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Melatonin - An Effective Remedy for Abiotic Stress in Plants and Microbes

Arun Kumar .P[1], Nancy Vohra[1,2], Sudhanshu Sharma[1,2], Prachi Tyagi[1], Brijesh Lekhak[1], Govindasamy .V[1], Aruna Tyagi[1] and Chirag Maheshwari[1*]

[1]ICAR-Indian Agricultural Research Institute, New Delhi, India.

[2]Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, India.

Corresponding author's e-mail: *cmchandak07@gmail.com*

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ABSTRACT

Melatonin, also known as N-acetyl-5-methoxytryptamine, is a biological indolamine with important plant biology consequences. Its synthesis happens naturally in plants, which contributes to its potential use in promoting sustainable agriculture. Melatonin, which acts as a modulator as well as a bio-stimulator and plant growth regulator, has a wide range of beneficial effects for plants. One of its important functions is to increase a plant's resistance to biotic and abiotic stressors. Drought, waterlogging, severe temperatures, salt, and alkalinity are examples of stressors. This article emphasizes the significance of melatonin-synthesizing microorganisms and dives into the role of exogenous melatonin in giving abiotic stress tolerance. It also investigates melatonin's reactivity to microorganisms and its role in phytoremediation processes.

INTRODUCTION

Melatonin, also known as N-acetyl-5-methoxytryptamine, is a secondary metabolite (hormone) with a low molecular weight, produced by the pineal gland in animals, exhibiting diverse pleiotropic activities. This tryptophan-derived indole molecule is present in organisms ranging from primitive photosynthetic bacteria to mammals, playing various roles in plants such as promoting rhizogenesis, enhancing plant growth, stimulating seed germination, increasing plant yield, facilitating biomass production, influencing photosynthesis, regulating circadian rhythms, and contributing to fruit ripening (Figure 1). While melatonin was initially identified in animal cells in 1958, a similar molecule known as phyto-melatonin was later discovered in plants during the 1990s.

Given its amphiphilic nature, melatonin is distributed across different cell compartments, including mitochondria, cytosol, and chloroplasts, functioning as an anti-stress agent against a range of biotic and abiotic stresses such as drought, salinity, potentially toxic metals, and pathogens. Under various stress conditions, there is an upregulation of genes involved in melatonin synthesis. Melatonin engages in an antioxidant cascade reaction by scavenging free radicals, thereby augmenting its antioxidant capacity.

Similarly, plant-growth-promoting rhizobacteria colonize plant roots and contribute to plant growth through mechanisms such as phosphate solubilization, nitrogen fixation, siderophore production, phytohormone synthesis, phytoremediation, disease suppression, and the production of 1-aminocyclopropane-1-carboxylate deaminase. This intricate interplay of melatonin and plant-growth-promoting rhizobacteria underscores their collective role in enhancing the resilience and well-being of plants under various environmental challenges.

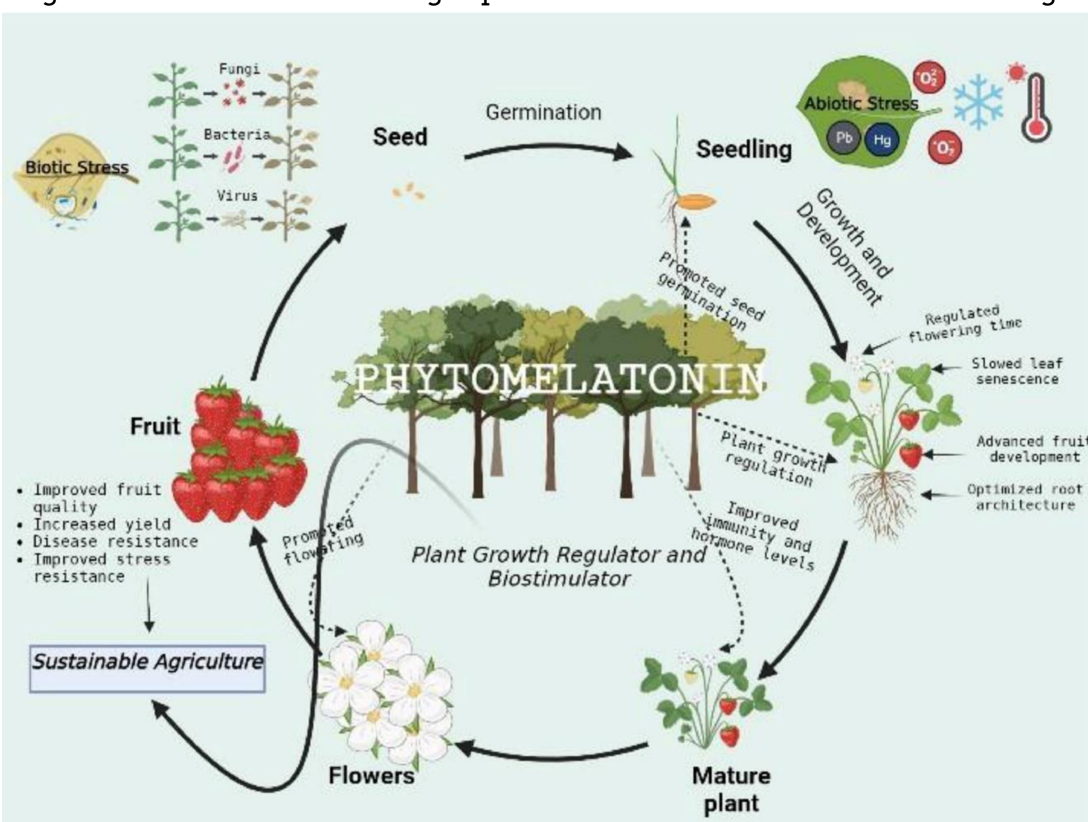

Figure 1. Phyto-melatonin – plant growth regulator and bio-stimulator (Sharma *et al.,* 2024)

MICROBES SYNTHESIZING MELATONIN

Melatonin production is not confined to animals and plants; various microbes have been identified as melatonin producers, expanding the scope to bacteria, yeast, and fungi. Bacterial genera such as *Agrobacterium, Bacillus,* and *Pseudomonas*, along with cyanobacteria and algae, have been documented as melatonin producers. Even yeast, notably *Saccharomyces cerevisiae*, has been found to synthesize melatonin, and recent studies have shed light on the melatonin biosynthetic pathway in this yeast species.

In the realm of filamentous fungi, melatonin has been detected in ascomycetes like *Neurospora crassa* and *Trichoderma* species. *Basidiomycetes*, prevalent in agricultural environments and encompassing genera such as *Cantharellus, Lactarius*, and *Leccinu*, have also been identified as melatonin synthesizers. Table 1 provides a comprehensive list of various microbes known for their ability to synthesize melatonin, showcasing the diversity of melatonin-producing organisms across different microbial groups.

Table 1. Melatonin synthesizing microbes

Microbial Class	Examples
Gram positive bacteria	*Bacillus amyloliquefaciens*
	Bacillus thuringiensis
Gram negative bacteria	*Agrobacterium tumefaciens*
	Pseudomonas fluorescens
	Erythrobacter longus
	Rhodospirillum rubrum
Cyanobacteria	*Synechocystis sp.*
Single-cell flagellate	*Euglena gracilis*
Dinoflagellate	*Gonyaulax polyedra*
Basidiomycetes	*Boletus edulis*
	Cantharellus cibarius
	Lactarius deliciosus
	Agaricus bisporus
	Leccinum rufum
Ascomycetes	*Trichoderma spp.*
	Saccharomyces uvarum
	Saccharomyces cerevisiae
Algae	*Chondrus crispus*
	Palmaria palmata
	Pterygophora californica

ROLE OF MELATONIN TO ALLEVIATE ABIOTIC STRESS

Abiotic stresses such as drought, heat, salt, and heavy metals, as well as altered cultivation environments, often result in diminished growth and yield across various crops. Melatonin emerges as a key player in mitigating the impact of abiotic stresses on plants, functioning as a frontline defender against environmental challenges such as extreme temperatures, heavy metals, drought, UV radiation, and heightened salinity.

The antioxidant activity of melatonin plays a pivotal role in this process, as it directly scavenges free radicals, stimulates antioxidant enzymes, and enhances the activities of other antioxidants.

This multifaceted approach protects antioxidant enzymes from oxidative damage, increases the efficiency of the mitochondrial electron transport chain, and mitigates electron leakage, ultimately leading to a modest reduction in Reactive Oxygen Species (ROS) signals, thereby facilitating the plant's survival (Figure 2). In instances of heat stress, the exogenous application of melatonin has been shown to promote increased root growth, elevated chlorophyll levels, improved gas exchange, and enhanced nutrient levels in crops. Similarly, under cold stress conditions, melatonin contributes to higher concentrations of cell growth promoters in plants, including sucrose, proline, and polyamines such as putrescine and spermidine, enhancing the plant's capacity to endure and adapt to challenging environmental conditions.

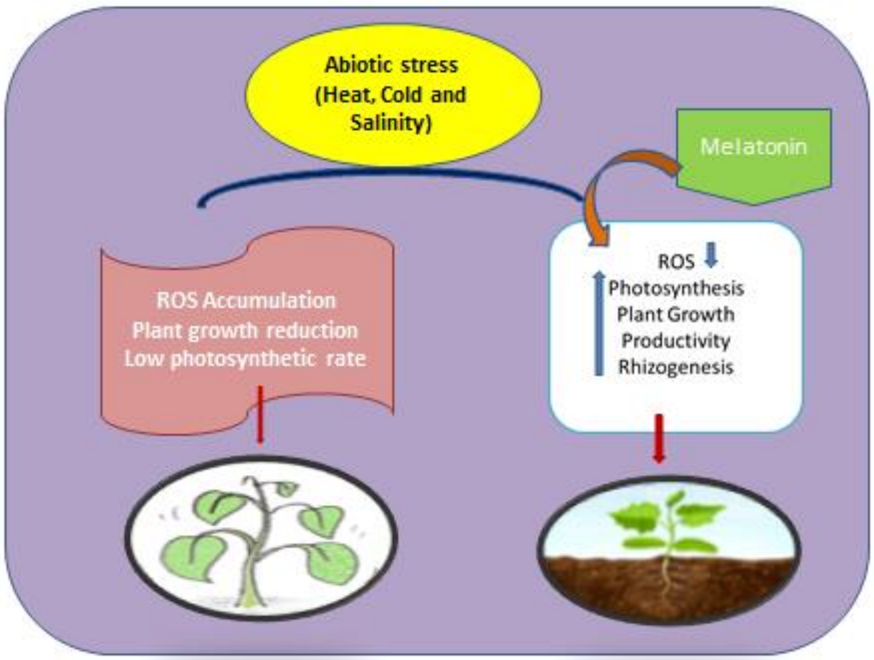

Figure 2. Response of plant to exogenous melatonin application during abiotic stress.

RESPONSES OF MICROBES TO EXOGENOUS MELATONIN

Exogenously applied melatonin, within the range of 130-530 μM exhibits antimicrobial properties against various human bacterial pathogens, including *Staphylococcus aureus, Pseudomonas aeruginosa, Acineteobacter baumannii,* and *Streptococcus agalactiae*. Notably, higher concentrations (1300 μM) have been reported to inhibit the growth of the human pathogenic yeast, *Candida albicans*. However, a contrasting observation was made with *Enterobacter aerogenes*, a bacterium residing in the human intestinal tract, where low melatonin concentrations (1nM) led to an increase in in vitro growth rate.

Melatonin's impact on fungal pathogens varies, with no effect on the in vitro radial growth of *Physalospora piricola, Botrytis cinerea,* or *Mycosphaerella arachidicola*. In contrast, inhibitory effects on the in vitro growth of the plant pathogen *Alternaria* spp. were detected only at extremely high concentrations (4000 μM). Melatonin (0.5-5 mM) demonstrated bio-oomyceticide properties by influencing cell viability, virulence intensity, and in vitro growth of *Phytophthora* *nicotianae*. However, the in vitro growth of plant pathogens *Botrytis cinerea* and *Fusarium oxysporum* remained unaffected at these concentrations.

Melatonin also plays a role in enhancing the survival of *Saccharomyces cerevisiae* against the cytotoxic effects of the amphipathic protein alpha-synuclein. In *Trichoderma asperellum*, endogenous melatonin levels increased up to threefold in response to chemical stressors such as cadmium (3mM; $CdCl_2$) and salt (1% NaCl), suggesting its importance in abiotic stress tolerance. Similarly, endogenous melatonin levels in *Saccharomyces cerevisiae* were found to increase during the fermentation process, potentially as a strategy to enhance tolerance to increased ethanol production. Furthermore, melatonin enhances plant resistance against bacterial and fungal pathogens by influencing the expression of genes associated with salicylic acid (SA), a phytohormone integral to plant defense signaling. The effects on SA-associated genes contribute to the plant's defense mechanisms, including pattern-triggered immunity (PTI) and effector-triggered immunity (ETI).

ROLE OF MELATONIN IN PHYTOREMEDIATION

Phytoremediation is a technology that harnesses the unique abilities of specific plants, referred to as hyperaccumulators, to absorb pollutants from soil or water. Among the substances targeted by this method, metals stand out due to their pronounced toxicity in biological systems, impacting both plants and animals. The efficacy of metal removal by plants is intricately linked to factors such as their growth rate, tolerance levels, and adaptability to diverse environments.

Melatonin, a ubiquitous molecule found in animals, plants, fungi, and bacteria, plays a crucial role in plants, serving not only as an antioxidant but also as a significant regulator in redox networks. Melatonin demonstrates the capacity to mobilize toxic metals by utilizing phytochelatins, facilitating the transport and sequestration of metal ions. This results in a bio-stimulatory effect of melatonin on plants, enhancing their tolerance to harmful pollutants. Additionally, melatonin contributes to the improved uptake of nitrogen (N), phosphorus (P), and sulfur (S) in stressful conditions, thereby augmenting overall cell metabolism. The multifaceted benefits of melatonin position it as a valuable tool in the realm of phytoremediation, offering a promising avenue for mitigating the impact of toxic pollutants on the environment.

CONCLUSION

Melatonin has been found to have a beneficial impact as a stress alleviator in both plants and microbes. Its positive effects are particularly evident in the realm of phytoremediation. While many microbes and plants possess the ability to produce melatonin, it becomes apparent that their inherent melatonin production is insufficient during stress conditions. Consequently, several studies highlight the noteworthy positive effects of externally applying melatonin to counteract specific stresses. Nevertheless, the mechanism through which melatonin safeguards against diverse abiotic and biotic stresses in various plant and microbe species remains somewhat mysterious. This aspect presents an intriguing avenue for future exploration in the field.

REFERENCES

Altaf, M. A., Lal, M. K., Tiwari, R. K., Naz, S., & Gahlaut, V. (2023). The potential role of melatonin in the regulation of abiotic stress in plants. Frontiers in Plant Science, 14, 1271973.

He, X., Yin, B., Zhang, J., Zhou, S., Li, Z., Zhang, X., ... & Liang, B. (2023). Exogenous melatonin alleviates apple replant disease by regulating rhizosphere soil microbial community structure and nitrogen metabolism. Science of The Total Environment, 884, 163830.

Iqbal, N., Tanzeem-ul-Haq, H. S., Turan, V., & Iqbal, M. (2023). Soil Amendments and Foliar Melatonin Reduced Pb Uptake, and Oxidative Stress, and Improved Spinach Quality in Pb-Contaminated Soil. Plants, 12(9), 1829.

Khattak, W. A., Sun, J., Abbas, A., Hameed, R., Jalal, A., Niaz, N., ... & Wang, Y. (2023). Melatonin alleviating drought stress in plants: A review. South African Journal of Botany, 161, 192-201.

Sharma, P., Thakur, N., Mann, N. A., & Umar, A. (2024). Melatonin as plant growth regulator in sustainable agriculture. Scientia Horticulturae, 323, 112421.