

Role of Jasmonic Acid In Modern Fruit Production- A Review

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Abstract

Jasmonic acid and its derivatives are collectively called “jasmonates” are naturally occurring regulators involved in the tree growth and development. The endogenous and exogenous effects varied and involved in the induction of plant defense mechanisms for both biotic and abiotic stresses, chilling injuries and fruit ripening. Jasmonates are widely used to improve the postharvest storage life, decay loss and defensive mechanism against postharvest diseases of many tropical and subtropical fruits. This review summarises the various application of jasmonates and derivatives on growth, physiology, protection from stresses in modern fruit production.

Keywords: Jamonates, Growth, Fruit crops, Post harvest management

Abbreviations: JA: Jasmonic acid, MeJA: Methyl jasmonates, PDJ : n-propyl dihydrojasmonate, LOX : Lipoxygenase, AOS: Allene oxide syntase, AOC: Allene oxide cyclise, ACS1 : Acetyl-coenzyme A synthetase 1, ACO1: Aminocyclopropanecarboxylate Oxidase 1.

Introduction: MeJA was identified as an essential oil component, first discovered in 1962 from flower (*Jasmonium grandiflorum* L.) extracts (Demole *et al.*, 1962) and now reported in several plant species (Hamberg and Gardner, 1992), while the JA extracted by filtration of fungal culture. In earlier studies of the exogenous application was found to promote senescence, but in recent studies revealed that JA was specifically used to alter the gene expression and also plays a role in plant defense mechanism. In this review revealed the commercial application of JA and JA based compound in modern fruit production. JA plays a role in growth, fruit development, fruit ripening, tendril coiling, pollen viability, post-harvest

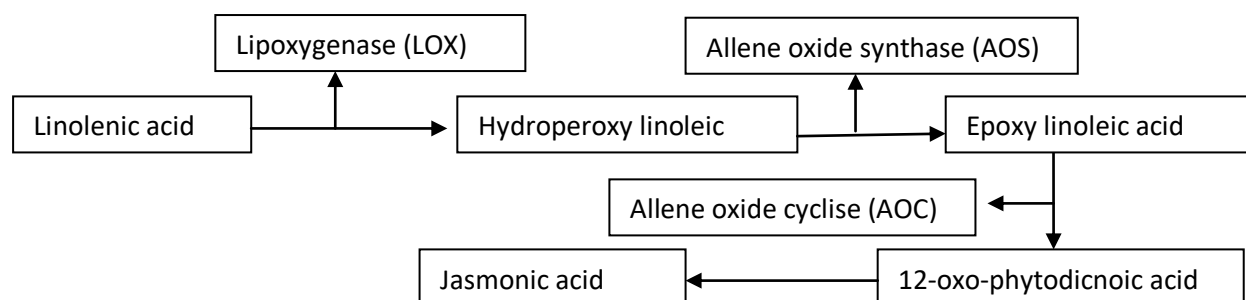
management, notorious pathogen and insect resistance in fruit crops (Creelman and mullet, 1997, Pena-Cortes, *et al.*, 2005).

Jasmonic acid is a stress hormone actively involved in growth and developmental processes. It actively involved in the stomatal movement (opening), defensive action against weather-based stresses by expressing stress-mediated genes. Biotic and abiotic stress tolerance/resistance in fruit crops is observed by the application or signaling of JAs or JA mediated hormones (Ruan, *et al.*, 2019). In this review discussed the various aspects of JAs synthesis pathway in fruit trees, resistance/tolerance to various pathogens, chilling injury, applications in fruit production and post-harvest management aspects.

Jasmonic acid synthesis in fruit crops

Basically, jasmonic acid is a naturally occurring lipid involving in plant growth regulation, fruit development, fruit ripening, leaf senescence and abscission (Zheng *et al.*, 2017). Jasmonates (JA and MeJA) are basically derived from linolenic acid compounds and n-propyl dihydrojasmonate (PDJ) is a derivative of jasmonic acid (Kondo *et al.*, 2007). The jasmonic acid biosynthesis, metabolism, transport, and accumulation in plants are detailed was reviewed (Guan-Zhu, 2017, Ruan, *et al.*, 2019). The level of JA and JA derivatives in fruit trees varies as a function of tissue and cell type, developmental stage, and in response to several different environmental stimuli. The several authors studied and reviewed the physiological and molecular aspects, signaling pathways of jasmonates in plants (Guan-Zhu, 2017, Ruan, *et al.*, 2019) but in this review focused on the commercial applications of JAs on fruit productions.

The jasmonic acid synthesis pathway in fruits (Kondo, 2010), polyunsaturated fatty acids (free linolenic acid) are the beginner of JAs biosynthesis (Feussner and Wasternack, 2002), it's also known as Vick and Zimmermann pathway (Schaller *et al.*, 2004). These fatty acids are converted to JAs by involving series of enzymes viz., Lipoxygenase (LOX), Allene oxide synthase (AOS) and Allene oxide cyclase (AOC) (for more details refer Kondo, 2010, Yan, *et al.*, 2013).

Figure 1. Jasmonic acid pathway (Kondo, 2010)

Application of jasmonates in modern fruit production

The jasmonic acid application to plants may cause changes in transcription, translation and mRNA populations (Sembdner and Parthier, 1993). But the effect of exogenous application of JAs and its derivatives studies on fruits is varied scanty. Interaction between other plant regulators and jasmonates assignments make a complicated physiological role in plants. JAs and its derivatives are influenced by various physiological processes of the plants viz., tolerance to biotic and abiotic stresses, leaf senescence, seed germination and ripening of fruits (Cherian *et al.*, 2014). This review summarises the various responses of JAs on major fruit crops.

Temperate fruit crops

Jasmonates and its derivatives stimulate the germination (by lipid peroxidation) of dormant seeds in many fruits (Dave *et al.*, 2011), and it was enhance the seed germination by lipid peroxidation causes membrane damage in fruit seeds (Ranjan and Lewak, 1992). In apple, Jasmonic acid derivatives stimulate the dormant embryos germination by lipase activation (Ranjan and Lewak, 1992). Jasmonic acid derivative (n-Propyl dihydrojasmonate) applications at 0.39 mM (100 mg L⁻¹) on apple fruit on tree 20-30 days before harvesting promote the fruit coloration (Kondo, 2010). Jasmonate derivatives regulate the ethylene synthesis. In Jonagold apples, MJ application has increased the production of CO₂ and inhibit ethylene biosynthesis activity (Miszczak *et al.*, 1995). The apple and pear fruits treatments by PDJ at preclimacteric stage increase the synthesis of ACS1 and ACO1 genes in the skin of fruits. But at the climacteric stage ACS1 mRNA accumulation was found to decrease in the skin of treated fruits (Kondo, 2010). The application of MeJA at 10 mM, 3 weeks before commercial harvesting increases the anthocyanin content in 'Hanfu' apple fruits (Liu, *et al.* 2018), in Cripps Pink' apple cultivar (Shafiq, *et al.* 2011), in apple cv. 'Fuji' peel (Rudell

and Mattheis, 2008). In apple, frost damage is more common at a temperature less than -2°C and fruits are sensitive to chilling. By the application of PDJ frost damage can be reduced by 14 to 10% (Yoshikawa *et al.*, 2007), and also stimulate the downstream enzyme in anthocyanin synthesis by increased transcription levels of UFGluT in apple fruit skin (Kondo, 2010). PDJ has greater stability under field conditions as compared with MeJA (Kondo, *et al.* 2007).

Several scientist and researchers reported the involvement of JAs in non-climacteric and climacteric fruit species viz, sweet cherry growth and ripening. In temperate fruits (apple, sweet cherry, and peach) the elevated level of JA was reported during the early stage of fruit development (Alkio *et al.*, 2012). Lower rate of fungal infestation in cheery fruits was reported by the application of MeJA (Wang *et al.* 2015). While Saracoglu *et al.* (2017) were reported that the increase in fruit firmness by the post-harvest application of MeJA at the last stage of fruit development of different cherry varieties.

Jasmonate improves the fruit color of several fruits by the degradation of chlorophyll pigments and promoting the synthesis of anthocyanins viz., preharvest applications of MeJA induce pigments developments in apple and strawberry (Rudell *et al.*, 2005; Concha *et al.*, 2013). JAs are responsible for strawberry (*Fragaria × ananassa* Duch. cv. Aromas) fruit ripening (Garrido-Bigotes, 2017). Further, few scientists reported that doesn't change the TA or SSC/TA ratio by the application of MeJA, but in peach and sweet cherry at fruit set stages found decreased in the TSS/TA ratio (Ziosi *et al.*, 2008; Saracoglu *et al.*, 2017). Delayed fruit ripening of peach fruits by affecting fruit ripening associated gene expression was reported by the application of MeJA (Ruiz *et al.*, 2013).

The jasmonic acid role on developing strawberry fruits was not understood completely in strawberry fruit development. The level of MeJA was found to decrease from immature to ripe fruits (Gansser and others 1997) of strawberry and in grapes (Böttcher, *et al.*, 2015). During strawberry fruit ripening ABA level was found increased in various cultivars (Jia, *et al.*, 2011, Symons *et al.*, 2012). MeJA induced an increase in anthocyanin accumulation and ABA and JA-Ile levels were found decreased respectively (Adrián, *et al.*, 2018). Endogenous JA accumulation of fruit and seeds during the early ripening stage of apples (*Malus sylvestris*) and sweet cherries (*Prunus avium*) and it also plays an important role in fruit and seed development (Kondo *et al.*, 2000). Application of MJ at post-harvest to plum cultivars accelerates ethylene synthesis, ascorbic acid synthesis, total carotenoids and

antioxidants (Khan and Singh, 2007), maintaining sensory qualities and also prolonged cold storability and shelf life period of avocado fruits (Ezzat., *et al.*, 2017).

Tropical and subtropical fruits

In mango, MJ applications prevent chilling injury symptoms without altering the ripening process (González-Aguilar, *et al.*, 2000). The 'Kensington Pride' mangoes are treated with MeJA at climacteric stage reported with improved in skin color, total aroma volatile, fatty acids and reduce the production of n-tetradecane and promote fruit ripening by ethylene biosynthesis (Lalel *et al.*, 2015). The MeJA fumigation on mango fruits at low-temperature condition has reported with increase in β -carotene content, and no improvement in color change, stem-end rot and anthracnose severity were observed (Boonyarittongchai, *et al.*, 2017). The MJ application at 1 and 10 $\mu\text{mol}\cdot\text{L}^{-1}$ on 'Kumagai' guavas influence on fruit ripening (Silva, *et al.*, 2017). JA induces tendril coiling in grapevine (Malabarba, *et al.*, 2018). Reduced chilling application of methyl jasmonate, can reduce chilling injury in stored grapefruit and avocado (Meir, *et al.*, 1996). Increase in the resveratrol accumulation by the application of MeJA in *Vitis vinifera* and strawberry (Belhadj *et al.*, 2006 and Wang *et al.*, 2007). Many scientists reported the commercial importance of postharvest quality improvement in fruits. As the MJ and its derivatives are the natural derivatives so no restrictions on its usage in fruit production. In grapes seeded berries have reported higher concentration of JA and MeJA at initial period of fruit development (Kondo and Fukuda, 2001).

In Citrus, MJ application (at 10, 20, and 100 mM) on Hamlin and Valencia oranges induce fruit abscissions, its helps for mechanical harvesting i.e. easy the detachment of fruits from the tree (Hartmond, *et al.*, 2000). Application of MJ at higher concentration accelerates severely leaf abscissions and cause phytotoxicity in floral tissues. The application of methyl jasmonate and salicylic acid develop tolerance against chilling injury by the accumulation of reactive oxygen species (ROS) and it also lowered the membrane lipid peroxidation, increase in lemon flavedo antioxidant activity and enhance the shelf life of fruits (Siboza and Bertling, 2015). Jasmonate derivatives are actively involved in the regulation of many processes, a pre-harvest spray of methyl jasmonate was found increased in antioxidants without affecting fruit quality parameters and yield parameters of lemon fruits (Serna-Escolano, *et al.*, 2019). In grape berries, preharvest application of MeJA (0.1 mM or 0.01 mM) change the endogenous hormone levels; reduced the C6 compounds viz., hexanol,

(Z)-3-hexenol, (E)-2-hexenol, hexanal and (E)-2-hexena and accelerate the production of nerol, linalool, alpha-terpineol etc (Wang, *et al.* 2017).

Improved chilling stress tolerance and fruit quality was reported by exogenous application of MeJA without affecting the process of fruit ripening in mango (*Mangifera indica*) (Gonzalez-Aguilar *et al.*, 2000). In Citrus, degreening is followed to increase infirmity in color, ethylene is most commonly used for that but now it has been proved that JA is an alternative degreening agent for mandarin fruits (Gómez, *et al.* 2017). The application of jasmonates and its derivatives involved in the reduction of post-harvest diseases, decay losses and enhanced shelf life in tropical, subtropical and temperate fruits reported by various scientists viz., Grapevine inhibition of *Erysiphe necator* (Belhadj *et al.* 2006a) and *Botrytis cinerea* (Wang *et al.* 2015), papaya post-harvest *Colletotrichum gloeosporioides* (González-Aguilar *et al.* 2004), *Colletotrichum acutatum* in loquat (Cao *et al.* 2009), *Monilinia fructicola* in sweet cherry and peach (Yao and Tian, 2005a, Yao and Tian, 2005b).

Role of jasmonates in biotic and abiotic stresses

Jasmonates (JAs) and methyl jasmonates (MeJAs) are involved in various growth, development and physiological processes. Exogenous application on fruits builds defensive action against biotic (fungal and bacterial pathogens) and abiotic stresses (drought, salinity and temperature conditions (Ahmad, *et al.*, 2016). Exogenous application of JA (50 mmol m^{-3}) in grafted *Pyrus bretschneideri* Redh speed up the level of glycine betaine, enhance the BADH enzyme activity and BADH proteins underwater deficit conditions (Gao *et al.*, 2004). Jasmonates and its derivatives tested on various biotic and abiotic stresses have been proved on different fruit crops. The treatment of PDJ acts defensive mechanism against environmental stress and also reduced the apple splitting and spotting caused by low temperature (Kondo, 2010). PDJ reduced the rate of transpiration by leaf stomatal closure in citrus.

Depending on kinds of stress or plants, gene reaction against stress varied. In preclimacteric stage, PDJ treated fruits showed accelerated ACC synthase activity, ACC oxidase activity, ACC concentration, and ethylene production. An increase in endogenous jasmonates accelerate the production of ethylene in system 2, including ACC oxidase and ACC synthase (Kondo, *et al.*, 2007). The exogenous JA-Me stimulates β -carotene

content in apples, banana, guava, and mango. It has found effective in reducing deterioration and chilling injury in tropical fruits such as avocados, grapefruits, guava, mangoes, etc and also it has found an increase in shelf life and reduces microbial contamination of pineapple fruits (Saniewski, *et al.*, 2010). The post-harvest application of JA-Me was effective in reducing post-harvest decay in berries and peach and also, reduce the post-harvest contamination of cut pineapples, reduced green mold (*Penicillium* spp.) of grapefruits during storage (Martínez-Ferrer and Harper, 2005, Droby *et al.*, 1999). JA application in grapes gives a defensive mechanism against biotrophic pathogens viz., powdery mildew and downy mildew (Guerreiro, *et al.*, 2016).

Chilling injury is a major issue in tropical and subtropical fruit production. The injury was reduced by the application of MeJA treatments in mango (cv. Tommy Atkins, Kent, Zill) (González-Aguilar, *et al.*, 2000, González-Aguilar, *et al.*, 2003), also reported in loquat (*Eriobotrya japonica* L.), pomegranate (*Punica granatum*), peach (*Prunus persica* L.) and guava (*Psidium guajava*) (González-Aguilar, *et al.* 2004, Meng *et al.* 2009)

In Cherry, rain-induced fruit cracking is a major problem in the cherry production and its occurrence cause significant economic losses. Sweet cherry (*Prunus avium* L.) fruits are affected by both abscisic acid (ABA) and methyl jasmonate (MeJA) during fruit development (Balbontín, *et al.*, 2018); this cracking was effectively controlled by the application of ABA and/ or MeJA application (Balbontín, *et al.* 2018). MJ has influenced defense mechanism against pathogens, the application of 1 and 10 $\mu\text{mol}\cdot\text{L}^{-1}$ did not show any control of anthracnose in 'Kumagai' guavas (Silva, *et al.* 2017). In Grapevine (*Vitis vinifera* L.), 'Bois noir' is an important phytoplasma disease common during late summer condition, it has been reported that defensive responses of MJ mediated responsive gene expression against *Bois noir* diseases (Paolacci, *et al.* 2017). Exogenous applications of MeJA (10^{-4} M) reduces ion leakage in mango tissues and accelerate the chilling tolerance (Gonzalez-Aguilar, *et al.* 2000). Similarly in pear, foliar application of JA (50 mmolm^{-3}) act as a defensive mechanism against drought stress by enhanced glycine betaine level, BADH activities, and BADH protein content (Gao, *et al.* 2004)

Conclusions

Jasmonic acid and its derivatives are the natural hormones commercially used in modern fruit production. Most of the fruit crops jasmonate derivatives accelerate defensive

mechanisms against various biotic and abiotic stresses, chilling injury and post-harvest management. It's applied as a pre-and post-harvest treatment and it enhances the production of secondary metabolite (antioxidants, phenolic acid, flavonoids, and anthocyanins). Apart from this also involved in protection from post-harvest fungal diseases, frost, and insect attacks, etc. It is an urgent need to study the jasmonates and derivatives or in combination with other growth regulators on growth, physiology, protection from stresses in modern fruit production.

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