate-subordinate dioxygenase superfamily. In Arabidopsis, M3H has been found to be expressed most strongly at night and is restricted to the cytoplasm. The M3H knockout mutant produced less 3-OHM than the wild-type, which delayed flowering and decreased antioxidant activity.

Some non-enzymatic reactions are also used to metabolize melatonin. A kind of metabolic pathway is formed when the superoxide anion and other ROS interact with melatonin to produce AFMK. In addition, melatonin is actuated by RNS, and the nitrosation created on the nitrogen molecule of the indole ring prompts the development of N-nitroso melatonin.

High-temperature stress

Agriculture will experience more heat-related losses as a result of global warming. High temperatures lead to the overproduction of ROS in plants, which is poisonous and adjust other biomacromolecules including layer lipids, DNA, and proteins, then, at that point, influence development and advancement. The complex regulatory networks of various sensors and signaling molecules, including heat shock proteins (HSPs) and heat shock transcription factors, are involved in the highly conserved response of plants to heat stress. Melatonin treatment in Arabidopsis significantly increased the transcript levels of heat-shock factor A1 (HSFA1), a master factor that responds to heat stress. Additionally, heat-responsive genes like HSFA2, heat stress-associated 32 (HSA32), heat-shock protein 90 (HSP90), and 101 (HSP101) were involved in melatonin-related thermotolerance. To help tomato plants survive heat stress, both exogenous melatonin and overexpression of the ASMT gene increased autophagy and the accumulation of HSPs to refold proteins that had been denatured by high temperature. Further exploration recommended that the instrument of phytomelatonin to ease cut short tomato dust brought about by high temperature is like the abovementioned [10]. Additionally, melatonin synthesis gene COMT1 silencing exacerbated heat stress-induced photosynthesis decline in tomatoes by lowering chlorophyll content, photosystem activity, and electron transfer efficiency. In a similar manner, the melatonin biosynthesis enzyme SNAT1 directly interacted with HSP40, a chloroplast-based DnaJ chaperone, to regulate melatonin biosynthesis and enhance tomato heat resistance. Ongoing exploration has shown that the AP2/ERF record factor, PlTOE3, enacted the PlTDC advertiser to expand the biosynthesis of phytomelatonin and upgraded the thermotolerance of herbaceous peonies.

When stressed by high temperatures, plants use an antioxidant enzyme defense system to protect themselves. Exogenous melatonin treatment has been shown to increase ascorbic acid (ASA) levels and the activities of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). Melatonin also modifies the polyamine metabolic and nitric oxide (NO) biosynthetic pathways, as well as the ascorbate-glutathione cycle (AsA-GSH). It has been affirmed that the proper measure of melatonin (29.0 mg · L−1) assumes a positive part in the development of cherry radish (Raphanus sativus L. var. absurd pers) under high temperatures (35 °C/30 °C day/night). Besides, melatonin not just expanded the record of catechin manufactured qualities in tea plants (Camellia sinensis L.) at sub-high temperatures yet in addition further developed caffeine content by prompting the declaration of CsTIDH, CssAMS, and CsTCS1, which decidedly affected the development and nature of tea. As per RNA-seq information, melatonin worked on the thermotolerance of kiwifruit seedlings by managing the outflow of key qualities engaged with carotenoid amalgamation at 45 °C. Plants under heat stress were also affected by melatonin's effects on photosynthesis [11]. At the point when tomato seedlings were presented to high temperatures (42 °C, 24 h), a 100 μmol · L-1 exogenous melatonin treatment expanded the items in photosynthetic colors, advanced the digestion of carbon dioxide, upgraded Rubisco and FBPase exercises, and worked on the photosynthetic rate. In addition, to guard against heat-stress-induced photoinhibition, melatonin collaborated with hydrogen sulfide to regulate carbohydrate metabolism.

Salt tension

Due to limited agricultural land and a growing population, crop productivity must rise. However, irrigation and climate change are making soil salinization a bigger problem for agricultural productivity, preventing plant growth and production. CaMIPS, CaSLAH1, and CaMYB73 expression was controlled, glucose metabolism, ion homeostasis and transcriptional regulation were triggered, and salt adaptation was improved when AsA and melatonin were applied together in citrus. To prevent salt damage, it was crucial to control Na+, Cl -, and K+ transport and absorption in order to maintain ion homeostasis. Melatonin, which functions as a signaling molecule, increased the amount of NO and ATP in rice roots subjected to salt stress, increased the activity of the H+ pump, and decreased the amount of hydrogen peroxide. The AtrbohF-dependent ROS signaling pathway was necessary for endogenous melatonin-induced salt tolerance through ion and redox homeostasis, according to some studies. These studies proposed that melatonin repaired the photosynthetic damage caused by salt stress by controlling the level of ROS, promoting recovery of the photosynthetic electron transport chain and D1 protein synthesis, and regulating the abundance of the TRXf and TRXm gene products. Mel The expression levels of stress-related genes were also higher in the overexpressed lines of cucumber, suggesting that CsSNAT had a positive regulatory effect on salt tolerance and growth of cucumber seedlings by promoting melatonin synthesis. CsSNAT overexpressing lines had stronger salt tolerance than wild-type and RNA interference lines of cucumber. In addition, heterologous MsSNAT overexpression in Arabidopsis relieved the effect that NaCl had on the plant's growth, increased ion homeostasis, and increased the expression of antioxidant and autophagy-related genes.

Multiple studies have demonstrated that, in conjunction with other hormones, melatonin regulates plant stress tolerance. Melatonin and ethylene enhanced grape tolerance to NaCl and melatonin strongly induced the expression of genes related to ethylene synthesis (MYB108A/ACS1), suggesting that ethylene was involved in melatonin-induced salt tolerance. Combined transcriptomic and metabolic analyses had revealed that melatonin activated the AP2/EREBP-HB-WRKY transcriptional cascade and plant hormone (e.g., auxin and ABA) signaling pathways Also, melatonin improved the salt resilience of cotton seeds by expanding ABA and GA contents and intervening the declaration of chemical related qualities (GhABF2, GhDPBF2, GhGID1C, and GhGIDIB) in chemical sign transduction under salt pressure. Specialists have cloned and overexpressed SlCOMT1 connected with melatonin biosynthesis from tomatoes and showed that it upregulated some pressure related qualities (AREBI, AIMI, MAPKI, WRKY33, and CDPKI) and expanded the resilience to 800 mM NaCl stress in tomato. Tomatoes' total soluble carbohydrates, root weight, and leaf area all increased when melatonin was applied under normal conditions. Melatonin expanded the degrees of photosynthesis, cancer prevention agent chemicals, and proline in tomatoes under salt pressure further developing photosynthesis and osmotic guideline and upgrading salt resistance. In addition, strawberry fruit yield and quality improved in a saline environment thanks to melatonin.

Additional abiotic stresses

Other abiotic stressors, such as oxidative stress, waterlogging, acid rain, and chemical pollution, all play a significant role in the tolerance of phytomelatonin.

Plant growth and development are impacted by UV-B, an abiotic stressor. Extreme focus UV-B harms DNA sets off the aggregation of ROS, and impedes photosynthesis. To protect plants from UV-B stress, melatonin affected the expression of several key components of the UV-B signaling pathway, such as COP1, HY5, HYH, and RUP1/2, and UV-B radiation altered endogenous melatonin levels by upregulating the melatonin biosynthesis genes SNAT, COMT, and ASMT. Melatonin then controlled the expression of the genes for glutathione peroxidase 2 (GPX2) and GPX7, thereby reducing UV-B stress. Melatonin also reduced the inhibitory effects of UV-B stress on the growth and biomass of germinated soybeans and increased total flavonoid and isoflavone monomer content.

Melatonin reduces direct oxidative stress by scavenging the ROS produced by stress. By altering metabolic pathways, reprogramming the Bermuda grass proteome, and influencing the activities of antioxidants, exogenous melatonin significantly slowed H_2O_2-induced plant growth, cell damage, and ROS accumulation. Cucumbers' tolerance to photo-oxidative stress was improved by exogenous melatonin [12]. In cassava (Manihot esculenta), two melatonin biosynthetic pathway chemicals, MeTDC2 and MeASMT2, straightforwardly cooperated with ascorbate peroxidase (MeAPX2) to actuate APX action and expanded cancer prevention agent limit.

In regions with poor soil drainage and heavy rainfall, waterlogging is a major abiotic stressor. Waterlogging-prompted melatonin collection and melatonin mitigates waterlogging-actuated harm in horse feed (Medicago sativa). Despite its importance as a horticultural crop (Prunus persica), peaches frequently suffer from waterlogging stress in southern China due to its shallow root system. By altering antioxidant metabolism, increasing Ca^{2+} signaling, and increasing the expression of hypoxia-related ERF VII transcription factor genes, a pretreatment with melatonin at a concentration of 200 mol L^{-1} improved peach seedlings' tolerance to waterlogging. Additionally, foliar spraying maize seedlings with 100 mol L^{-1} melatonin and 0.50 g KNO_3 improved growth and alleviated the negative effects of waterlogging stress.

The majority of the pesticides used in agricultural production are harmful to the environment. Overexpression of SlCOMT1 improved the limit of tomatoes to lessen the poisonousness of the fungicide carbendazim and buildup by actuating glutathione S-transferase-interceded pesticide detoxification. Methyl viologen, also known as paraquat, is a common pesticide that affects the photosynthetic system and causes oxidative stress. By reducing membrane damage and lipid peroxidation and increasing the activities of antioxidant enzymes in apple and poplar leaves, melatonin treatment was able to effectively reduce the effects of oxidative stress.

Soil nitrogen (N) levels may not be ideal for plant growth in nature, causing nutritional stress. Under a nitrogen-lacking climate, melatonin essentially further developed plant development, chlorophyll content, and root improvement in apple seedlings [13]. Exogenous use of melatonin had benefit impact on the retention of NH_4^+ and upgraded the movement of nitrogen digestion related chemicals including nitrate reductase (NR), nitrite reductase (NiR), glutamine synthetase (GS), ferredoxin-subordinate glutamate synthase (Fd-GOGAT), nicotinamide adenine dinucleotide. Moreover, transcriptome results showed that melatonin lightened supplement pressure by controlling glutathione digestion and upregulating particle transport qualities [14-19].

Under acid rain stress, melatonin enhanced the yield and quality characteristics of tomato fruit. Exogenous melatonin had an effect on the expression of biosynthetic genes for plant secondary metabolites and transcription factors for acid rain stress, according to RNA-seq and qPCR results. Additionally, treatment with exogenous melatonin significantly reduced the ethylene response in grape leaves caused by

O3 stress.

Conclusion

Research on melatonin is a hotly debated issue in plant science. Especially since the first phytomelatonin receptor, CAND2/PMTR1, was found, phytomelatonin has been considered a potential phytohormone.

Melatonin assumes a significant part in plant abiotic stress flagging. Under abiotic stress conditions, melatonin and its metabolites straightforwardly or by implication rummage ROS and RNS and go about as a critical controller of the redox organization, subsequently restricting the harming impacts brought about by oxidative pressure. To mitigate the damage brought on by abiotic stress, melatonin also plays a role in regulating key aspects of primary and secondary metabolism, such as the transcription of related genes and the activity of important enzymes. Also, melatonin crosstalk with different phytohormones to initiate the plant reaction signs to abiotic stress.

Due to its complexity, there is still a lot of work to be done to gain a deeper understanding of phytomelatonin. The sign detecting, signal transduction atoms, and transport methods of melatonin in plants are muddled, so the revelation of new receptors, record variables, chaperones, and other vital components is normal. Regardless of that melatonin assumes a significant part in the protection from abiotic stress, it is as yet testing to foster yields with higher resilience to outrageous temperatures, dry season, salt, or weighty metal pressure. Additionally, a way to translate these findings into commercial use is through the use of melatonin as a biostimulant, which may have interesting applications, particularly in reducing fertilizer and pesticide usage.

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Conflict of Interest

None

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