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Melatonin; an Emerging Physiological Regulator in Postharvest Management of Horticultural Crops: Mechanisms and Practical Applications

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Abstract

The increase in postharvest losses in horticultural crops, especially fruits and vegetables, has become one of the major challenges in food security and supply chain sustainability due to high perishability, physiological stresses, and oxidative damage. The use of traditional chemical compounds, although effective to some extent in spoilage control, has highlighted the need for safe and biocompatible alternatives due to environmental concerns and consumer health risks. In the meantime, melatonin (N-acetyl-5-methoxytryptamine) as an endogenous, non-toxic, and multifunctional signaling molecule has great potential for application in postharvest technology. Research evidence shows that exogenous application of melatonin can prevent the occurrence of physiological disorders and premature aging by strengthening the antioxidant defense system, increasing the activity of protective enzymes and non-enzymatic compounds, reducing the accumulation of reactive oxygen species, and maintaining the integrity of cell membranes. In addition, melatonin modulates the expression of defense genes and increases the tolerance of horticultural products to post-harvest stresses, including frost, by regulating ethylene-, salicylic acid-, and abscisic acid-dependent signaling pathways. These properties maintain quality traits such as tissue firmness, soluble matter content, phenolic compounds, and vitamins during storage. Accordingly, melatonin can be a suitable alternative to conventional chemical methods as a green and sustainable preservative and play an effective role in reducing waste, increasing shelf life, and improving the quality of horticultural products.

Keywords: Antioxidant, Aging, Frost Damage, Photosynthesis, Phenolic, Fruit Quality.

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1. Introduction

The growing global population has significantly increased the demand for food (Ema et al., 2024). A certain percentage of food produced globally is lost or wasted. (Lau et al., 2021), is a serious challenge in the food supply chain. Several post-harvest technologies, including cold storage and the use of synthetic chemicals, have been applied to reduce this waste and improve product quality (Ferreira et al., 2024; Patil et al., 2024; Zhang, 2024). However, due to increasing environmental and health concerns, the use of synthetic chemicals is decreasing (Bose et al., 2021), which highlights the need to develop new and sustainable technologies. In this regard, exogenous plant hormone treatments have been proposed as a natural and promising solution to maintain the quality and increase the shelf life of fruits and vegetables (Aghdam et al., 2020; Baswal et al., 2020; Adhikary et al., 2021; Islam et al., 2022; Gutiérrez-Villamil et al., 2023). Phytohormones, natural organic compounds, play a pivotal role in coordinating plant physiological activities, responding to environmental stresses, and regulating growth and development (Hu et al., 2022; Massolo et al., 2022). Horticultural crops, due to their vital role in food security, commercial economy, and industrial applications, have a special place in global agriculture and are considered a rich source of micronutrients, vitamins, and bioactive compounds (Gao et al., 2022). However, the production of these products is always constrained by biotic (e.g., pests and pathogens) and abiotic (e.g., temperature fluctuations, drought, salinity, and heavy metals) stresses, which lead to a decrease in the quantity and quality of products (Ahmad et al., 2019; Kumari et al., 2021; Umamaheswari et al., 2020). Therefore, it is essential to develop effective management strategies to increase the resilience and sustainability of the production of these products. The high perishability of horticultural products due to mechanical damage, physiological deterioration, and improper post-harvest management is a serious obstacle in their supply chain and marketing (Xu et al., 2019). Despite the widespread use of technologies and chemicals to control spoilage, their environmental and health-related risks have drawn researchers' attention to natural preservatives (Bose et al., 2021). In response to the increasing demand for safe and nutritious products, the use of compounds such as melatonin has attracted special attention as a novel and sustainable solution to increase the shelf life and maintain the quality of horticultural products (Nitu et al., 2024; Padilla-González et al., 2026).

Melatonin (N-acetyl-5-methoxytryptamine, MT), an indole compound first identified in the pineal gland of animals (Wang et al., 2026; Favero et al., 2026; Huang and Wong, 2026), has been widely considered in recent years as an effective tool in promoting stress tolerance and improving plant growth (Ahmad et al., 2023). This compound, which is endogenously present in many plant species, plays a key role in regulating physiological activities (Arnao and Hernández-Ruiz, 2014). Research has shown that exogenous application of melatonin, in addition to stimulating growth, increases tolerance to environmental stresses and delays the aging process by modulating defense responses (Zhou et al., 2021; Wang et al., 2023; Nguyen and Ha, 2025).

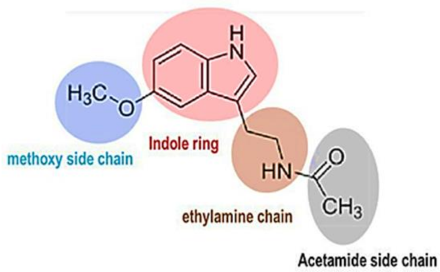

Figure 1.
Chemical structure of Melatonin (MEL). (Padilla-González et al., 2026).

Melatonin, as a plant growth regulator (PGR), affects important processes such as fruit formation, seed germination, root proliferation, flowering, and fruit ripening (Dai et al., 2020). In plants, melatonin acts as a biological signal in several plant processes such as photosynthesis, growth, defense, germination, budding, flowering, leaf senescence, membrane integrity, root growth, osmotic regulation, and plant protection against biotic and abiotic stresses (Sharma and Zheng, 2019). Also, this compound is able to increase the shelf life and freshness of fruits after harvest. The role of melatonin in stress resistance, hormone regulation, and postharvest quality improvement has been consistently reported (Wang et al., 2020; Jabbari and Jabbari, 2023). Treatment with exogenous melatonin can improve the stress resistance, antioxidant capacity, and antimicrobial ability of fruits after harvest, thereby increasing their shelf life and quality (Hernández-Ruiz et al., 2022). In particular, the function of melatonin in delaying fruit ripening and senescence during storage has attracted the attention of researchers, as the mechanism of its influence on the quality of harvested fruits has become an important research focus (Arnao and Hernández-Ruiz, 2020; Kumar Bose and Howlade, 2026). Melatonin has recently been studied to maintain postharvest quality and increase the shelf life of various horticultural crops (Hei et al., 2025). External application of melatonin can enhance endogenous melatonin to enhance its activities in several physiological processes and scavenge Reactive Oxygen Species (ROS) from fruits and vegetables during storage by increasing the activity of antioxidant enzymes. Several previous reports have indicated that external application of melatonin can maintain quality, control postharvest diseases, and extend the shelf life of jujube (Hei et al., 2025), plum (Zhang et al., 2024), pepper (Li et al., 2024; Charoenphun et al., 2024), guava (Yang et al., 2023), papaya (Wang et al., 2022), sweet cherry (Wang et al., 2019; Bal, 2023), strawberry (Liu et al., 2018), tomato (Sharafi et al., 2019), grape (Meng et al., 2019), peach (Gao et al., 2018), pear (Liu et al., 2019) and many others have gradually attracted the attention of researchers and consumers. In this review, we systematically summarize recent research advances that reveal the multiple functions and mechanisms of action of melatonin during postharvest storage of horticultural crops and provide future research directions for the use of melatonin for postharvest management.

2. Melatonin metabolism in plants

Melatonin (N-acetyl-5-methoxytryptamine) is an indoleamine compound derived from the amino acid tryptophan that is found in a wide range of organisms, from microorganisms to vertebrates (Juhnevica-Radenkova et al., 2020). It was first isolated and identified in 1958 from the bovine pineal gland.

In the early decades after its discovery, melatonin was known solely as a neurohormone in mammals, and studies focused on its role in regulating circadian rhythms, modulating immune responses, and controlling seasonal reproductive cycles; however, with the development of biochemistry, the functional scope of this hormone is now being evaluated far beyond these classical definitions (Shao et al., 2024).

As research progressed, melatonin was also found in other biological domains. In the 1980s, it was reported in invertebrates, and in 1989, it was first identified in a phototrophic unicellular organism called Lingulodinium polyedrum (formerly Gonyaulax polyedra). Finally, findings in 1995 showed that melatonin is also present in plant species, thus introducing this compound as a biological molecule with a wide distribution in nature (Salehi et al., 2019). In plants, melatonin is a multifunctional compound whose biosynthesis occurs through the Shikimate metabolic pathway using the amino acid tryptophan as the main precursor. This biosynthetic process is complex and takes place in various cellular organelles, including the cytoplasm, chloroplasts, mitochondria, and endoplasmic reticulum (Kumari et al., 2023).

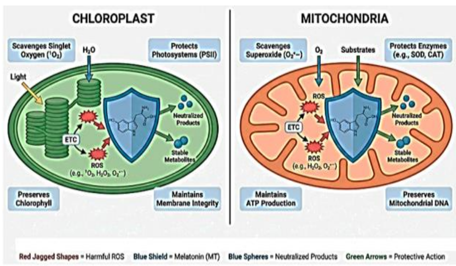

Figure 2.

Melatonin (MT) acts as a dual-organelle antioxidant shield against ROS (Eisa et al., 2026).

The main pathway of melatonin biosynthesis in plants involves four sequential enzymatic reactions: tryptophan is decarboxylated by the enzyme tryptophan decarboxylase (TDC) and converted to tryptamine; tryptamine is converted to serotonin (5-hydroxytryptamine) by the enzyme tryptamine-5-

hydroxylase (T5H); serotonin is converted to N-acetyl serotonin (NAS) by the enzyme serotonin-N-acetyltransferase (SNAT); in the final step, NAS is methylated by the activity of the enzymes N-acetyl serotonin methyltransferase (ASMT) or caffeic acid-O-methyltransferase (COMT) and converted to melatonin (He et al., 2023; Chen et al., 2026). The melatonin biosynthesis pathway in plants is linked to the synthesis of other secondary metabolites and is influenced by a complex network of genetic factors, plant hormones, and environmental stresses.

Previously, several researchers have identified melatonin biosynthesis genes in various horticultural crops such as apple, cherry, pepper, tomato, and watermelon, suggesting that melatonin is endogenously biosynthesized and plays an important role in growth and defense responses. For example, the MdTDC, MdT5H, MdAANAT, and MdASMT genes were identified in the fruit of 'Red Fuji' apple and are involved in melatonin biosynthesis (Lei et al., 2013). In another study, the PaTDC gene was identified in cherry fruit, and it was suggested that PaTDC positively regulates melatonin biosynthesis (Yu Zhao et al., 2012). SlCOMT1 is another gene identified in tomato fruit (Solanum lycopersicum Mill. cv. Ailsa Craig) (Liu et al., 2019). Various genes such as ClTDC, ClT5H, ClSNAT, ClASMT, and ClCOMT are involved in melatonin biosynthesis in watermelon (Mandal et al., 2018). Therefore, the above findings indicate that melatonin is endogenously produced in different parts of plants including fruits, flowers, leaves, seeds, etc.

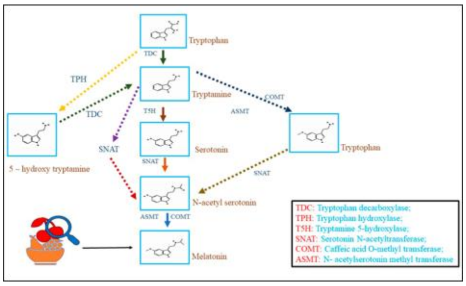

Figure 3.
Melatonin biosynthesis pathways in horticulture crops (Gao et al., 2022).

Table 1.
Effect of melatonin on different fruit crops

Scientific name	Application method	Effective concentration (µM/ppm)	Plant response	References
Mangifera indica L.	Immersed	500 µM	Delayed ripening and softening	Liu et al., 2020
Musa acuminata L.	Immersed	200 or 500 µM	Delayed postharvest ripening	Hu et al., 2017
Kiwifruit	Immersed	50 µM	Enhanced their germination rate and germination potential	Shen et al., 2019
Apple	Sprayed	–	Promoted adventitious root formation mainly at the stage of AR induction by increasing IAA levels and activating the function of MdWOX11 (overexpres-sion lines)	Mao et al., 2020
Grapes (5BB rootstock and the cultivar Cabernet Sauvignon)	Immersed	0.1 and 0.5 µM	Induced rooting in cultivar and root-stock	Gökbayrak et al., 2020
Pomegranate	sprayed	5 ppm	Reduces the fruit drop and viable hermaphrodite flowers drop, which increases the fruit set	Usanmaz et al., 2022
Apple	sprayed	20 and 200 µM	Improved flowering rate	Zhang et al., 2019
Apricot	sprayed	25 ppm	Increased vegetative growth	El-Naby et al., 2019
Sweet cherry	sprayed	0.3 mM	Improved crop yield and quality	Carrión-Antolí et al., 2021
Pomegranate	sprayed	0.1 mM	Increased crop yield as well as fruit quality	Medina-Santamarina et al., 2021
Grape (Kyoho)	Immersed	200 µM	Reduced berry abscission and rotten index	Wang et al., 2019
Grape (Moldova)	Immersed	10 and 100 µM	Promoted berry ripening	Xu et al., 2018
Banana	Immersed	–	Delayed chilling injury and alleviating peel browning	Cao et al., 2018
Jujube	sprayed	200 $\mu molL^{-1}$	Increased the disease resistance against *Alternaria rot*	Zhang et al., 2022
Apple (golden delicious)	Immersed	50 $\mu molL^{-1}$	Induced resistance to blue mold	Wang et al., 2023

Table 2.
Melatonin concentration in different fruit species

Fruits	Scientific name	Variety/cultivar	Concentration (ng g^{-1})	Stage of evaluation	References
Almond	*Prunus dulcis*	–	0.12	Mature	Paroni et al., 2019
Red grape (wine)	*Vitis vinifera* L.	Nebbiolo	0.57 to 0.63	Ripe	Fracassetti et al., 2019
		“Nero d’Avola	0.05 to 0.62	Ripe	Fracassetti et al., 2019
Sour cherry	*Prunus ceracus*	–	20	In the Second stage of fruit development	Tijero et al., 2019
Goji berry/wolfberry	*Lycium barbarum*		1600.48 ± 23.66	Mature	Yılmaz, 2021
Black mulberry	*Morus nigra*		178.70 ± 0.57		
White mulberry	*Morus alba*		183.29 ± 6.27		
Blackberry	*Rubus fructicous* L.		177.91 ± 27.51		
Purple mulberry	*Morus rubra*		233.86 ± 7.20		
Bursa black mulberry	–		123.44 ± 2.05		
Cornelian cherry	*Cornus mas* L.	–	130.82—201.84	Mature	Uğur, 2023
Date Palm	*Phoenix dactylifera*	Deglet Nour	0.02	Mature	Verde et al., 2019
		Allighes	0.0074		
		Medjbouda	0.02		
		Kenta	0.17		
		Khadrawy	0.0148		
		Medjou	0.0087		
Walnut	*Juglans regia*	Hartley	3.3	Mature	Verde et al., 2022
		Franquette	1.6		
		Pizarro	1.19		
		Native	2.07		
Apple	*Malus domestica* Mill.	Granny Smith	7.37	Ripe	Zhang et al., 2018
		Fuji	67.63		
Mulberry	*Morus alba*	–	1.739 ± 0.076	Mature	Pranil et al., 2021
Guava	*Psidium guajava*	–	1.570 ± 0.015	Mature	

Banana	*Musa sapientum*	–	1.741 ± 0.103	Ripe
Mango	*Mangifera indica*	–	2.401 ± 0.036	Mature
Pineapple	*Ananas comosus*	–	1.693 ± 0.088	Mature
Orange	*Citrus sinensis*	–	1.704 ± 0.028	Mature
Longan	*Dimocarpus longan*	–	1.676 ± 0.080	Mature
Red passion fruit	*Passiflora edulis*	–	1.528 ± 0.113	Mature
Yellow passion fruit	*Passiflora edulis*	–	1.744 ± 0.140	Mature
Jujube	*Ziziphus jujuba*	–	1.679 ± 0.163	Mature

3. Increasing shelf life and improving post-harvest quality

The use of melatonin as a post-harvest treatment plays an effective role in maintaining the quality and increasing the shelf life of agricultural products. In a study on nectarine (Fantasia cultivar), immersing fruits in different concentrations of melatonin (250, 500, and 1000 $\mu molL^{-1}$) and storing at temperatures of 0 to 1 °C and relative humidity of 85 to 90% resulted in maintaining the texture (firmness) of the fruit and preventing browning of its skin and flesh. In addition, this treatment, while reducing respiration rate and weight loss, favorably maintained quality indicators such as total soluble solids (TSS) and soluble sugars (Chen et al., 2022). In another study on cassava root tubers, exogenous melatonin significantly prevented postharvest physiological deterioration (PPD) by modulating oxidative stress through reducing hydrogen peroxide levels and increasing the activities of antioxidant enzymes catalase and peroxidase (Hu et al., 2016). Overall, the available evidence suggests that melatonin application is an effective strategy to delay the aging process and reduce postharvest losses in horticultural crops, which is achieved through improving antioxidant defense mechanisms and maintaining physicochemical properties.

4. Effect of melatonin on the quality of harvested fruits

The visual quality of fruits includes factors such as size, firmness, skin smoothness, color, and other aspects. These visual characteristics directly affect the commercial value of the fruit and also influence consumer choice (Li et al., 2023; Shi et al., 2024). Studies have shown that melatonin enhances antioxidant systems and improves membrane integrity, thereby reducing chilling injury and increasing fruit firmness and color (Padilla-González et al., 2026). Melatonin (100 $\mu molL^{-1}$) delayed the loss of firmness of guava fruit and reduced fruit weight loss (Chen et al., 2022). Spraying melatonin at a concentration of 100 $\mu molL^{-1}$on grapes during the variation period induced skin pigmentation earlier than the control group and also caused higher transcript abundance of genes related to anthocyanin biosynthesis and the transcription factors MYBA1 and MYBA2 (Xia et al., 2021).

5. Slowing down ripening and delaying senescence

Melatonin treatments delay ripening by reducing softening, weight loss, ethylene production and respiration rate (Zhai et al., 2018; Rastegar et al., 2020; Onik et al., 2021). This leads to increased TSS, TA and inhibition of surface browning (Aghdam and Fard, 2017; Xu et al., 2018; Liu et al., 2018; Zheng et al., 2019; Fan et al., 2023). The efficacy of melatonin is strongly linked to its ability to suppress ROS production by increasing the activity of antioxidant enzymes (Zhang et al., 2018; Ze et al., 2021). For example, Gao et al. (2016) reported increased APX, SOD, POD, and CAT activities in peach fruit treated with 100 µM melatonin during 7 days of storage at ambient temperature. Similar results were observed in pomegranate fruit stored at 4°C for 120 days with the same melatonin concentration (Seyed et al., 2020). Melatonin treatments are significantly associated with increases in nonenzymatic antioxidant systems, including anthocyanins, flavonoids, and ascorbic acid (Sun et al., 2020; Seyed et al., 2020).

Table 3.

Several studies on the effect of exogenous melatonin on the postharvest treatment of fruits

Botanical Name	Optimum Concentration (μM)	Effects	Application	References
Mangifera indica L.	100	Soluble solids, pH, total soluble solid and acidity ratio; maintained a higher concentration of total phenolics and total flavonoids; increased the activities of antioxidant enzymes superoxide dismutase and CAT; and improved membrane stability.	Dipped for 120 min	Bhardwaj et al., 2022
Mangifera indica	1000	Improved postharvest quality; maintained firmness; improved bioactive compounds; increased phenolic content; and increased the activity of CAT and peroxidase (POD).	Immersed for 10 min	Rastegar et al., 2020
Carica papaya	400	Delayed fruit softening; reduced anthracnose incidence; enhanced antioxidant activity; and decreased fruit oxidative injury; induced total phenol, total flavonoid, and ascorbic acid accumulation; increased CAT, ascorbate peroxidase, NADH oxidase, glutathione reductase, polyphenol oxidase, superoxide dismutase, and peroxidase activity; enhanced the activity of defense-related enzymes, such as chitinase, 4-coumaric acid-CoA-ligase, and phenylalanine ammonia lyase; repressed lipid metabolism.	Immersed for 2 h	Fan et al., 2022
Momordica charantia L.	120	Increased chlorophyll, total soluble solids (TSS), soluble sugar, soluble protein, and ascorbic acid (AsA); promoted the synthesis of total phenols and flavonoids.	Immersed for 10 min	Lin et al., 2020
Vaccinium spp.	50	Maintained the contents of AsA, anthocyanin, and total phenol; reduced the accumulation of reactive oxygen species and membrane lipid peroxidation; and promoted the activities of ascorbate peroxidase (APX), glutathione S-transferase, and phenylalanine ammonia lyase (PAL).	Sprayed	Shang et al., 2021
Musa paradisiaca L.	200–500	Inhibited the ripening process.	Soaked for 2 h	Hu et al., 2017
Psidium guajava L.	600	Maintained postharvest quality, delayed fruit softening, and reduced the incidence of anthracnose; enhanced the antioxidant capacity and reduced the oxidative damage; enhanced the activities of CAT, superoxide dismutase, ascorbate peroxidase, and glutathione reductase; and maintained total flavonoids and AsA.	Soaked for 2 h	Fan et al., 2022
Malus domestica	1000	Reduced ethylene production and weight loss; maintained skin structure; increased the activity of three enzymes, including POD,	Sprayed	Onik et al.,

Borkh		superoxide dismutase (SOD), and CAT.		2021
Malus domestica Borkh	200	Inhibited gray mold diseases.	Immersed	Cao et al., 2017
Prunus persica	100	Reduced weight loss, decay incidence, and respiration rate; maintained firmness, TSS, and AsA contents; enhanced the activities of superoxide dismutase, CAT, peroxidase, and ascorbate peroxidase; decreased the activity of lipoxygenase, levels of superoxide anion and hydrogen peroxide, and malondialdehyde content.	Dipped for 10 min	Gao et al., 2016
Prunus persica	100	Reduced chilling injury; increased extractable juice rate and TSS; enhanced expression of PpADC, PpODC, and PpGAD; increased polyamines and γ-aminobutyric acid (GABA) contents.	Immersed for 2 h	Cao et al., 2016

Other nonenzymatic systems induced by melatonin treatments include carotenoids, dehydroascorbic acid, and glutathione, which contribute to ROS homeostasis (Miranda et al., 2020). Melatonin treatments also induce proline synthesis and increase endogenous melatonin content (Liu et al., 2018; Sharafi et al., 2021;). Notably, melatonin treatments reduce MDA content and EL and LOX enzyme activities while maintaining a higher ratio of unsaturated to saturated fatty acids (Gao et al., 2018; Jannatizadeh et al., 2019). This efficacy is also related to the ability of melatonin to reduce oxidative stress by enhancing antioxidant defense systems.

6. Post-harvest quality and shelf life

Given that the quality of horticultural products after harvest can only be maintained and not improved (Arah et al., 2015), the development of post-harvest technologies is essential to reduce waste (Ullah et al., 2025). In the meantime, melatonin plays a pivotal role in maintaining the quality of products due to its safe nature and high efficiency (Badiche-El Hilali et al., 2024). Studies show that exogenous melatonin treatment can ensure the nutritional value of products such as jujube and Chinese cabbage by preserving their antioxidant compounds (such as TPC (Total Phenolic Content), TFC (Total Flavonoid Content) and acetylsalicylate (ASA)) and total soluble solids (TSS) (Gurjar et al., 2024; Kang et al., 2025). Furthermore, melatonin significantly increases the physical and chemical shelf life of fruits such as plums, cherries, and papayas by delaying weight loss, softening tissue, and reducing respiration and ethylene production (Zhang et al., 2024; Bal, 2023; Borthakur et al., 2024). These findings make melatonin an ideal option for post-harvest management and reducing horticultural crop waste.

Table 4.
Multifunctional role of melatonin during postharvest storage of horticultural crops

Botanical Name	Application Method	Effective Concentration	Function and Mechanism	References
Anthurium andreanum	Dipped	100 µM	Increased higher phenylalanine ammonia lyase activity and DPPH scavenging activity, ameliorate chilling injury during low temperature storage	Aghdam et al., 2019
Malus domestica	Sprayed	500 µM	Stimulated fruit ripening through the induction of ethylene synthesis	Verde et al., 2022
Persea americana	Immersed	50 mM	Enhanced total phenol and flavonoid accumulation and maintained titratable acidity, total soluble solids, lipid and ascorbic acid contents	Tu et al., 2022
Musa paradisiaca	Immersed	1000 µM	Maintained quality and enhanced shelf life during ambient and cold storage	Devi et al., 2025
Vaccinium spp	Soaked	300 µM	Inhibiting cell wall degradation, improved fruit quality and increased antioxidant capacity	Qu et al., 2022
Brassica oleracea var. italica	Dipped	100 µM	Maintained higher chlorophyl content and phenolic content during storage	Abou-Elwafa and Safaa, 2025
Manihot esculenta	Soaked	500 mg/L	Delayed postharvest physiological and root deterioration	Hu et al., 2018
Solanum lycopersicum L.	Dipped	0,1 mM	Induced phenylpropanoid pathway and resist against Botrytis cinerea during postharvest storage	Li et al., 2019
Citrus reticulate Blanco	Immersed	50 µM	Decreases resistance to green mold on citrus fruit by scavenging defense related reactive oxygen species	Lin et al., 2019
Cucumis sativus L.	Immersed	500 µM	Delayed the loss of chlorophyll, vitamin C, and the content of titratable acidity and soluble protein	Xin et al., 2017
Vitis vinifera L.	Soaked	10 and 100 µM	Increased the levels of ABA, H2O2, and ethylene production and promoted berry ripening	Xu et al., 2018
Crataegus spp	Immersed	0.10 and 0.25, mM	Maintained fruit quality by increasing phenolic compound during cold storage	Küçüker et al., 2024
Actinidia deliciosa	Immersed	100 and 200 µM	Inhibited cell wall degradation and preserved fruit quality	Cao et al., 2022
Litchi chinensis	Immersed	0.2 and 0.6	Preserved fruit quality and delayed senescence	Xie et al., 2022

		mM		
Mangifera indica	Immersed	0.5 mM	Reduced chilling injury and enhanced shelf life	Ping et al., 2024
Abelmoschus	Immersed	100 μM	Delayed senescence by increasing endogenous IAA, GABA, GA and ABA	Shi et al., 2024
Passiflora edμlis	Soaked	200, μM	defense-related mechanisms. Enhanced antioxidant activity and delayed senescence	Cai et al., 2024
Prunus persica	Sprayed	150 μM	Promotes the sugar accumulation and organic acid degradation in early-ripening	Zhou et al., 2023
Pyrus communis	Immersed	100 μM	Inhibited ethylene synthesis via nitric oxide regulation and delayed senescence	Jia Zhiwei et al., 2019
Capsicum	Sprayed	100, 200 and 300 μM	Improved chilling tolerance and enhanced shelf life	Huang et al., 2024
Punica granatum	Immersed	100 μM	Enhanced antioxidant enzymes activity and maintained nutraceutical properties	Aghdam et al., 2020
Rubus idaeus	Immersed	0.001 and 0.01 mM	Improved phenolic compounds, as well as antioxidant and enzyme activities	Rahmanzadeh-Ishke et al., 2024
Rosa hybrida	Sprayed	20 μM	Reduced weight loss and bacterial growth	Tongtong et al., 2018
Fragaria ananassa	Immersed	200 and 500 μM	Maintained postharvest quality during storage	Kahramanog˘lu, 2024
Prunus avium	Immersed	100 and 200 μM	Delayed softening by reducing cell wall disruption, and maintain the postharvest quality	Ghorbani and Najafzadeh, 2022
Solanum lycopersicum L.	Dipped	100 μM	Increasing chilling tolerance by enhancing linoleic and linolenic acids accumulation	Jannatizadeh et al., 2019

7. Control of Postharvest Decay and Diseases

Postharvest diseases caused by microorganisms are a major factor in reducing the quality and shelf life of horticultural crops. Melatonin enhances resistance to pathogens by stimulating plant defense pathways, including the phenylpropanoid (PP) pathway and disease-related proteins (PRs) (Fan et al., 2022). By activating defense enzymes such as PAL, chitinase, and 4-coumaric acid-CoA ligase, this compound can significantly inhibit the occurrence of diseases such as anthracnose, gray mold (Botrytis cinerea), and black spot caused by Alternaria alternata in crops such as mango, blueberry, and pear (MiaoLian et al., 2022; Wei et al., 2025; Njie et al., 2022). In addition to directly inhibiting pathogens, melatonin prevents physiological damage including browning, frost damage, and tissue deterioration in crops such as tomato and cassava by regulating redox homeostasis and enhancing the antioxidant system (Aghdam et al., 2019; Ma et al., 2016). Overall, melatonin has great potential in managing decay and maintaining the quality of postharvest products with a multifaceted approach.

8. Role of Melatonin in Inhibiting Oxidative Stress

Excessive production of Reactive Oxygen Species (ROS) and subsequent lipid peroxidation are considered to be the main factors in cell membrane damage and accelerating the aging process in postharvest products (Li et al., 2016). Melatonin can effectively inhibit this destructive process by playing a dual role as a direct antioxidant and a signaling molecule (Shi et al., 2015). Melatonin treatment leads to efficient scavenging of ROS and a significant reduction in the levels of oxidative products, including malondialdehyde (MDA), by inducing the activities of key antioxidant enzymes such as SOD, CAT, APX, POD, and GR, as well as by improving the glutathione to glutathione disulfide ratio (Li et al., 2024; Wan et al., 2024). In addition to protecting membrane integrity and reducing chilling-induced damage, melatonin increases the concentrations of phenolic compounds, anthocyanins, vitamins, and other nutrients by stimulating biosynthetic pathways (such as the shikimate pathway) (Bhardwaj et al., 2022). Extensive evidence supports that melatonin maintains the nutritional quality and significantly increases the shelf life of horticultural products by regulating cellular defense responses and enhancing antioxidant capacity (Borthakur et al., 2024; Kang et al., 2025).

9. Conclusion

Melatonin has emerged as a multifunctional, environmentally benign signaling molecule with considerable potential in the postharvest physiological management of horticultural crops. Converging experimental and molecular evidence indicates that melatonin acts as a central regulatory hub that preserves tissue and membrane integrity, attenuates oxidative damage, and effectively delays ripening and senescence through the modulation of hormonal signaling networks, the reinforcement of plant defense systems, and the stimulation of both enzymatic and non-enzymatic antioxidant machinery. Furthermore, its capacity to enhance tolerance to biotic and abiotic stresses—including chilling and frost injury—and to elevate the concentration of health-promoting bioactive compounds underscores its strategic relevance for safeguarding both the nutritional and commercial value of harvested produce.

However, despite these promising findings, the translation of melatonin-based treatments from controlled laboratory conditions to routine commercial application remains constrained by several unresolved challenges. First, the dose–response relationship of melatonin is frequently non-linear and species-, cultivar-, and maturity-dependent; both suboptimal and supraoptimal concentrations can produce negligible or even detrimental effects, necessitating the precise determination of optimal doses for each commodity and storage scenario. Second, the efficacy of melatonin is strongly influenced by the application strategy—including timing (preharvest vs. postharvest), mode of delivery (dip, spray, fumigation, or incorporation into coatings), carrier formulation, and interaction with storage environment—yet standardized protocols for these variables are still lacking. Third, the economic feasibility of large-scale application, particularly regarding the cost of formulation, labor, and infrastructure, has not been rigorously assessed within real supply-chain contexts. Finally, the absence of validated quality benchmarks, regulatory frameworks, and consumer acceptance data limits the industrial adoption of melatonin-based postharvest interventions.

To address these gaps, future research should be directed along three complementary axes: (i) elucidation of the precise molecular mechanisms underlying melatonin action through integrated omics approaches and the identification of key regulatory transcription factors; (ii) systematic evaluation of the synergistic effects of melatonin with emerging postharvest technologies, such as edible coatings, modified/controlled atmosphere storage, and biocontrol agents; and (iii) optimization of application protocols—including dose, formulation (e.g., nanoencapsulation), and timing—together with comprehensive techno-economic and life-cycle assessments under pilot and commercial-scale conditions. Ultimately, once these translational barriers are overcome, melatonin can serve as a sustainable, cost-effective, and innovative solution for reducing postharvest losses and enhancing the resilience of the horticultural supply chain.

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