

Review

Methyl Jasmonate: A Key Regulator of Postharvest Fruit Quality Maintenance and Its Crosstalk with Phytohormones

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Abstract

Methyl jasmonate (MeJA) is a volatile phytohormone that regulates diverse physiological processes and mediates plant responses to various external stressors. Recently, MeJA has emerged as a promising postharvest alternative for the improvement of fruit quality. Here, we reviewed the research progress on the application of exogenous MeJA to postharvest fruits, focusing on its regulatory roles in regulating fruit ripening, improving postharvest fruit quality, alleviating postharvest chilling injury, and controlling postharvest diseases. The potential physiological and biochemical mechanisms mainly include: (1) inducing endogenous JA biosynthesis; (2) mediating JA signaling transduction; (3) enhancing antioxidant capacity; (4) inducing the defense system; (5) regulating sucrose metabolism; and (6) modulating energy metabolism. Additionally, a specific finding is the possible crosstalk of applications of MeJA and various phytohormones during postharvest fruit storage, which provides a new method and insight for the fruit quality industry.

Keywords: methyl jasmonate; JA signaling; fruit quality; phytohormones; postharvest regulation; interaction

1. Introduction

Fruits and vegetables are essential components of the human diet because of their desirable flavor and abundant nutrients and health-promoting compounds, including organic acids, soluble sugars, amino acids, proteins, starch, and vitamins. However, fruits and vegetables are highly perishable and experience the highest loss rate among major food commodity groups, with approximately 25.4% being lost globally along the supply chain [1]. Consequently, the quality of fruits and vegetables has attracted considerable research interest in recent years. Fresh fruits are widely valued as essential components of daily diets because of their good taste and their rich nutritional and health properties derived from constituents like organic acids, soluble sugars, amino acids, proteins, starch, and vitamins. Hence, with rising improvements in living standards and evolving consumption patterns, the global economic significance of the fruit industry has grown substantially [2,3]. However, chilling injury, pathogen infection, and postharvest senescence can accelerate fruit deterioration during storage, resulting in substantial losses of sensory quality, nutritional value, and commercial value. Consequently, maintaining fruit quality

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and prolonging postharvest shelf life have emerged as critical priorities for the fruit industry.

The deterioration of postharvest fruit exhibits an intricate biological mechanism affected by both internal factors and external conditions, resulting from the coordinated interaction of multiple signaling transductions and metabolic pathways [4]. The endogenous small molecular substances play an important role in regulating senescence and stress responses. For example, ethylene (ETH), as an essential endogenous factor of climacteric fruit, not only induces fruit ripening, but also induces postharvest senescence [5–7]. Therefore, ethylene primarily promotes fruit ripening and senescence during postharvest storage. In addition, other factors also are found to simultaneously modulate fruit ripening, maintain quality, and delay senescence of postharvest fruit as positive effectors, such as gas signaling molecules nitric oxide (NO) [8], hydrogen sulfide (H₂S) [9], and hydrogen (H₂) [10]. Additionally, various phytohormones, such as jasmonates (JAs) [11], salicylic acid (SA), melatonin (MT) [12], and brassinosteroids (BR) [13], also have an important regulatory effect on fruit ripening and senescence during storage.

Methyl jasmonate (MeJA), a member of the JA family, is a pivotal plant hormone first isolated in the oil of *Jasminum grandiflorum* blossoms in 1962, and is now recognized as a widely distributed compound across the plant kingdom [14,15]. Since then, the physiological roles of JA in diverse higher plants have attracted considerable interest. JA, as a vital plant hormone, has been indicated to modulate various physiological processes of plant growth, such as seed germination, root growth, seedling development, flowering, fruit ripening, and senescence and stress response [15–17]. For example, a recent study underscored that MeJA treatment triggers the antioxidant defense system and reduces Cd translocation and Cd accumulation in wheat, thereby enhancing the safe production ability of Cd-stressed wheat [18]. Research demonstrated that JA acts as a growth inhibitor in *Vicia faba* L., yet it does not delay leaf emergence [19]. Moreover, MeJA has also been used as a sustainable technology to alleviate chilling injury of ‘Xuxiang’ kiwifruit from transcriptomic evidence [20]. Meanwhile, exogenous MeJA improved the quality of Ruixue apple fruit by triggering the cell-wall metabolism [21]. Thus, MeJA plays an important role in regulating the plant growth processes and improving postharvest fruit quality. In addition to MeJA, other plant hormones such as BR, MT, and SA are involved in the regulation of fruit quality. In particular, it is well known that MeJA might interact with other plant hormones to co-regulate fruit senescence. Lv et al. concluded that MeJA regulates the expression of genes involved in ETH biosynthesis and the signaling pathway during postharvest ripening of apple fruits [22]. To date, a small number of publications have simultaneously reported the roles of MeJA in combination with other signaling molecules in plants. Thus, significant progress in understanding of the mechanism of MeJA in improving fruit quality has been achieved.

Relevant literature was collected from Web of Science, Scopus, PubMed, and Google Scholar, covering publications from database inception to January 2026, with an emphasis on studies published during the past five years. Keyword combinations were used to retrieve studies related to methyl jasmonate (MeJA), postharvest fruit, fruit ripening, senescence, chilling injury, disease resistance, JA signaling, and phytohormone crosstalk. English-language original research articles and relevant reviews directly related to MeJA-mediated postharvest fruit quality regulation, physiological mechanisms, molecular signaling, or hormonal interactions were included.

Previous reviews have addressed several related aspects of MeJA application, including its effects on postharvest fruit quality and preservation [23], as well as its role in alleviating chilling injury and regulating associated metabolic processes [24]. However, these reviews provided limited integration of fruit ripening, quality maintenance, disease resistance, chilling tolerance, endogenous JA biosynthesis, JA signaling, and phytohormone

crosstalk during postharvest storage. Therefore, this review systematically links the major physiological effects of exogenous MeJA with its underlying regulatory mechanisms and its synergistic or antagonistic interactions with multiple phytohormones. In this review, the effects of MeJA on postharvest fruits were examined comprehensively and the detailed regulatory mechanisms of MeJA in regulating ripening, delaying senescence, enhancing disease tolerance, and alleviating chilling damage of postharvest fruit were reviewed and discussed based on future perspectives. Notably, the interplay between MeJA and other phytohormones in the quality regulation of postharvest fruit present a promising new area of research, particularly regarding the potential signaling functions. Accordingly, the review will help readers have a clearer and faster understanding about the roles of MeJA and its hormonal crosstalk in delaying postharvest fruits senescence.

2. Effects of Methyl Jasmonate on Postharvest Fruit Quality

2.1. Regulating Fruit Ripening

MeJA application has been shown to regulate postharvest fruit ripening by modulating multiple metabolic processes (Figure 1; Table 1). A finding of Concha et al. indicated that MeJA (10 and 100 mM) treatments promoted the ripening of *Fragaria chiloensis* fruit [25]. The upregulations of several ripening genes and physiological changes, including color change, an increment in the soluble solid content/titratable acidity ratio, and a decrease in fruit firmness, were observed at 2 and 5 d treatments. However, the long-term treatment of MeJA at 9 d appeared to be mostly related to senescence processes of this type of non-climacteric fruits [25]. Previously, Lalel et al. demonstrated that MeJA is involved in early steps in the regulation of mango fruit ripening [26]. In addition, MeJA-treated fruit exhibited lower firmness and a higher a^* value and ETH production, significantly promoting the ripening process of tomato. Based on the above findings, we discovered that lower effective concentrations of MeJA in tomatoes produce similar results to higher effective concentrations of MeJA in strawberries, suggesting that the optimal concentration of MeJA for application varies by fruit species [25,27]. Similarly, postharvest treatment of 1 mM MeJA accelerated the ripening process of sweet cherry, as evidenced by decreased firmness and total acidity in comparison with control fruit [28]. The authors think that this phenomenon might be due to higher rates of respiration exhibited in MeJA-treated fruit. Remarkably, Zuñiga et al. revealed the response of strawberry (*Fragaria ananassa* 'Camarosa') fruit to MeJA applications in flowering (M3), large green (M2 and M3), and ripe fruit stages (M1, M2, and M3) stages [29]. The results concluded that an increasing number of MeJA applications (M3 treatment) increased anthocyanin levels, causing an improvement in fruit ripening during postharvest storage. This further proves that fruit maturity stage and treatment timing are key factors modulating MeJA efficacy. MeJA exerts the most prominent promoting effect on pigment accumulation when applied at early developmental stages of non-climacteric strawberry fruit [29].

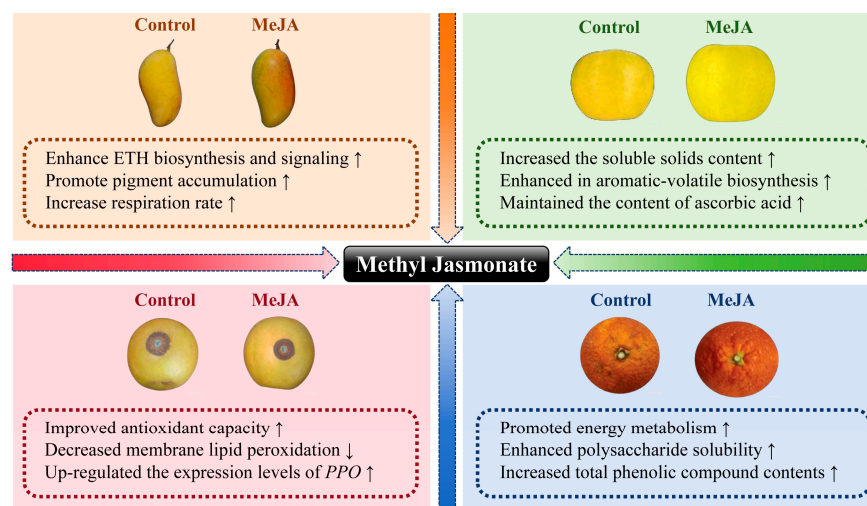


Figure 1. The major effects of MeJA on postharvest fruit physiology.

Table 1. The mechanisms and roles of MeJA in improving postharvest fruit quality.

Fruit	Treatment	Physiological Character	Effect	Reference
Strawberry (<i>Fragaria ananassa</i>)	immersing with 100 mM MeJA	increased SSC/TA ratio, anthocyanin and softening and transient firmness drop	promoting postharvest fruit ripening	[25]
Mangoes (<i>Mangifera indica</i>)	exposing to 10 ⁻³ M MeJA vapor	promoted biosynthesis of ethylene, fatty acids, aroma volatiles, and fruit ripening	promoting postharvest fruit ripening	[26]
Tomato (<i>Solanum lycopersicum</i>)	soaking with 0.5 mM MeJA	enhanced SPS activity; inhibited acid invertase and neutral invertase activities	promoting postharvest fruit ripening	[27]
Cherry (<i>Prunus avium</i>)	exposing to 1 mM MeJA vapor	decreased firmness and total acidity	promoting postharvest fruit ripening	[28]
Strawberry (<i>Fragaria ananassa</i>)	spraying with 250 µM MeJA	increased anthocyanin levels, CAT, and APX activities, and higher ascorbic acid levels	promoting postharvest fruit ripening	[29]
Mangoes (<i>Mangifera indica</i>)	spraying with 80 µL/mL MeJA	increased β-carotene, vitamin C, sugars, and SS/TA; maintained firmness; delayed weight loss	promoting postharvest fruit ripening	[30]
Avocado (<i>Persea americana</i>)	spraying with 10 or 100 µM MeJA	improved exocarp quality attributes, color parameters	promoting postharvest fruit ripening	[31]
Strawberry (<i>Fragaria ananassa</i>)	immersing with 50 µM MeJA	increased respiratory activity and ethylene production	promoting postharvest fruit ripening	[32]
Peach (<i>Prunus Persica</i>)	infiltrating with 200 µM MeJA	enhanced transcript abundance of the genes associated with anthocyanins biosynthesis	promoting postharvest fruit ripening	[33]
Red raspberries (<i>Rubus idaeus</i>)	spraying with 100 µM MeJA	upregulated MYB10 expression and ANS transcription	promoting postharvest fruit ripening	[34]
Pear (<i>Pyrus ussuriensis</i>)	immersing with 1 mM and 5 mM MeJA	enhanced in aromatic-volatile biosynthesis	Improving fruit flavor quality	[35]
Apple (<i>Malus pumila</i>)	immersing with 0.5 mM MeJA	increased ethylene production; upregulated most ethylene-pathway genes	promoting postharvest fruit ripening	[22]
Banana (<i>Musa</i>)	spraying with 100 µM MeJA	upregulated <i>MbACS7/MbACO13</i> ; promoted ethylene biosynthesis	promoting postharvest fruit ripening	[36]
Blueberry (<i>Vaccinium</i>)	–	increased fruit firmness and titratable acidity	promoting postharvest fruit ripening	[37]
Date palm	Spraying with 50 ppm MeJA	elevated total phenolics and peroxidase/polyphenol oxidase activities	improving postharvest fruit quality	[38]
Medlar (<i>Mespilus germanica</i>)	immersing with 0.1 mM MeJA	reduced the losses of oxalic acid, ascorbic acid, and citric acid	improving postharvest fruit quality	[39]
Blueberry (<i>Vaccinium</i>)	exposing to 50 µM MeJA vapor	restrained cell-wall-material degradation and maintained energy metabolism	improving postharvest fruit quality	[40]

Cantaloupe (<i>Cucumis melo</i>)	immersing with 1.5 mM MeJA	decreased weight loss and decay rate	improving postharvest fruit quality	[41]
Blackberry (<i>Rubus</i>)	immersing with 200 μ M MeJA	enhanced DPPH radical scavenging capacity, elevated total phenolic and flavonoid contents; increased activities of the antioxidant enzymes	improving postharvest fruit quality	[42]
Plum (<i>Prunus salicina</i>)	spraying with 0.5 mM MeJA	increased total phenolics, total antioxidant activity, and the antioxidant enzymes	improving postharvest fruit quality	[43]
Pear (<i>Pyrus ussuriensis</i>)	dipping in 100 μ M MeJA	maintained the content of ascorbic acid and titratable acidity; enhanced the contents of ATP and ADP and energy charge	improving postharvest fruit quality	[44]
Pomegranate (<i>Punica granatum</i>)	spraying with 10 mM MeJA	increased concentration of anthocyanins; increased total phenolic and ascorbic acid contents and total antioxidant activity	improving postharvest fruit quality	[45]
Apricot (<i>Prunus armeniaca</i>)	spraying with 0.2 mM MeJA	reduced fruit weight loss, fruit softening and juice pH and maintained soluble solid content and acidity	improving postharvest fruit quality	[46]
Pitaya (<i>Hylocereus undatus</i>)	exposing to 100 μ M MeJA vapor	inhibited ascorbic-acid and organic-acid decline, prevented flesh-color deterioration, accelerated sugar consumption, and elevated energy metabolism enzyme activities	improving postharvest fruit quality	[47]
Longan (<i>dimocarpus longan</i>)	treating with 100 μ M MeJA	increased the enzyme activities and expression of genes associated with sugar metabolism	improving fruit flavor quality	[48]
Strawberry (<i>Fragaria ananassa</i>)	exposing to 40 μ L MeJA vapor	improve fruit aroma	improving fruit flavor quality	[49]
Pepper (<i>Capsicum frutescens</i>)	exposing to 10 ppm MeJA vapor	enhanced the production of the most relevant aroma-active compounds	improving fruit flavor quality	[50]
Pear (<i>Pyrus ussuriensis</i>)	immersing in 100 μ M MeJA	upregulated the expression of LOX pathway-related genes and transcription factors	improving fruit flavor quality	[51]
Blueberry (<i>Vaccinium</i>)	treating with 50 μ M MeJA vapor	increased the accumulation of NO and H ₂ O ₂ , and activated downstream antioxidant enzymes and defense proteins	inhibiting postharvest diseases	[52]
Strawberry (<i>Fragaria ananassa</i>)	spraying with 250 μ M MeJA	upregulated expression of disease-related genes, enhanced cell wall against pathogenic bacteria	inhibiting postharvest diseases	[53]
Jujube (<i>Ziziphus jujuba</i>)	soaking in 0.1 mM MeJA	elevated the enzymatic activities of PAL and 4CL; promoted the accumulation of lignin and total phenolic compounds	inhibiting postharvest diseases	[54]
Pear (<i>Pyrus pyrifolia</i>)	fumigating with 100 μ M MeJA	enhanced activities of PPO, SOD, POD, CAT, GLU, and chitinase CHI; increased total phenol content and decreased membrane lipid peroxidation	inhibiting postharvest diseases	[55]
Tomato (<i>Solanum lycopersicum</i>)	treating with 500 μ L ⁻¹ MeJA	inhibited the mycelial growth, spore production and germination of <i>A. alternata</i> .	inhibiting postharvest diseases	[56]
Toquat (<i>Eriobotrya japonica</i>)	treating with 10 μ M MeJA	elevated the water- and CDTA-soluble pectins levels; enhanced polysaccharide solubility	alleviating chilling injury	[57]
Peach (<i>Prunus persica</i>)	exposing to 1 μ M MeJA vapor	promoted energy metabolism and enhanced the activities of antioxidant enzymes	alleviating chilling injury	[58]
Lemon (<i>Citrus limon</i>)	soaking in 10 μ M MeJA	promoted the synthesis of total phenols and PAL	alleviating chilling injury	[59]
Carambola (<i>Averrhoa carambola</i>)	spraying or dipping in 0.2 or 0.5 mM MeJA	increased the ascorbic acid and decreased antioxidant activity	alleviating chilling injury	[60]

Kinnow (<i>Citrus nobilis</i>)	dipping in 0.5 mM MeJA	increased the total phenolic content, antioxidant activity, and peroxidase enzyme activity	alleviating chilling injury	[61]
Okra (<i>Hisbiscus esculentus</i>)	fumigating with 10 ⁻² M MeJA	reduced weight loss and delayed peel color	alleviating chilling injury	[62]
Banana (<i>Musa</i>)	dipping in 1 mM MeJA	increased total phenolic compound contents; maintained the total antioxidant activity	alleviating chilling injury	[63]
Banana (<i>Musa</i>)	treating with 0.1 mM MeJA	induced ICE-CBF cold-responsive pathway genes	alleviating chilling injury	[64]
Peach (<i>Prunus persica</i>)	fumigating with 10 µM MeJA	upregulated expressions of <i>PpMYC2.2</i> and <i>PpCBF3</i> ; downregulated <i>PpMYC2</i>	alleviating chilling injury	[65]
Tomato (<i>Solanum lycopersicum</i>)	fumigating with 0.05 mM MeJA	involved in AsA-GSH cycle and ICC signaling pathway	alleviating chilling injury	[66]
Strawberry (<i>Fragaria ananassa</i>)	treating with 8 µM MeJA	improved fruit defense systems, antioxidant capacity and storage life	improving postharvest fruit quality	[67]
Eggplant (<i>Solanum melongena</i>)	dipping in 1 mM MeJA	inhibited calyx browning and reduced weight loss, while retarding the decline in sensory quality, firmness, and anthocyanin content	extending postharvest life	[68]
Bayberry (<i>Myrica rubra</i>)	treating with 1000 µM MeJA	improved antioxidant capacity	inhibiting postharvest diseases	[69]
Chestnut (<i>Castanea sativa</i>)	immersing with 0.2 mM MeJA	maintained total phenolics, antioxidant activity, and vitamin C	improving postharvest fruit quality	[70]
Loquat (<i>Eriobotrya japonica</i>)	exposing to 10 µM MeJA	enhanced total phenolic content and DPPH radical scavenging activity	improving postharvest fruit quality	[71]
Kiwifruit (<i>Actinidia deliciosa</i>)	exposing to 10 mM MeJA	enhanced the activities of related antioxidant protective enzymes and defense-related enzymes	inhibiting postharvest diseases	[72]
Banana (<i>Musa</i>)	spraying with 50 mM MeJA	enhanced the activities of the defense-related enzymes	inhibiting postharvest diseases	[73]
Apple (<i>Malus pumila</i>)	soaking in 200 µM MeJA,	upregulated the expression levels of <i>PPO</i> , <i>EXPA1</i> , <i>TFT6</i> , <i>GHR5</i> , and <i>CYP73</i>	inhibiting postharvest diseases	[74]
Strawberry (<i>Fragaria ananassa</i>)	exposing to 1 µM MeJA	enhanced the PPO activity pathogen defense	inhibiting postharvest diseases	[75]

Color is a critical factor in estimating fruit freshness and maturity stage. Additionally, the accumulation of pigments like carotenoids and anthocyanins is regulated by diverse environmental and physiological factors, such as light exposure, temperature fluctuations, mineral availability, nutrient status, and hormonal signaling mediated by plant growth regulators. MeJA is an important cellular regulator that enhances uniform color development and then improves fruit quality. Muengkaew et al. examined the role of MeJA in stimulating uniform red pigmentation development in mango peels and improving fruit quality parameters [30]. In this study, mango fruit sprayed with an 80 µL/mL MeJA solution significantly increased the total concentration of anthocyanin and a* and b* values and decreased the hue angle values of peel compared to the control fruit. Meanwhile, MeJA treatment also delayed the weight loss and improved the quality attributes of fruit such as carotene, vitamin C, sucrose, glucose, and fructose concentrations in mango fruits. These changes may explain why MeJA-treated mango fruit could be stored for up to 18 days [30]. Different from the dipping method adopted in tomato research, spraying was used for mango in this study, indicating that the treatment method also affects MeJA absorption and subsequent physiological performance [30]. Therefore, given the significance of color in promoting purchasing decisions of consumers, strategically adapting products to regional aesthetic preferences can optimize market demand and enhance profitability for agricultural producers. Further, postharvest treatment with either

10 μ M or 100 μ M MeJA could increase exocarp color parameters and visual color, and total anthocyanin and cyanidin-3-O-glucoside content during the ripening of “Hass” avocado fruit, improving early color developments of matured fruit and then affecting fruit quality and consumer preference [31]. Similar results have also been shown in strawberry [32] and peach ripening [33]. Interestingly, previous results observed that specific steps during red raspberry (*Rubus idaeus* L.) maturation are regulated by the interplay of IAA and MeJA, such as transcription factors MYB10 of the anthocyanin pathway [34]. These findings suggest that IAA and MeJA may regulate anthocyanin biosynthesis and ETH production through partially distinct pathways during red raspberry fruit ripening. Combined with the above cases, it is clear that MeJA regulates fruit coloration via divergent hormonal crosstalk networks in different species, and the difference between climacteric and non-climacteric fruits is particularly prominent [32,33]. Moreover, the authors suggested a mechanistic dissociation between IAA and MeJA-mediated anthocyanin biosynthesis and ETH production during red raspberry fruit ripening, revealing distinct phytohormonal pathways governing pigment accumulation. Therefore, the roles of MeJA in fruit coloration during fruit maturation remain very important and worthy of attention.

Aroma is also considered a characteristic of ripe fruit. Exogenous application of MeJA has been reported to enhance the production of aroma-volatile compounds, including esters, alcohols, and acetic acid, in fruit at the ripening stage. Lalel et al. found that MeJA increases levels of total aroma volatiles, monoterpenes, norisoprenoid, sesquiterpenes, aromatics, alcohols, and esters during pulp fruit ripening [26]. However, the author also noted that MeJA did not alter the biosynthesis pattern of these compounds during normal ripening. Thus, the direct role of MeJA in regulating the enzymes responsible for the biosynthesis of aroma-volatile compounds of mango remains unexplored. In addition, MeJA treatments (1 and 5 mM) boosted the total content of aromatic volatiles by 53.75% and 66.82% in normally harvested ‘Nanguoli’ pears, but did not affect aromatic volatile production in early-harvested fruit [35]. This implies that the observed effects were dependent on the maturity stage of fruit rather than exogenous MeJA concentration in the study. These observations highlight the need to clarify the relationship between MeJA treatment and aroma-volatile formation during fruit ripening.

Numerous studies have investigated the effects of MeJA on the ripening of fruit by regulating other plant hormones biosynthesis and signaling pathway. Lv et al. indicated that the expressions of genes involved in the ETH biosynthesis such as *MdACS1*, *MdACS6*, *MdACS3a*, *MdACS8*, *MdACO1*, *MdACO2*, and signaling pathway (*MdETR1*, *MdCTR1-3*, *MdCTR1-4*, *MdCTR1-5*, *MdEIN2A*, *MdEIN2B*, *MdEIL4*, and *MdERF1*) were differentially regulated by 0.5 mM MeJA during postharvest ripening of apple fruit (*Malus × domestica* Borkh.) [22]. This study provides evidence relevant to the potential crosstalk between ETH and JA signaling during fruit ripening [22]. Similarly, the application of exogenous 0.5 mM MeJA accelerated postharvest fruit ripening by enhancing ETH biosynthesis and signaling pathways in tomato [76], banana [36] and rabbiteye blueberry [37]. These results suggest that enhanced ethylene biosynthesis and signaling may contribute to the MeJA-induced acceleration of postharvest tomato ripening. Interestingly, Wang et al. found that several phytohormones contribute to the regulation of fruit ripening in rabbiteye blueberry, which includes MeJA, ETH, and abscisic acid (ABA) [37]. However, the precise mechanisms by which MeJA regulates blueberry maturation processes and influences postharvest quality characteristics remain unexplored in existing agricultural research. Collectively, these observations suggest that MeJA may contribute to fruit ripening, although the underlying mechanisms require further investigation (Figure 1; Table 1). However, intensive future research on the action mechanism of MeJA-mediated fruit ripening is required.

2.2. Improving Postharvest Fruit Quality

Rapid biochemical and physiological changes determine fruit quality attributes, including appearance, color, texture, nutritional value, aroma, and flavor. Multiple studies suggested that MeJA could delay postharvest fruit senescence and improve fruit quality during storage (Figure 1; Table 1).

Over-softening and browning of fruit lead to the rapid loss of commercial value during the fruit senescence stage. Available studies indicate that MeJA treatment may delay excessive softening and browning. In date palm fruit, lower weight loss and decay and higher firmness following MeJA treatment were associated with improved storage quality [38]. This further improves fruit quality-related attributes during fresh date palm storage and transit. Moreover, at the end of storage, as compared with the control, lower weight loss and higher flesh firmness were found in MeJA+ modified atmosphere packaging (MAP)-treated medlar (*Mespilus germanica*) fruit, which revealed that MeJA+ MAP could be used as an effective tool for delaying quality loss of medlar fruit [39]. Similarly, Wang et al. reported that reduced postharvest softening in MeJA-treated blueberry fruit was associated with changes in cell-wall modification and energy metabolism [40]. Additionally, MeJA-mediated retardation of fruit postharvest softening in cantaloupe (*Cucumis melo* L.) fruit [41], blackberry fruit [42], plum fruit [43], pears [44, 77], pomegranate fruit [45], and apricot fruit [46] was elucidated. Collectively, these studies suggest that MeJA may help delay postharvest fruit softening.

There have also been observations of the improvement of taste in most fruits. The balance between sugar and acids plays a critical role in regulating fruit flavor and quality. MeJA treatment was found to modulate sugar and acidity level and postharvest fruit quality. In tomato fruit, MeJA treatment increased the soluble solids content and elevated the activities and transcript levels of amylase, sucrose phosphate synthase (SPS), and sucrose synthase (SUS) compared to the control [66]. These findings suggested that MeJA-mediated sugar metabolism plays critical roles in improving the postharvest quality of tomato fruit. Simultaneously, Li et al. indicated that MeJA supplication significantly induced the consumption of sugars and partially maintained most of the quality attributes of fresh-cut pitaya fruit [47]. Additionally, MeJA treatment could preserve the status of sugar by regulating the enzyme activities and the expression of genes in sugar metabolism, thereby improving the flavor quality of longan fruit [48]. Thus, MeJA-induced sugar accumulation is not only one of the most important measures of quality, but also plays crucial roles in fruit development and ripening processes [38,78]. Furthermore, in the study of García-Pastor et al. [45], losses in fruit weight, firmness, and organic acids during storage were delayed in MeJA-treated fruit, resulting in an improvement in pomegranate fruit quality. Notably, co-treatment of MeJA and SA significantly increased soluble solid and acidity content in apricot fruit [46] and cantaloupe [41] over the whole storage period, suggesting that the combined application of MeJA and SA represents a promising strategy for improving fruit quality.

Aroma is another prominent characteristic of fruit quality. As a key sensory quality indicator of fruits, aroma is usually attributed to the complex mixture of volatile compounds, including acids, aldehydes, alcohols, esters, olefins, ketones, and hydrocarbons. These metabolites serve important roles in plant defense and are responsible for green aroma of fresh plants, fruits, and vegetables [79]. Additionally, various natural volatile compounds have been shown to possess antimicrobial activity [80]. Furthermore, exogenous application of MeJA has shown considerable potential for improving fruit aroma. de la Pena Moreno et al. have reported the effect MeJA on the volatile composition of strawberries [49]. In general, postharvest MeJA treatment significantly enhanced the production of key aroma-active compounds, suggesting a positive role for MeJA treatment in improving strawberry aroma. Magalhães et al. have also demonstrated that the promotion

and biosynthesis of aroma formation in hot pepper fruits were related to the postharvest applications of MeJA and ETH [50]. Moreover, postharvest application of MeJA has been shown to improve the aroma quality of different fruits such as ‘Nanguo’ pears [51] and cherry tomato [79]. Notably, MeJA also upregulated the expression of genes and transcription factors related to the LOX pathway, which might be useful in preventing cold storage-induced reduction in ester biosynthesis and aroma, consequently improving the quality of cold-stored ‘Nanguo’ pears [51]. This fully reflects the interaction between storage temperature and MeJA, and low temperature normally suppresses aroma synthesis, while MeJA can reverse this negative effect, specifically in cold-stored pear fruit [51]. Hence, all the above results suggested that exogenous MeJA application has the potential to enhance volatile organic compounds in postharvest fruits. Overall, the application of MeJA could be a beneficial approach for improving postharvest fruit quality by delaying over-softening and browning of fruit and improving taste and aroma quality in fruits.

2.3. Controlling Postharvest Diseases

Postharvest fruit diseases are one of the main factors restricting the development of the fruit and vegetable industry. In addition, fruit rot caused by fungal pathogens (such as *Botrytis cinerea* and *Alternaria tenuissima*) leads to enormous economic losses in fruit quality. Consequently, biological and chemical treatments have become promising strategies for controlling postharvest fruit diseases. In recent years, MeJA has been found to particularly enhance disease resistance by activating defense-related genes and metabolic pathways (Table 1). MeJA activates the JA signaling pathway, triggering the burst of reactive oxygen species (ROS) and nitric oxide (NO) as an early defense signal. For example, in blueberry fruits, MeJA treatment significantly increased the early accumulation of NO and H₂O₂, and activated downstream antioxidant enzymes (SOD and CAT) and defense proteins (chitinase, β -1, 3-glucanase), thereby inhibiting the spread of *botrytis cinerea* in blueberry fruits [52]. In strawberry fruit, the upregulation of defense-related genes following MeJA treatment was associated with enhanced cell-wall defenses and reduced postharvest disease incidence [53]. Moreover, MeJA promoted the synthesis of antibacterial substances by activating key enzymes such as phenylalanine ammonia lyase (PAL), cinnamic acid 4-hydroxylase (C4H), and 4-coumarate coenzyme A ligase (4CL). For example, exogenous application of MeJA to winter jujubes markedly elevated the enzymatic activities of PAL and 4CL, which consequently promoted the accumulation of lignin and total phenolic compounds, ultimately suppressing *Alternaria tenuissima*-induced black rot disease [54]. Similarly, reduced gray mold development in MeJA-treated *Botrytis cinerea* fruit was associated with enhanced phenylpropanoid metabolism and flavonoid accumulation. Moreover, MeJA could induce disease resistance by regulating the expressions of defense-related genes. In pear fruits, MeJA significantly upregulated the expressions of genes such as *PpPPO*, *PpPOD*, *PpCAT*, *Cu-ZnSOD*, *PpCHI*, and *PpGLU*. The proteins encoded by these genes may contribute to the suppression of blue mold development [55]. Notably, MeJA treatment effectively reduced the diameter of lesion spots caused by blue mold rot in pear fruits [55]. Additionally, the combined use of MeJA and chitosan has a dual impact on the in vivo and in vitro resistance of *Alternaria alternata* on cherry tomato fruit [56]. In vitro experiments, 500 μ L/L MeJA could significantly inhibit the mycelial growth, spore production, and germination of *A. alternata*. The addition of 0.1% chitosan further reduced the spore germination rate by 99.67% and shortened the mycelial length to 10 μ m. The vivo experiments showed that in artificially inoculated cherry tomatoes, treatment with 0.1% chitosan +500 μ L/L MeJA reduced the diameter of the lesion by 50% and significantly decreased the incidence rate. Collectively, these findings demonstrate that MeJA serves as a key regulator of postharvest disease control, and its integration with chitosan offers an effective strategy for mitigating postharvest fruit deterioration.

2.4. Alleviating Chilling Injury

Fruits are susceptible to chilling injury during prolonged low-temperature storage, which can substantially reduce their quality and marketability. Chilling injury disrupts the cellular architecture of fruit, leading to metabolic dysfunction and accelerated senescence. [57,81,82]. In recent years, extensive research has demonstrated that treatment with exogenous MeJA enhances cold resistance during fruits storage, consequently mitigating cold-induced damage to fruits (Figure 1; Table 1). For instance, the application of 10 μ M MeJA elevated levels of water- and CDTA-soluble pectins, which contributed to mitigating the cold damage in loquat fruits [82]. This implied that the mitigation of cold damage in fruits by MeJA may be attributed to the enhancement of polysaccharide solubility within the cell wall. In addition, MeJA treatment is capable of sustaining the energy supply, promoting energy metabolism and enhancing the activities of antioxidant enzymes in peach fruits during storage, thereby improving the low-temperature tolerance of peaches and effectively mitigating the incidence of cold damage [57]. Moreover, cold damage is closely associated with the degradation of membrane integrity, leading to impaired cellular function. Sibozza et al. demonstrated that the exogenous application of 10 μ M MeJA could potentially enhance the cold resistance of lemon fruits by promoting the synthesis of total phenols and PAL, thereby effectively mitigating membrane permeability and lipid peroxidation induced by cold stress [58]. Additionally, exogenous application of MeJA also had a significantly positive effect on the cold resistance of carambola [66], cirtus [60], okra [61], and banana [62]. These protective effects have been associated with regulation of the antioxidant system and energy metabolism, as well as maintenance of membrane integrity. Collectively, these data demonstrated that MeJA has considerable potential in alleviating chilling injury in fruits. Notably, MeJA contributes to the mitigation of cold-induced damage in tropical fruit species. Research indicated that exogenous MeJA treatment enhanced the resistance of mango fruit to chilling injury. Studies suggested that MeJA treatment mitigated the cold-induced damage by reducing ion leakage while preserving normal ripening processes, as evidenced by unaltered physiological markers such as respiration rate and fruit softening [63]. In summary, MeJA emerges as a versatile postharvest method that mitigates chilling injury across diverse fruit species, highlighting its commercial potential for cold storage preservation of fruit.

3. The Regulatory Mechanism of Methyl Jasmonate in Postharvest Fruit

3.1. Inducing Endogenous JA Biosynthesis

Accumulating evidence suggested that MeJA improves postharvest fruit quality by mediating endogenous JA biosynthesis. JAs are synthesized from α -linolenic acid via the octadecanoid pathway, involving key enzymes like lipoxygenase (LOX), allene oxide synthase (AOS), and 12-oxophytodienoate reductase 3 (OPR3). Concha et al. indicated that 100 μ M MeJA treatment upregulated the expressions of LOX, AOS, and OPR3 genes involved in the biosynthesis of JAs, and this upregulation correlated with the transient activation of *Fragaria chiloensis* fruit ripening observed [25]. Thus, regulation of endogenous JAs biosynthesis by exogenous MeJA could be a potentially effective strategy for activating fruit ripening. Lalel et al. identified trans-methyl jasmonate from the pulp of the mangoes using a gas chromatography-mass spectrometer during the ripening period [26], thereby clarifying the role of endogenous JAs involved in fruit ripening [83]. Meanwhile, Luo et al. investigated whether MeJA acts via the LOX pathway in cold-stored 'Nanguo' pears, which further improves fruit quality pears under cold stress [51]. Accordingly, we preliminarily speculate that the MeJA activates JAs accumulation through the octadecanoid pathway, thereby establishing a positive feedback loop between MeJA and improvement of postharvest fruit quality (Figure 2; Table 1). However, knowledge about

specific endogenous JA biosynthesis needs to be obtained through the analysis of related mutants.

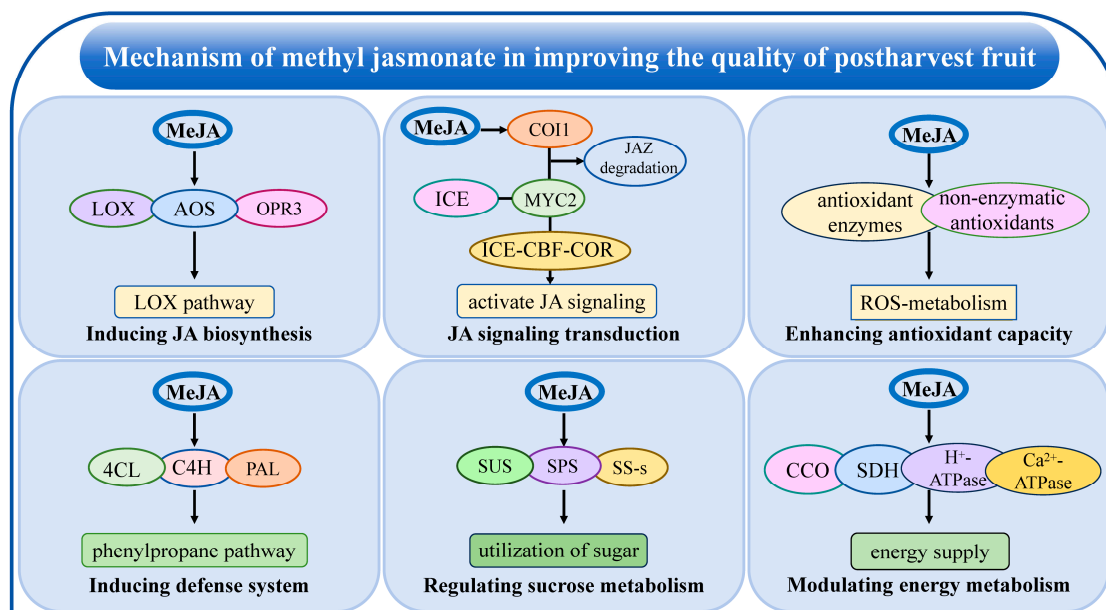


Figure 2. Mechanism of methyl jasmonate in improving the quality of postharvest fruit. LOX, lipox-ygenase; AOS, allene oxide synthase; OPR3, 2-oxophytodienoate reductase 3; SPS, sucrose phos-phate synthase; SUS, sucrose synthase; SS-s, sucrose synthase synthesis direction; GLU, β -1,3-glu-canase; CHI, chitinase; PAL, phenylalanine ammonia lyase; CHS, chalcone synthase; C4H, cinnamic acid 4-hy-droxylase; 4CL, 4-coumarate coenzyme A ligase; H⁺-ATPase, H⁺-adenosine triphospha-tase, Ca²⁺-ATPase, Ca²⁺-adenosine triphosphatase, CCO cytochrome C oxidase, SDH, succinic dehy-drogenase.

3.2. Mediating JA Signaling Transduction

The JA signaling module includes F-box protein COR-ONATIN INSENSITIVE 1(COI1), jasmonate-ZIM domain (JAZ repressors), and the transcription factor MYC2. Under normal conditions, JAZ proteins inhibit MYC2 transcriptional activity to suppress JA responses. However, stress triggers the synthesis of bioactive JA-isoleucine (JA-Ile), which promotes the high-affinity interaction between COI1 and JAZ proteins. This interaction leads to the ubiquitination of JAZ via the SCF^{COI1} complex and their subsequent degradation by the 26S proteasome, thereby liberating MYC2 to activate JA signaling [84–86]. An increasing number of studies have demonstrated that MYC2, a major regulator of JA signaling, plays an important role in MeJA-mediated postharvest fruit quality regulation [87]. Zhao et al. suggested that *MaMYC2* is involved in MeJA-induced chilling tolerance in banana fruit through physical interaction with *MaICE1*, improving banana fruit quality during postharvest cold storage [88]. Similar results in peach fruit were obtained by Chen et al. It was reported that MeJA treatment could activate JA signaling to further alleviate chilling injury in peach fruit [67]. Recent research on postharvest tomato fruit showed that *SlMYC2* is involved in MeJA-induced chilling tolerance by regulating polyamines biosynthesis through activation of the transcription of *SlARG1*, *SlARG2*, *SlADC*, and *SlODC* related to polyamines biosynthesis [65]. Interestingly, *SlMYC2* participated in MeJA-enhanced cold tolerance of tomato fruit through the regulation of ASA-GSH cycle and *SlICE-SlCBF-SlCOR* signaling pathway [66]. It is presumed that these pathways of polyamines biosynthesis, ASA-GSH cycle, and *SlICE-SlCBF-SlCOR* signaling exert multiple and important roles in JA signaling pathway during postharvest senescence. These findings collectively demonstrate that MYC2 directly regulates downstream genes associated with

polyamine metabolism, antioxidant recycling, and cold-responsive pathways. In this way, JA signaling is transduced into enhanced chilling tolerance and oxidative stress resistance in fruits. Moreover, extensive studies indicate that MYC2 is involved in the postharvest diseases control process of many horticultural crops. Min et al. reported that *SlMYC2* is required for MeJA-induced resistance to *Botrytis cinerea* in tomato fruit [87]. Moreover, emerging evidence suggests that MYC2 also participates in the regulation of the phenylpropanoid pathway (e.g., PAL, 4CL), linking JA signaling to the accumulation of antimicrobial phenolics and lignin that reinforce disease resistance and fruit quality [89]. Therefore, these studies have important practical relevance for the quality improvement of postharvest fruit via JA signaling actions through the transcription factor MYC2 (Figure 2; Table 1). However, the functions of the JA signaling module, COI1, and JAZ repressors on maintaining quality remain unknown. Future studies should explore how different JAZ family members selectively bind to COI1 and MYC2 proteins in a fruit species-specific manner. Meanwhile, it is critical to clarify the regulatory mechanisms of key postharvest factors on the stability of this core signaling module and to further elucidate the intrinsic correlation between upstream JA signal perception and downstream fruit quality-related phenotypes.

3.3. Enhancing the Antioxidant Capacity

ROS are widely believed to affect the process of postharvest fruit senescence. To rapidly remove excess ROS, plants activate a complex antioxidant system involving both antioxidant enzymes and non-enzymatic antioxidants, which protect cellular components from oxidative damage [90,91]. It is well known that key enzymatic antioxidants include catalase (CAT), superoxide dismutase (SOD), peroxidase (POD), polyphenol oxidase (PPO), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), glutathione peroxidase (GPX), and glutathione reductase (GR). The major non-enzymatic antioxidants are phenolic compounds, flavonoids, ascorbic acid (AsA), and glutathione (GSH), among others. In recent years, numerous studies have found that the antioxidant enzymatic activity and non-enzymatic antioxidants content also have been associated with MeJA application during postharvest storage.

For instance, Zuñiga et al. indicated that MeJA treatment increases the antioxidant-related enzymatic activities of CAT and APX, and the contents of total flavonoid, phenolic, and AsA, further enforcing the fruit antioxidant response in postharvest storage of strawberry (*Fragaria × ananassa* ‘Camarosa’) [29]. Similarly, MeJA effectively enhanced total antioxidant capacity, prolonging the postharvest life of “Sabrosa” strawberry fruit [67]. Similar results were observed in other horticultural crops, such as eggplant fruits [68], pomegranate [45], and grapes [92], suggesting that MeJA has a potential effect on maintaining the quality and extending the postharvest life of fruit. Moreover, the activities of ROS-metabolizing enzymes like SOD, CAT, and APX were enhanced by MeJA treatment, which might enhance disease resistance in peach fruits [93]. In blueberry fruits, MeJA promoted antioxidant enzyme activities and phenolic and flavonoid contents, then inducing the resistance of postharvest blueberry to gray mold caused by *Botrytis cinerea* [52]. The consistent results were found in Chinese bayberries [69]. Thus, the above results indicate that MeJA might modulate antioxidant capacity, resulting in alleviating postharvest disease-caused damage to fruit, consequently improving the quality and shelf life of postharvest fruits. Notably, chilling injury is accompanied by ROS accumulation. García-Pastor et al. revealed that 5 mM MeJA treatment may be sufficient to induce the cold storage potential of pomegranate fruit by reducing chilling injury symptoms and enhancing the content bioactive compounds with antioxidant activity [94]. It is reported that the preharvest spray of MeJA remarkably maintained higher phenolics, antioxidant levels, and POD activities during cold storage, revealing that MeJA can be effective in maintaining the

quality and shelf life of *Kinnow mandarin* fruit during cold storage [60]. Preharvest spraying and postharvest immersion represent two distinct treatment timings and methods, and both can activate antioxidant systems, but the lasting effect varies among species [60]. In addition, postharvest quality traits of Chestnut (*Castanea sativa* Mill.) fruit [70] and Okra (*Hibiscus esculentus* L.) [61] are affected by MeJA during cold storage. In short, the regulation of the antioxidant system acts as a potential mechanism underlying MeJA-improved quality of postharvest fruits (Figure 2; Table 1). However, detailed molecular insights into the mechanisms underpinning how MeJA enhances the antioxidant capacity of postharvest fruits have not been explored and remain to be established.

3.4. Inducing the Defense System

Postharvest infestations and deterioration caused by phytopathogenic fungi render fruit susceptible, causing major losses of fruit and limiting fruit industry development. MeJA has become a promising alternative treatment due to its natural character, antifungal activity, and elicitation of defense responses in plant tissue. Two defense proteins, β -1,3-glucanase (GLU) and chitinase (CHI), are crucial for protecting plants from pathogen infection and directly execute its antifungal role in the degradation of structural polysaccharides in microbial cell [95]. In inoculated blueberry fruit, treatment of 50 μ mol MeJA significantly promoted the activity of defense-related enzymes CHI and GLU, inducing the disease resistance of blueberries to gray mold caused by *Botrytis cinerea* [52]. Furthermore, Chen et al. also indicated that MeJA-enhanced resistance of postharvest pear fruit to blue mold rot may be related to the enhancement of defense enzymes activities and gene expression [56]. In this study, MeJA significantly enhanced the activities of antioxidant and defense-related enzymes, such as SOD, POD, CAT, GLU, and CHI, and promoted the expression of *PpPOD*, *PpCAT*, *PpCHI*, and *PpGLU* in pear fruits. These results are consistent with the data from loquat fruit [71,96–98], kiwifruit [72], peach fruit [93], banana fruit [73], and Chinese bayberry [99]. That is to say, exogenous MeJA might induce resistance against phytopathogenic fungi by promoting the activities and transcriptional expression of defense proteins CHI and GLU. Moreover, the phenylpropane pathway plays an essential regulatory role in enhancing the defense ability of postharvest fruit against pathogens. Key phenylpropane pathway enzymes, phenylalanine ammonia lyase (PAL), chalcone synthase (CHS), cinnamic acid 4-hydroxylase (C4H) and 4-coumarate coenzyme A ligase (4CL), catalyze the rate-limiting conversion of phenylalanine to antibacterial phenolic compounds such as phenolic acids, flavonoids, and lignin [100]. Recently, both MeJA and MeSA have been shown to enhance the resistance of winter jujube to *Alternaria tenuissima* by enhancing the activities of enzymes related to the phenylpropane metabolism and increasing the accumulation of phenylpropane metabolites, including lignin, total phenol, and total flavonoid [54]. In addition, MeJA treatment enhanced the phenylpropanoid pathway by provoking PAL, C4H, and 4CL activity and elevated of phenolics and flavonoids levels in blueberry fruit, significantly inducing resistance against *Botrytis cinerea* infection [52]. Thus, these results revealed the roles of the MeJA-mediated phenylpropane pathway in enhancing the defense capacity of postharvest fruits (Figure 2; Table 1). Polyphenol oxidase (PPO) enhances pathogen defense by oxidizing phenolic compounds to directly toxic quinones. In postharvest apples, MeJA treatment upregulated the expression levels of *PPO*, *EXPA1*, *TFT6*, *GHR5*, and *CYP73* and enhanced the stress resistance of apple [74]. Similarly, activities of PPO, CHI, and GLU and the accumulation of total phenolic content were significantly enhanced after MeJA treatment, indicating that MeJA is a promising and safe strategy for controlling postharvest rot soft of kiwifruit [72]. Similar results of MeJA-induced PPO activity in enhancing pathogen defense were also found in postharvest strawberry fruit [75] and pear fruit [56]. This research will provide a theoretical basis for improving postharvest fruit quality with MeJA.

Chitosan is found to have fungicidal effects and to elicit defense mechanisms in plants. Notably, the combined treatments of MeJA and chitosan were able to increase the shelf life of fruits, as evidenced by the enhanced activity of postharvest defense mechanisms [81,101]. MeJA-mediated disease control may involve both the activation of host defense responses and the suppression of pathogen development, thereby enhancing resistance to postharvest diseases [102]. In kiwifruit, coordinated changes in JA-pathway genes, phenylpropanoid enzymes, related metabolites, and disease development suggest a functional link between JA signaling and phenylpropanoid defense during MeJA-induced soft rot resistance [103]. In summary, these findings underscore the role of MeJA in enhancing postharvest fruit disease resistance, highlighting its potential as a strategy for improving both fruit quality and disease resistance and reducing storage losses.

3.5. Regulating Sucrose Metabolism

In fruits, as both an energy source and signaling molecule, soluble sugar, such as fructose, sucrose and glucose, regulates fruit sweetness and multiple physiological processes like ripening, senescence, and stress response. Consequently, sugar metabolism plays a critical role in maintaining fruit quality during postharvest storage [30]. A recent study highlighted the importance of MeJA-regulated sucrose metabolism in improving the pulp flavor of postharvest longan fruit [48]. In the study, 100 μ M MeJA-treated fruit exhibited higher levels of total soluble solids, sucrose, and total sugar, and lower levels of glucose and fructose. These mentioned results might be attributed to the MeJA-inhibited activities of acid invertase, neutral invertase, and sucrose synthase-cleavage direction (SS-c) in longan fruit, which quickly decompose sucrose into glucose and fructose. Concomitantly, these authors reported an increased in the sucrose synthase synthesis direction (SS-s) and sucrose phosphate synthase (SPS) activities, which accelerates sucrose accumulation. MeJA could modulate the enzyme activities and expression of genes in sugar metabolism pathway to improve the balance of sugar, thereby maintaining the flavor quality of postharvest longan fruit [48]. This report is in agreement with Li et al. [103] and Tao et al. [27] in tomato fruits, who reported that MeJA enhanced the activities and transcript levels of amylase, SPS, and sucrose synthase (SUS), while decreasing the activities and transcript levels of acid invertase and neutral invertase, improving the postharvest quality of tomato fruit. Simultaneously, postharvest treatment of MeJA was found to affect color development and anthocyanins biosynthesis by regulating sucrose metabolism during postharvest storage of peach fruit [33], which implied that MeJA might accelerate anthocyanins biosynthesis by inducing amounts of the signal molecule sucrose during postharvest storage. Notably, Li et al. demonstrated that MeJA and injury stress synergistically induce the utilization and transformation of sugar, providing essential precursors and energy for the wound-induced phenolic accumulation in fresh-cut pitaya fruit [47]. Thus, MeJA plays an essential role in regulating sugar metabolism to maintain postharvest fruit quality (Figure 2; Table 1). However, there were no more reports about the detailed signaling pathways of MeJA-mediated sugar translocation and uptake in fruit. Hence, more detailed mechanisms about sugar translocation and uptake by MeJA need to be studied.

3.6. Modulating Energy Metabolism

The energy status in plant cells is closely associated with the physiological metabolism of postharvest fruits and vegetable. Adequate energy levels are well established as being crucial for preserving membrane integrity during this period [13,104]. It has been found that insufficient energy supply induces the browning of longan pericarp, whereas pure oxygen effectively enhances the energy status to further decrease skin browning [105]. Consequently, maintaining balanced cellular energy is vital for horticultural products during the postharvest storage. Recently, some research has focused on the effect of

MeJA on postharvest fruit due to energy status regulation in plants (Figure 2; Table 1). For example, activities and expression levels of enzymes involved in energy metabolism, including H⁺-adenosine triphosphatase (H⁺-ATPase), Ca²⁺-adenosine triphosphatase (Ca²⁺-ATPase), cytochrome C oxidase (CCO), and succinic dehydrogenase (SDH), were increased after MeJA treatment in blueberry. Furthermore, the activity and transcript level of cell wall-degrading enzymes were markedly restrained in MeJA-treated blueberry. These results revealed the regulatory roles of MeJA in delaying the softening of postharvest blueberry by inhibiting the degradation of the cell wall and maintaining energy supplement [40]. Moreover, Li et al. reported that MeJA also effectively elevated the activities of H⁺-ATPase, Ca²⁺-ATPase, SDH, and CCO in fruits, thus maintaining the quality of Nanguo pears by modulating mitochondrial energy metabolism during room temperature storage [44]. Similar results were reported by Jin et al. in peach fruit during chilling stress, who found that MeJA can enhance the chilling resistance of peach fruit by maintaining high levels of ATP and energy charge [57]. In MeJA-treated kiwifruit infected with *Botryosphaeria dothidea*, maintenance of cellular energy status was accompanied by reduced ROS accumulation and membrane lipid peroxidation. Correlation analysis further linked energy metabolism with membrane lipid stability, providing additional evidence that redox regulation, membrane maintenance, and energy supply jointly contribute to MeJA-induced disease resistance [106]. Therefore, energy maintenance is an important component of MeJA-mediated postharvest regulation and is closely linked with JA signaling, phenylpropanoid defense, sugar utilization, membrane stability, and cell-wall maintenance. However, the causal relationships among these processes and the underlying regulation of mitochondrial respiration require further validation. Therefore, energy accumulation plays an important role in MeJA-treated postharvest fruit. However, further studies are needed to explore the detailed mechanism of mitochondrial respiration regulated by MeJA in postharvest fruits.

4. The Crosstalk Between MeJA and Phytohormones in Improving Postharvest Fruit Quality

As an important plant hormone involved in signaling, MeJA interacts extensively with other plant hormones during fruit postharvest, such as ETH, SA, ABA, melatonin, and BR. This interplay highlights potential application prospects of phytohormone molecules in prolonging fruit fresh life and improving fruit quality (Figure 3; Table 2).

Table 2. The crosstalk between MeJA and phytohormones in improving postharvest fruit quality.

Fruit	Interaction Hormones	Interaction	Physiological Character	Effect	Reference
Strawberry (<i>Fragaria ananassa</i>)	ETH	synergistic	increased the expression of ETH and lignin biosynthesis genes (<i>ACS</i> , <i>ACO</i> , <i>CAD</i> , and <i>POD27</i>)	promoting postharvest fruit ripening	[25]
Plum (<i>Prunus salicina</i>)	ETH	synergistic	increased respiration, <i>ACS/ACO</i> activities and <i>ACC</i> content	promoting postharvest fruit ripening	[107]
Mangoes (<i>Mangifera indica</i>)	ETH	synergistic	elevated ETH production, improved skin color, increased fatty-acid pools, and enhanced aroma volatiles	promoting postharvest fruit ripening	[26]
Banana (<i>Musa</i>)	ETH	synergistic	activated the Ma14-3-3e–MabHLH130–MbACS7/MbACO13 module	promoting postharvest fruit ripening	[36]
Loquat (<i>Eriobotrya japonica</i>)	ETH	antagonistic	lowered respiration and ETH production	delaying postharvest ripening	[97]
Eggplant (<i>Solanum melongena</i>)	ETH	antagonistic	depressed ETH production	delaying postharvest ripening	[68]

Plum (<i>Prunus salicina</i>)	ETH	antagonistic	reduced ETH production, respiration rate, and softening	delaying postharvest ripening	[108]
Apple (<i>Malus pumila</i>)	ETH	synergistic	upregulated most ETH biosynthetic and signaling genes	promoting postharvest fruit ripening	[22]
Tomato (<i>Solanum lycopersicum</i>)	ETH	synergistic	enhanced the activities and expression levels of ACS and ACO	promoting postharvest fruit ripening	[27]
Cantaloupe (<i>Cucumis melo</i>)	SA	synergistic	improved the superior quality performance	improving postharvest fruit quality	[41]
Blackberry (<i>Rubus</i>)	SA	synergistic	enhanced antioxidant capacity and flavonoid and phenol compound synthesis	improving postharvest fruit quality	[42]
Dragonfruit (<i>Hylocerus</i>)	SA	synergistic	enhanced the betacyanin content and antioxidant activity	alleviating chilling injury	[109]
Lemon (<i>Citrus limon</i>)	SA	synergistic	activated the key enzyme regulating the shikimic acid pathway; inhibited the activity of POD and PPO	alleviating chilling injury	[59]
Apricot (<i>Prunus armeniaca</i>)	SA	synergistic	reduced fruit weight loss, fruit softening, and juice pH; maintained soluble solid content and acidity	improving postharvest fruit quality	[46]
Sweet cherry (<i>Prunus avium</i>)	SA	synergistic	elevated β -1,3-glucanase and PAL activities, and enhanced POD response	inhibiting postharvest diseases	[110]
Sweet cherry (<i>Prunus avium</i>)	ABA	synergistic	reducing cracking index; increased fruit firmness and fruit color parameters	improving postharvest fruit quality	[111]
Pear (<i>Pyrus</i>)	ABA	antagonistic	inhibited anthocyanin accumulation and antioxidant enzyme (POD, CAT, APX, POD) activities	improving postharvest fruit quality	[77]
Grape (<i>Vitis vinifera</i>)	ABA	synergistic	improved the content of total anthocyanins and individual anthocyanins	improving postharvest fruit quality	[112]
Apple (<i>Malus sieversii</i>)	ABA	antagonistic	upregulated MdMYB3/9/10 and the structural genes <i>MdCHS</i> , <i>MdF3H</i> , <i>MdDFR</i> , and <i>MdUFGT</i>	improving postharvest fruit quality	[113]
Grape (<i>Vitis vinifera</i>)	ABA	synergistic	promoted anthocyanin accumulation and enhanced berry skin coloration	improving postharvest fruit quality	[114]
Date palm	MT	synergistic	increased total phenolic content and activity of peroxidase and polyphenol oxidase enzymes	improving postharvest fruit quality	[38]
Pitaya (<i>Hylocereus</i>)	MT	synergistic	enhanced the antioxidant capacity	alleviating chilling injury	[115]
Strawberry (<i>Fragaria ananassa</i>)	MT	synergistic	enhanced pH, total soluble solids (TSS), lightness and color hue	extending postharvest life	[116]
Blueberry (<i>Vaccinium virgatum</i>)	MT	synergistic	enhanced the accumulation of flavones and flavanols	improving postharvest fruit quality	[117]
Blueberry (<i>Vaccinium virgatum</i>)	MT	synergistic	promoted the accumulation of total phenols, flavonoids, anthocyanins, and lignin	inhibiting postharvest diseases	[118]
Grape (<i>Vitis vinifera</i>)	BR	antagonistic	regulated the interaction between <i>VvDWF4</i> and <i>VvTIFY 5 A</i>	promoting postharvest fruit ripening	[119]
Apple (<i>Malus domestica</i>)	BR	synergistic	increased fruit mass and the health-promoting compounds of phenolics, anthocyanins, ascorbic acid and total antioxidants	extending postharvest life	[120]
Red raspberries (<i>Rubus idaeus</i>)	auxin	antagonistic	regulated the anthocyanin metabolism	improving postharvest fruit quality	[34]
Peach (<i>Prunus persica</i>)	auxin, ETH	antagonistic	induced auxin biosynthesis and signaling pathways	delaying postharvest ripening	[121]
Grape (<i>Vitis vinifera</i>)	GR	synergistic	induced the accumulation of anthocyanins and the expression of anthocyanin-related genes; increased the levels of total soluble sugars and organic acids	improving postharvest fruit quality	[122]

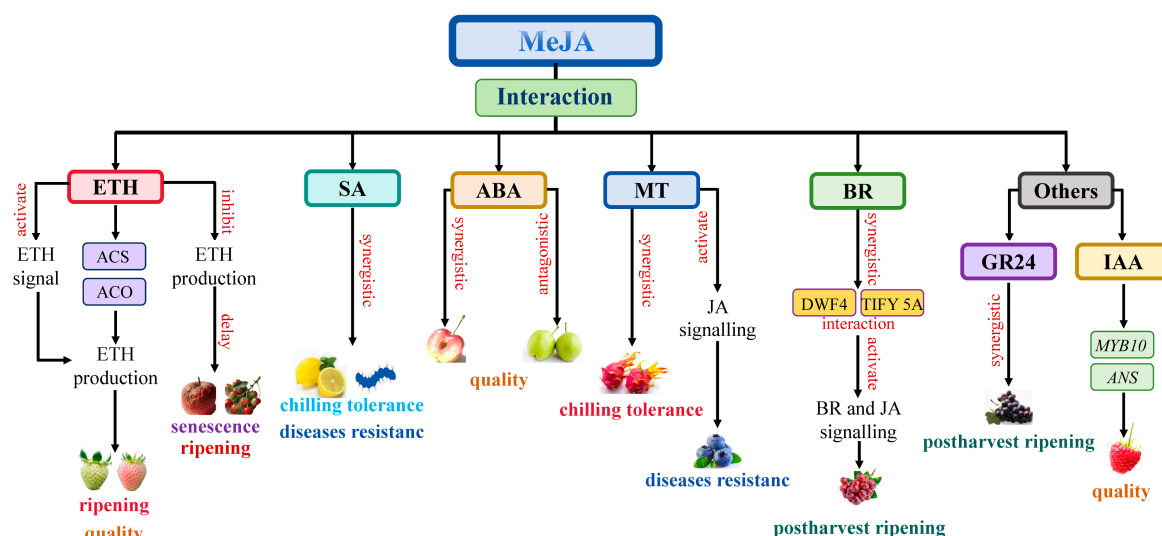


Figure 3. The model of crosstalk between MeJA and phytohormones in improving postharvest fruit quality. ETH, ethylene; ACS and ACO, ETH biosynthetic enzymes; SA, salicylic acid; MT, melatonin; BR, brassinosteroids; ABA, abscisic acid; DWF4, a key enzyme regulating the endogenous BR biosynthetic; TIFY 5 A, belonging to the jasmonate ZIM-domain family; MYB10, a transcriptional regulator of anthocyanin pathway; ANS, anthocyanidin synthase; GR24, strigolactone analog; IAA, indole-3-acetic acid.

4.1. MeJA and Ethylene

Ethylene (ETH), as a vital hormone in plants, plays a significant role in regulating fruit ripening and senescence. In recent years, an increasing amount of research has explained the intricate crosstalk networks between MeJA and ETH in modulating postharvest fruit quality [76,36]. First, many studies have pointed out that MeJA could positively modulate ETH production or accelerate its biosynthesis to affect fruit ripening. In the ripening of *Fragaria chiloensis* fruit, MeJA treatment upregulated ETH biosynthesis genes ACS and ACO, thereby partly accelerating *Fragaria chiloensis* fruit ripening by inducing ETH production [25]. Similarly, the activities of ETH biosynthetic enzymes ACS and ACO and the content of ACC increased in MeJA-treated Japanese plum, which further promotes the ripening and improves quality of Japanese plum [107]. In addition, exogenous application of MeJA promoted biosynthesis of ETH and aroma-volatile compounds, thereby inducing mango fruit ripening [26]. Recently, Li et al. found that the MeJA-responsive *Ma14-3-3e-MabHLH130-MbACS7/MbACO13* module induced ETH biosynthesis and accelerated bananas fruit ripening [36]. To sum up, these results explain an interrelationship for MeJA-induced ETH production, thus promoting fruit ripening. However, the reports regarding the effect of MeJA on ETH biosynthesis in fruits are slightly contradictory across different studies. Cao et al. reported that MeJA can improve the quality and functional properties of harvested loquat fruit by maintaining a higher level of antioxidants and lower levels of ETH production [71]. Similarly, 5 mM MeJA treatment depressed ETH production and effectively delayed the senescence of non-climacteric eggplant (*Solanum melongena* L.) fruit [67]. Therefore, this reveals a negative linear relationship between MeJA and ETH production in improving the quality and delaying senescence of fruit. However, the reported effects of MeJA on ETH production are inconsistent among studies. MeJA reduced ETH production and delayed senescence in loquat and eggplant fruit, whereas preharvest treatment with 2.0 mM MeJA accelerated maturation in two plum cultivars, while 0.5 mM MeJA delayed postharvest ripening by reducing ETH production, respiration rate, and softening [123]. Similarly, postharvest treatment with 1 and 5 mM MeJA-enhanced aroma-volatile accumulation in normally harvested ‘Nanguoli’ pears but showed no comparable

effect in early-harvested fruit [33]. Nevertheless, field applications above 10 mM have been reported to cause unacceptable leaf abscission in citrus [108]. These observations suggest that both the efficacy and potential adverse effects of MeJA depend on the concentration, fruit species, cultivar, maturity stage, application method, and storage conditions, and may reflect a potential biphasic, hormesis-like response. Therefore, crop-specific dose–response studies, together with assessments of residue behavior, sensory quality, economic feasibility, consumer acceptance, regulatory compliance, and scalability, are required before widespread commercial application. It is worth noting that some studies have found that the interaction between MeJA and ETH is manifested not only in the regulation of ETH biosynthesis, but also in ETH signal transduction pathways. Lv et al. indicated that the expression of genes involved in the ETH biosynthesis and signaling pathway was differentially regulated by JAs during postharvest ripening of apple fruit [22]. Furthermore, the ETH production, activities, and expression levels of ACS and ACO were enhanced. Meanwhile, the expression levels of genes involved in ETH signal transduction *ETR3*, *ETR4*, *ETR6*, *ETR7*, *EIN2*, *EIL2*, *EIL3*, *EIL4*, and *ERF1* were upregulated by MeJA during tomato ripening [76]. These studies revealed that the upregulation of ETH biosynthesis, as well as the activation of ETH signal transduction, led to an increase in ETH production, response, and action in fruit. This would be one of the major mechanisms of MeJA in accelerating postharvest fruit quality.

At the molecular level, the JA signaling master regulator MYC2 directly binds to the promoters of ACS and ACO genes to activate ETH biosynthesis, as well as physically interacting with EIN3/EIL1 transcription factors to co-regulate ripening-related genes [22,76]. Based on the observed results, it is possible to conclude that the postharvest quality of fruits could be improved through the crosstalk between MeJA and ETH. Several studies on the interaction between MeJA and ETH have implicated shared signaling components, indicating that the relationship is one of signaling crosstalk rather than a simple additive effect. On the one hand, MeJA can promote or inhibit the production of ETH by regulating the activity of ETH biosynthesis enzymes. On the other hand, MeJA can activate the genes expression in ETH signaling transduction, thus affecting the transmission of ETH and response to ETH signaling (Figure 2). Although there is increasing research on the crosstalk mechanism between MeJA and ETH, the participation of mutants related to ETH biosynthesis or signaling transduction involved in this crosstalk mechanism still needs to be further elucidated.

4.2. MeJA and Salicylic Acid

Salicylic acid (SA) is an important endogenous phytohormone involved in plant growth and development. SA is widely used in postharvest fruit, which can regulate fruit ripening, quality, and postharvest senescence [124]. Typically, MeJA and SA have been widely applied as bio-regulators in pre- or postharvest applications, extending shelf life and preserving fruit quality in storage (Figure 3). The research by Minh demonstrated that the combined use of MeJA and SA at half the treatment dose resulted in a significant synergistic improvement, with almost superior quality performance of cantaloupe (*Cucumis melo* L.) fruit in comparison to either MeJA or SA at all treatment doses [41]. Meanwhile, in postharvest blackberry fruit, the MeJA, SA, and the combination of MeJA +SA treatments could delay fruit softening and improve fruit quality by enhancing antioxidant capacity and flavonoid and phenol compound synthesis and upregulating structural enzyme-encoding genes and transcription factors expressions, with MeJA + SA co-treatment having the greatest effect on fruit improvement [42]. Thus, the synergistic application of MeJA and SA represents a promising alternative to improve fruit quality, extending shelf life and enhancing chilling tolerance in cold-stored fruit. Treatment of dragon fruit (*Hylocereus polyrhizus*) with MeJA and SA enhanced the chilling resistance of fruit by improving

postharvest physicochemical properties and antioxidant activity during cold storage [109]. Similarly, co-treatment of MeJA and SA also improve chilling tolerance in cold-stored lemon fruit (*Citrus limon*), thereby improving the postharvest fruit quality of lemon [58]. In addition, during cold storage of apricot fruit, applications of 0.2 mmol/L MeJA and 2 mmol/L SA significantly reduced fruit weight loss, fruit softening, and juice pH and maintained soluble solid content and acidity, improving the fruit quality of apricot [46]. Due to the ease of application and low cost of MeJA and SA treatments, it could offer a practical way to maintain physicochemical and sensory quality parameters of apricot fruit under cold stress [46]. Notably, Yao and Tian reported that the application of signal molecules SA and MeJA, especially in preharvest applications, could significantly induce the defense resistance system against postharvest diseases in sweet cherry fruit [110]. This reveals that the application of SA and MeJA may be a useful and promising measure for controlling postharvest diseases, subsequently improving fruit quality and prolonging shelf-life period on a commercial scale. Currently, most of the evidence for MeJA-SA interaction is limited to improved physiological outcomes from combined application, which should be regarded as co-treatment effects. Mechanistically, synergistic effects of MeJA and SA on postharvest fruit quality may involve coordinated activation of antioxidant enzymes (SOD, CAT, APX) and phenylpropanoid pathway genes (PAL) [58,124]. However, due to some uncertainties in the molecular mechanism of MeJA and SA in regulating postharvest fruit quality, more studies are needed to clarify the detailed interaction mechanism between MeJA and SA during postharvest.

4.3. MeJA and Absciscic Acid

Absciscic acid (ABA) has been extensively researched owing to its unique role in diverse physiological processes and developmental stages. A growing body of studies indicated that the crosstalk between MeJA and ABA exerts an important role in the regulation of fruit ripening and quality (Figure 3). Balbontín et al. indicated that MeJA and ABA preharvest applications improve the fruit quality and enhance the cracking tolerance of non-climacteric fruit sweet cherry (*Prunus avium* L.) [111]. However, Wu et al. focused on the antagonistic interplay between MeJA and ABA in ‘Red Zaosu’ pear fruit and found that combined ABA + MeJA treatment inhibited postharvest senescence compared with individual applications, thereby compromising fruit quality improvement [77]. Notably, co-applications of ABA (600–1000 mg L⁻¹) and MeJA (0.5–1 mM) did not appear to alter the ripening progression of *rabbiteye blueberry* fruit [37]. Therefore, the divergent effects of combined ABA + MeJA applications in fruit are likely attributed to variations in plant species, ABA and MeJA concentrations, or treatment durations. In addition, the effects of ABA and MeJA on anthocyanin biosynthesis in fruit have recently been clarified. For instance, Ju et al. reported that exogenous ABA and MeJA increased the accumulation of both total and individual anthocyanins, thereby contributing to grape quality improvement [112]. Furthermore, MeJA at a concentration of 10⁻⁴ mol/L could promote anthocyanin biosynthesis in red-fleshed apple callus. ABA, by contrast, inhibited anthocyanin synthesis, yet this inhibitory effect could be effectively mitigated by MeJA [113]. These observations indicate that MeJA and ABA jointly regulate anthocyanin synthesis in fruits. Notably, postharvest MeJA vapor treatment improved skin coloration in grapes. Intriguingly, however, postharvest MeJA application was found to have no effect on the endogenous ABA content in grape berry skins [114]. Hence, these findings lay a scientific foundation for the application of ABA and MeJA in the postharvest quality management of fruits. In addition, the crosstalk between MeJA and ABA has been observed during fruit ripening and anthocyanin biosynthesis, possibly implying interactions between their signaling pathways [40,112]. However, current evidence for MeJA–ABA interaction is limited to phenotypic outcomes from combined application, and no direct signaling crosstalk

has been established. Research on the molecular mechanisms underlying the interaction between MeJA and ABA in the regulation of postharvest fruit quality remains limited, so further investigation is necessary.

4.4. MeJA and Melatonin

Melatonin (MT), an emerging phytohormone, is considered a major regulator of plant growth and stress responses [125]. Fekry et al. concluded that the dual application of MeJA + MT as a preharvest treatment effectively enhances growth of barhi date palm trees, prolongs the storability of date palm fruits, and maintains fruit quality during 4 °C storage periods [38]. Recently, in postharvest pitaya fruit, MT and MeJA treatment enhanced the antioxidant capacity, subsequently alleviating chilling injury during cold storage of pitaya fruit [115]. This reveals a simple crosstalk relationship between MeJA and MT in regulating fruit quality during postharvest cold storage. In addition, postharvest applications of MeJA and MT exert significant impacts on the quality parameters of Albion strawberries [116]. These treatments extend the shelf life of fruits during storage, thereby contributing to the understanding of postharvest management strategies. Furthermore, Zheng et al. revealed that three plant growth regulators (MeJA, MT, and BR) promote flavonoid accumulation in blueberry fruits, providing valuable implications for the cultivation of high-quality blueberries [117]. Notably, melatonin treatment enhanced the postharvest disease resistance of blueberry fruits by inducing the activation of JA signaling and phenylpropane pathways as defense responses [118], implying the signaling crossover of JA and MT in resisting the postharvest disease of fruits. Therefore, the reasonable application of MeJA and MT in postharvest storage and preservation of perishable fruits would yield higher economic benefits. However, the detailed physiological and molecular mechanisms by which the interaction of MeJA and MT improves postharvest fruit quality remain unclear. Although direct molecular links are yet to be fully established, current evidence indicates that MT can enhance postharvest fruit resistance by mediating the JA signaling pathway and activating the antioxidant system, with MeJA potentially acting as a synergistic partner in these processes [115,118]. Therefore, the MeJA–MT relationship currently falls into the category of co-treatment effects, requiring future dissection of whether they share common downstream signaling nodes.

4.5. MeJA and Brassinosteroids

Brassinosteroids (BRs) exert a wide range of functions during crop growth stages, such as promoting cell expansion and division, facilitating color development, regulating phenolic compound biosynthesis, enhancing photosynthetic processes, and influencing fruit maturation, growth, ripening, as well as postharvest aging [126]. A recent study showed that MeJA and BR had certain protective effects on postharvest grape [119]. *DWF4*, as a key enzyme, regulates the endogenous BR biosynthetic, and *TIFY 5 A* belongs to the Jasmonate ZIM-domain (JAZ) family. The authors found that BR and MeJA promoted postharvest ripening in grape through the interaction between *VvDWF4* and *VvTIFY 5 A* [119]. This provides a new insight into the relationship between BR and JA signaling pathways during postharvest ripening of grape. In addition, Wang et al. proposed that foliar spray with EBL and MeJA during the growth season is helpful for enhancing apple fruit quality, marketability, and postharvest life [120]. Notably, researchers emphasized that the combination treatment was more effective in increasing fruit mass, compounds of phenolics, anthocyanins, ascorbic acid, and total antioxidants, and reducing postharvest breakdown susceptibility [120]. Asgari et al. noted that 200 µM MeJA treatment improved ascorbic acid, total anthocyanin contents, and total antioxidant activity in strawberries fruit, whereas EBR had no significant effect on the studied characteristics, except for fruit weight [127]. These findings indicate that preharvest whole-plant

spraying of MeJA promisingly improved the commercial quality and nutritional value of strawberries compared to BR. Therefore, according to the above conclusions, we can further speculate that MeJA may interact with BR to improve ripening and postharvest fruit quality (Figure 3). However, apart from the reported VvDWF4-VvTIFY5A interaction in grape, the molecular mechanisms of BR-MeJA crosstalk in most fruits remain poorly understood [119,120].

4.6. MeJA and Other Phytohormone

In addition to its involvement with the aforementioned phytohormones, MeJA also interacts with other hormones to regulate fruit quality and delay postharvest senescence (Figure 3; Table 2). There is evidence that indole-3-acetic acid (IAA) and MeJA are related to flavonoids levels in red raspberries. Moro et al. found that preceding anthocyanin accumulation, the MeJA-treated fruit developed an intense red color within 2 days of harvest, coinciding with upregulated expression of key anthocyanin pathway genes *MYB10* (a transcriptional regulator of anthocyanin pathway), *ANS* (anthocyanidin synthase), and *DFR* (dihydroflavonol 4-reductase) [34]. Five days after harvest, IAA-treated fruit exhibited lower anthocyanin and total phenolic content, which was related to the inhibition of *MYB10* and *ANS* transcription. These observations suggest that postharvest IAA and MeJA may differentially influence anthocyanin metabolism in red raspberry through changes in *MYB10* and *ANS* expression [34]. However, the concerted actions of IAA and MeJA on other processes involved in red raspberry ripening need to be investigated. Soto et al. found that the transient slowing down of ripening to peach fruit induced by exogenous MeJA was associated with an interference with genes involved in auxin biosynthesis and signaling pathways [127]. Thus, this confirms that MeJA is suitable for regulating fruit ripening, and this mechanism likely implies a crosstalk with auxin. Ju et al. investigated the effects of exogenous strigolactone and MeJA on grape quality [121] and found that co-treatment with GR24 (a strigolactone analog) and MeJA accelerated fruit ripening and coloration. It induced the accumulation of anthocyanins and expression of anthocyanin-related genes, increased the levels of total soluble sugars and organic acids, and promoted the accumulation of volatile compounds, ultimately improving the quality of red wine grapes [122]. Based on this, we can assume that MeJA and strigolactone/auxin may have synergistic effects on regulating postharvest fruit ripening and quality improvement, thereby prolonging the freshness of postharvest fruit (Figure 3; Table 2). Nevertheless, this needs to be further confirmed in subsequent studies.

5. Concluding Remarks and Future Perspectives

In recent years, the application of exogenous signaling molecules in the modulation of postharvest fruit quality has facilitated our understanding of regulatory networks and molecular mechanisms governing the postharvest physiological processes of fruits. A longstanding and prominent challenge in postharvest fruit management lies in the fact that inherent perishability and rapid senescence during storage result in impaired taste and nutrients. Accordingly, research endeavors have centered on the regulation of postharvest fruit quality and the development of preventive preservation technologies. MeJA, a key plant growth regulator in the jasmonate family, has emerged as a promising tool for maintaining postharvest fruit quality. Based on extensive data, this review elucidated the applications of MeJA in improving the quality of postharvest fruit and discussed its crosstalk mechanisms with other phytohormones (Figure 4). In terms of available data, we conclude that exogenous MeJA treatment can regulate fruit ripening, improve postharvest fruit quality, alleviate fruit chilling injury, and control fruit postharvest diseases (Figures 1 and 4; Table 1). Further, this review indicated that exogenous treatment with MeJA improved the storage quality of postharvest fruit through the following mechanisms: (1)

inducing endogenous JA biosynthesis; (2) mediating JA signaling transduction; (3) enhancing antioxidant capacity; (4) inducing the defense system; (5) regulating sucrose metabolism; and (6) modulating energy metabolism (Figures 2 and 4; Table 2). Accordingly, this research may be a viable strategy, potentially offering scientific guidance for postharvest fruit preservation to address our agricultural requirements in the future. Although substantial progress has been made in understanding the role of MeJA in postharvest fruit preservation, several important questions remain unresolved. The effects of mutations in key JA biosynthetic genes, such as *LOX*, *AOS*, and *OPR3*, on fruit quality and stress responses during storage remain poorly understood, while the regulatory functions of JA signaling components and transcriptional regulators, including *COI1* and *JAZ* proteins, require further investigation. Future studies should also clarify how responses to MeJA vary among fruit species and cultivars, treatment doses, maturity stages, and storage conditions. In particular, excessive or inappropriate MeJA treatment may cause phytotoxicity, abnormal ripening, or undesirable changes in fruit flavor and quality. Before large-scale commercial application, further research is needed to optimize treatment concentration and duration and to evaluate production costs, scalability, residue levels, food safety, consumer acceptance, and regulatory requirements. Large-scale trials and standardized application protocols are therefore essential for assessing the commercial feasibility of MeJA-based preservation technologies. In addition, integrating multi-omics approaches with precision postharvest technologies may deepen the understanding of MeJA-mediated regulatory networks and facilitate its safe and effective application in fruit storage.

Currently, the crosstalk between MeJA and phytohormones (such as ETH, SA, ABA, MT, BR, auxin, and strigolactone) in postharvest fruit has attracted extensive scholarly attention (Figures 3 and 4; Table 2). MeJA can promote or inhibit the production of ETH and activate ETH signaling transduction, thus responding to ETH signaling, which further affects fruit ripening process and postharvest fruit quality. Combined application of MeJA and SA/ABA/melatonin might also be a useful and promising measure for the improvement of postharvest fruit quality during storage. The relationship between BR and JA signaling pathways is helpful for postharvest ripening of fruit. Although the interrelationship between MeJA and various phytohormones has been shown to regulate postharvest fruit quality, crosstalk, with the exception of ETH, is largely confined to the co-treatment effects of hormonal signals and the influence of MeJA on the synthesis or signaling activation of other phytohormones is rarely involved. Therefore, for both preharvest and postharvest MeJA treatments in fruits, more studies are necessary in order to clarify the intricate crosstalk network of MeJA-phytohormones, particularly regarding the crosstalk within phytohormonal signaling pathways. Furthermore, studies investigating the crosstalk between MeJA and specific phytohormones, such as auxins and strigolactones, in postharvest fruits remain relatively scarce, and this therefore requires further elucidation.

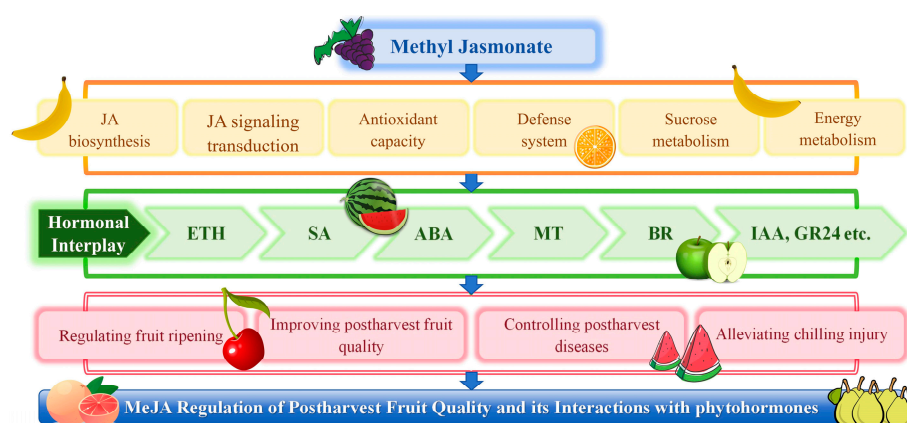


Figure 4. The integrative model of MeJA regulation of postharvest fruit quality and its interactions with phytohormones. MeJA regulates postharvest fruit quality through JA biosynthesis, JA signaling transduction, antioxidant capacity, defense system activation, sucrose metabolism, and energy metabolism, thereby contributing to the regulation of fruit ripening, improvement of postharvest quality, control of postharvest diseases, and alleviation of chilling injury. MeJA, methyl jasmonate; JA, jasmonic acid/jasmonate; ETH, ethylene; SA, salicylic acid; ABA, abscisic acid; MT, melatonin; BR, brassinosteroids; IAA, indole-3-acetic acid; GR24, strigolactone analog.

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