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Phytomelatonin: Stress Shield for Crops

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Phytomelatonin, a naturally occurring indoleamine ubiquitously present in plants, has emerged as a promising next-generation phytohormone due to its multifunctional role in regulating plant growth, development, and stress tolerance. Originally identified in animals as a regulator of circadian rhythms and antioxidant defense (Lerner *et al*., 1958), melatonin was later discovered in plants and termed *phytomelatonin* (Dubbels *et al*., 1995; Hattori *et al*., 1995). Accumulating evidence suggests that phytomelatonin enhances plant resilience against a wide range of abiotic stresses, including drought, salinity, extreme temperatures, heavy metals, and oxidative stress, primarily through redox regulation and stress signaling (Arnao & Hernández-Ruiz, 2019). This article provides a comprehensive and original review of phytomelatonin, focusing on its biosynthesis, distribution, mechanisms of action, interaction with other phytohormones, and agricultural applications, highlighting its potential in developing climate-resilient crops.

Keywords: Phytomelatonin; Plant stress tolerance; Abiotic stress; Antioxidant defense system; Reactive oxygen species; Drought stress; Salinity stress; Temperature stress; Heavy metal stress; Hormonal crosstalk; Crop resilience; Sustainable agriculture

Introduction

Environmental stresses represent a major limitation to global agricultural productivity, causing significant yield losses every year. Abiotic stresses such as drought, salinity, heat, cold, and heavy metal toxicity disrupt cellular homeostasis, impair photosynthesis, and induce excessive production of reactive oxygen species (ROS) in plants (Mittler, 2002). To survive under such adverse conditions, plants rely on a complex network of signaling molecules and phytohormones that coordinate growth and stress responses. Phytomelatonin (*N-acetyl-5-methoxytryptamine*) has gained increasing attention as an important regulatory molecule in plants. Although chemically identical to animal melatonin, phytomelatonin exhibits unique physiological roles in plants, acting both as a potent antioxidant and a signaling molecule (Arnao & Hernández-Ruiz, 2015). It is synthesized endogenously in almost all plant species and is present in diverse tissues, suggesting an evolutionarily conserved function (Sun et al., 2021). Due to its hormone-like behavior and broad spectrum of action, phytomelatonin is increasingly regarded as an emerging or next-generation phytohormone involved in plant stress adaptation.

Importance of Phytomelatonin in Plants

Phytomelatonin regulates multiple physiological and biochemical processes that collectively enhance plant performance under both optimal and stressful environments.
Key functions include:

- Enhancement of tolerance to abiotic stresses such as drought, salinity, temperature extremes, and heavy metal toxicity
- Improvement of resistance to biotic stresses through activation of plant defense responses

- Direct scavenging of ROS and reactive nitrogen species
- Upregulation of antioxidant enzymes including SOD, CAT, and POD
- Promotion of seed germination, seedling vigor, and root development
- Regulation of stomatal movement and water-use efficiency during stress
- Delay of leaf senescence and preservation of photosynthetic efficiency

Biosynthesis of Phytomelatonin

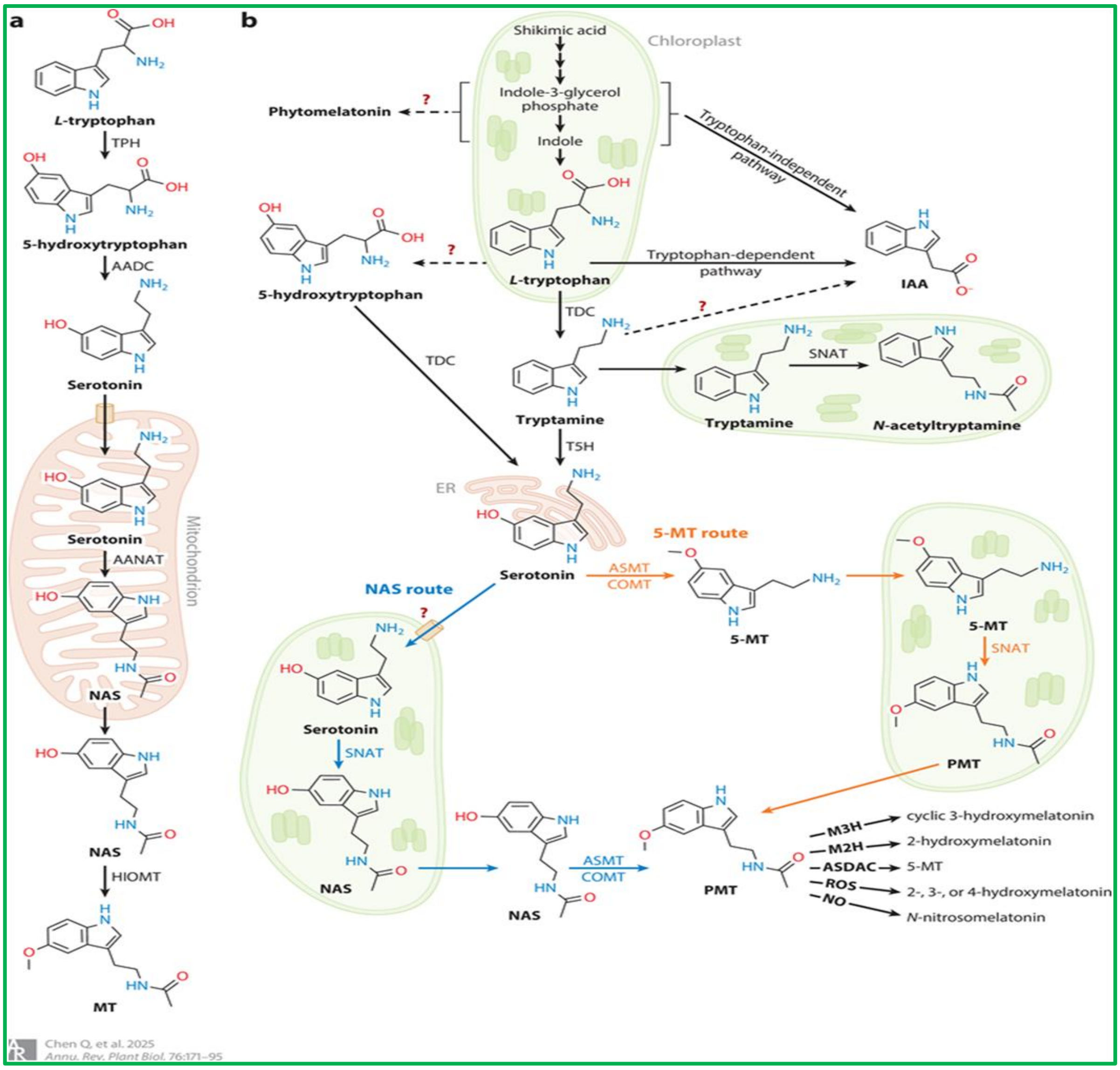
Precursor & Cellular Sites: Phytomelatonin is synthesized from the amino acid tryptophan via a conserved biosynthetic pathway. Unlike many classical phytohormones, phytomelatonin biosynthesis occurs in multiple cellular compartments, including the cytosol, chloroplasts, and mitochondria (Back et al., 2016). Chloroplasts and mitochondria are particularly significant sites because they are major sources of ROS, especially under stress conditions.

Agricultural Applications: The application of phytomelatonin in agriculture has attracted considerable interest due to its natural origin and broad-spectrum effectiveness.

Major applications include:

- Seed priming and coating to enhance germination and early seedling establishment (Posmyk et al., 2008)
- Foliar application to improve tolerance to drought and salinity
- Yield improvement and stabilization under stress conditions (Li et al., 2025)
- Enhancement of fruit quality and post-harvest shelf life (Wang et al., 2013)

Biosynthetic Pathway: The biosynthesis of phytomelatonin involves four sequential enzymatic reactions:



Mode of Action of Phytomelatonin

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Environmental Stress
        |
        ▼
Enhanced Phytomelatonin Synthesis
        |
        ├──▸ ROS Scavenging
        ├──▸ Antioxidant Enzyme Activation
        ├──▸ Hormonal Crosstalk
        └──▸ Stress-Responsive Gene Expression
        |
        ▼
Improved Stress Tolerance and Growth
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Role of Phytomelatonin in Major Abiotic Stresses

- **Drought Stress**

Under drought stress, phytomelatonin enhances root growth, regulates stomatal closure, improves water-use efficiency, protects photosynthetic pigments, and reduces oxidative damage (Li et al., 2025).

- **Salinity Stress**

Phytomelatonin mitigates salinity-induced damage by maintaining Na^+/K^+ homeostasis, improving osmotic adjustment, preserving chlorophyll content, and strengthening antioxidant defenses (Ali et al., 2021).

- **Temperature stress**

Phytomelatonin improves tolerance to heat and cold stress by stabilizing membranes and proteins, inducing heat shock proteins, activating cold-responsive genes, and reducing membrane lipid peroxidation (Zhao et al., 2017).

- **Heavy Metal Stress**

In heavy metal-stressed plants, phytomelatonin contributes to metal detoxification, protection of root systems, reduction of oxidative injury, and restoration of growth and biomass (Zhang et al., 2018).

Conclusion

Phytomelatonin has emerged as a powerful regulator of plant stress tolerance, combining direct antioxidant action with hormone-like signaling properties. Its ability to enhance plant resilience under multiple abiotic stresses highlights its significance as a next-generation phytohormone. Continued research and judicious agricultural application of phytomelatonin may play a crucial role in developing stress-resilient crops and ensuring sustainable food production in the face of climate change.

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