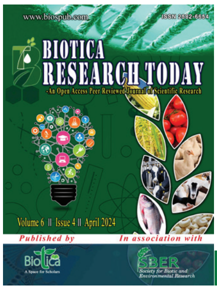
Bio. Res. Today 2024, 6(4):178-179




Biotica Research Today

e-ISSN: 2582-6654

April, 2024

Article ID: RT1606

Popular Article

# Melatonin: Antioxidative Role in Plant Stress Tolerance

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Open Access

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***Conflict of interests:*** The author has declared that no conflict of interest exists.

***How to cite this article?***

Barman, D., Gupta, S., 2024. Melatonin: Antioxidative Role in Plant Stress Tolerance. *Biotica Research Today* 6(4), 178-179.



## Abstract

Melatonin, initially identified as a neurohormone in mammals, has been recognized as a crucial signalling molecule within plants, exerting significant influence over growth, development and the plant's reactions to various environmental stresses. Studies on rice melatonin biosynthesis have highlighted its significance in enhancing plant growth and conferring ability to withstand environmental pressures like drought and salt stress by modulating antioxidant defence mechanisms. Additionally, melatonin serves a crucial function in enhancing plant resilience against varied environmental stressor including drought, salt, heat, cold, heavy metals and light stress. Its multifaceted mechanisms include stabilizing plasma membranes, preserving chloroplast integrity, enhancing photosynthetic rates and reducing reactive oxygen species (ROS) levels. Furthermore, melatonin derivatives contribute to ROS scavenging, enhancing plants' ability to withstand environmental challenges. Melatonin might play an important role in stress response mechanisms with great potential in agriculture and crop improvement strategies.

**Keywords:** Abiotic stress, Antioxidant, Biotic stress, Melatonin

## Introduction

Melatonin has become increasingly recognised in plants for its influence on growth, development and responses to environmental stresses. This pineal gland hormone has been found across various organisms, ranging from bacteria and fungi to animals and plants. Unlike its role as a neurohormone in mammals influencing sleep, immunity and circadian rhythms; melatonin plays a crucial role as a signalling molecule for stress tolerance and developmental processes in plants (Sun *et al.*, 2021). Studies on rice melatonin biosynthesis over-expression lines, particularly involving serotonin N-acetyltransferase (SNAT), have demonstrated enhanced root and shoot growth compared to wild-type plants, with RNAi lines exhibiting reduced shoot and root phenotypes. Additionally, under different abiotic stresses, melatonin detoxifies oxidants like reactive oxygen species (ROS) and activates antioxidant defence mechanisms. Melatonin reduces salt and drought stress by scavenging ROS which enhances photosynthesis rate. These findings highlight melatonin's importance in enhancing plant adaptation and resilience to environmental pressures, offering insights into potential applications in agriculture and crop improvement.

## Melatonin Biosynthesis

Tryptophan act as the precursor amino acid for melatonin synthesis (Zeng *et al.*, 2022) (Figure 1). In plants, melatonin synthesis involves six distinct biosynthetic enzymes: serotonin N-acetyltransferase (SNAT), tryptophan decarboxylase (TDC), N-acetyl-serotonin methyltransferase (ASMT), tryptophan hydroxylase, tryptamine 5-hydroxylase (T5H) and caffeic acid O-methyltransferase (COMT). Tryptophan is converted to tryptamine by TDC dependent decarboxylation, trailed by the hydroxylation of tryptamine by T5H. Subsequent steps are catalyzed by SNAT and ASMT/COMT. In healthy plants, melatonin biosynthesis predominantly follows serotonin to N-acetyl-5-hydroxytryptamine synthesis followed by melatonin production. However, in stressed plants, distinct ASMT isoforms are induced, leading to the O-methylation of serotonin, resulting in the formation of 5-methoxytryptamine, which is then acetylated to yield melatonin.

## Abiotic Stress Tolerance and Antioxidative Properties

Melatonin, a versatile signalling molecule in plants, functions a crucial role in enhancing tolerance to environmental stresses. Through exogenous treatment, melatonin has

**Article History**

RECEIVED on 27th March 2024 RECEIVED in revised form 16th April 2024 ACCEPTED in final form 17th April 2024

demonstrated efficacy in improving plants' resilience against drought, salt, heat, cold, heavy metals and light stress (Figure 2). It achieves this by stabilizing plasma membranes, preserving chloroplast integrity, enhancing photosynthetic rates, maintaining cell turgor and reducing levels of ROS, like $H_2O_2$ and $O_2^{\bullet-}$. Additionally, melatonin boosts the function of antioxidant enzymes, thus fortifying the plant's defence mechanisms against oxidative stress. Furthermore, melatonin's role extends beyond stress mitigation to include modulation of chloroplast structure during drought stress and preservation of chlorophyll content under adverse conditions in various plant species, including wheat and apple.

Renowned for its antioxidant properties, melatonin serves as an environmentally friendly compound, aiding plants in combating oxidative stress. It scavenges ROS, such as $O_2^{\bullet-}$, $H_2O_2$, RNS and OḤ which effectively reduces cellular injury (Arnao and Hernández-Ruiz, 2019; Barman *et al.*, 2024). Its ability to stimulate endogenous melatonin production under stress conditions further strengthens plants' adaptive responses, promoting cell membrane integrity and photosynthetic efficiency. Moreover, melatonin's effectiveness in reducing oxidative damage induced by heavy metals and other stressors highlights its potential as a protective agent for plants. Derivatives of melatonin such as c3-OHM and AFMK, also contribute to ROS scavenging, enhancing plants' ability to withstand environmental challenges. Melatonin also induces $H_2O_2$ and NO-mediated biotic stress defence, which work through MAPKKK3-OXI1 signalling mechanism in *Arabidopsis*.

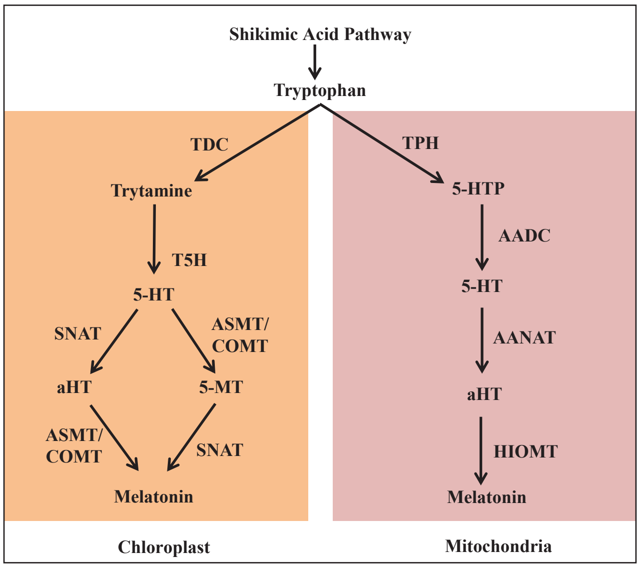


Figure 1: Melatonin biosynthesis pathway involves chloroplast and mitochondria

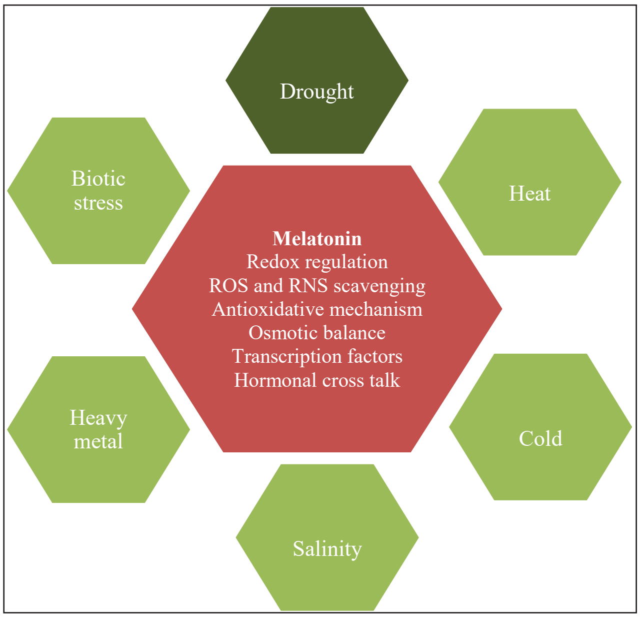


Figure 2: Melatonin modulates antioxidative mechanisms and enhances stress tolerance

## Conclusion

In conclusion, melatonin plays in important role in plant defence and agriculture, as it has been shown to improve resistance to various abiotic and biotic stresses; which underscore its potential as a sustainable signalling molecule for improving crop productivity and resilience under climate change scenario.

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