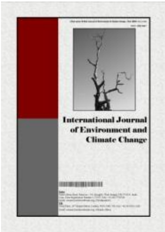

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Pre- and Post-harvest Salicylic Acid Application Improves Plant Growth, Fruit Quality and Storability of Pear- A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AA and KR created Conceptualization. Authors AA and KR wrote-original draft preparation. Authors AA, KR, NAG and AHW wrote-review and editing. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Pears (*Pyrus spp*.) are important fruit of the temperate and sub-temperate zone worldwide commercially cultivated for its delicate flavour and smooth texture. Although several other species are grown on a large scale, *Pyrus communis* and *P. pyrifolia* are the two most important commercial pear species. Salicylic acid (SA) is a naturally occurring phenolic compound that is widely distributed in plants and is thought to be a hormone due to its regulatory role in plants. Salicylic acid as plant growth regulator has attracted a lot of attention because of its role in modulating plant responses particularly the biotic and abiotic stresses. Salicylic acid application in pear has the potential to improve plant performance and yield, reduce chilling injury, postharvest diseases and decay, and preserve fruit quality after harvest during storage. Further research in larger perspectives is needed to validate the predictors' reliability in production and postharvest management of pear.

Keywords: Fruit quality; growth regulator; pyrus spp.; salicylic acid.

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1. INTRODUCTION

Pears (*Pyrus spp.*) are typical fruit of temperate climate with a delicate pleasant taste and smooth texture. Several pear species are thought to have evolved during the Tertiary period in Western China's mountainous regions, and dispersal and speciation are thought to have followed the mountain chains both east and west [1,2]. The most important commercial pear species grown are *Pyrus communis* and *P. pyrifolia*, though several other species are grown on a large scale [3]. In 2018, global pear production was 23.2 Mt, with 1.3 million ha under cultivation. China leads in production, followed by the United States and Italy, with India ranking among the top ten [4]. Pears are grown in wide range of climatic conditions and can tolerate as low as -26^{0}C in dormancy and as high as 45^{0}C during growing period and a large number of pear cultivars require about 1200 hours below 7^{0}C during winter to complete their chilling requirements in order to flower and fruit satisfactorily [5]. In India, it is primarily grown in Jammu and Kashmir, Himachal Pradesh, Punjab, Tamil Nadu, and, on a smaller scale, subtropical areas of the Northern region. In the recast past decades, several semi-dwarfing pear rootstocks with improved precocity have become available, and techniques for managing tree growth have been developed, allowing for the evaluation of high density pear.

Plant growth regulators have extensively been widely used in fruit production and post-harvest management. Plants produce naturally occurring molecules called phytohormones, which play a role in controlling plant growth and are complex chemical regulators of plant growth. When these compounds are synthesised, they are referred to as plant growth regulators (PGRs) [6-8]. Some of the most well-known PGRs used in fruit production are auxins, gibbrellins, cytokinins, ethylene, and abscisic acid, which have proven to be valuable partners in the quest to increase productivity while improving commercial quality and postharvest storability of fruits. Plant growth regulators have also been reported to regulate or manipulate fruit set, yield, and fruit quality in pear [9-10]. Besides classical plant growth regulators, several new generation PGRs, such as Salicylic acid (SA), Brassinosteroids (BR), Jasmonate (JA), and other compounds, have emerged in recent decades to play important roles in plant processes.

2. SALICYLIC ACID

Salicylic acid is a phenolic compound that, despite its widespread distribution in plants, has widely differing basal levels among species [11]. To synthesise SA, plants are thought to have both an isochorismate synthase (ICS) and a phenylalanine ammonia-lyase (PAL) pathway [12]. It is widely assumed that SA is a natural derivative of cinnamic acid, an intermediate in the shikmic acid pathway involved in phenolic compound synthesis, and that plants have both an isochorismate synthase (ICS) and a phenylalanine ammonia-lyase (PAL) pathway for SA synthesis [12,13]. The importance of both pathways for biosynthesis varies between plant species, making it difficult to make broad statements about SA production that apply to the entire plant kingdom. Although plants use both biosynthetic pathways at the same time, ICS is the major pathway, accounting for more than 90% of SA synthesis [14,15]. Also, a wide range of bacterial genera have been found to synthesise SA or its related metabolites, most notably plant-growth-promoting *Rhizobacteria* [16].

Salicylic acid has received a lot of attention recently because it regulates the expression of different modalities in plant responses to biological activities [16-18], as well as abiotic stressors [13,19,20]. SA has been linked to a variety of plant physiological and biochemical processes such as growth, flowering, thermogenesis, and senescence [21,22]. It also has a significant impact on fruit quality, membrane permeability, and specific enzyme activities [23]. Endogenous SA levels and resistance responses to biotrophic and hemibiotrophic diseases are well established [24].

Due to its key role in photosynthesis, plant water relations, various enzyme activities, and plants exposed to various biotic and abiotic stresses; exogenous application of salicylic acid has been shown to be beneficial to crop growth and biological productivity under constantly changing environmental conditions [13]. In several plant species, SA treatment causes both local and systemic acquired resistance to a variety of diseases [25]. SA is a plant hormone that aids in the defence of plants against a variety of microbial diseases such as viruses, bacteria, fungi, and oomycetes [25,26]. Salicylic acid can be used both before and after harvest to improve the nutritional quality of fruits and extend their shelf life. It has been widely used to increase storage/shelf life and improve quality in a variety of fruit crops [27,28]. It could be used postharvest to reduce freezing injury and degradation, postpone ripening, and increase antioxidant capacity in fruits and vegetables to increase their health benefits [29].

3. ROLE OF SALICYLIC ACID IN PEAR

3.1 Gene Signalling and Expression

The transcriptional levels of anthocyanin biosynthesis genes in Wujiuxiang pears during developmental ripening and temperature-induced storage were studied by [30]. The expression of genes encoding flavanone 3-hydroxylase, dihydroflavonol 4-reductase, anthocyanidin synthase, UDP-glucose: flavonoid 3-O-glucosyltransferase, and R2R3 MYB transcription factor (PcMYB10) was strongly correlated with anthocyanin accumulation in response to both developmental and cold-temperature induction. Using hierarchical clustering analysis, the expression patterns of the set of target genes were discovered, with PcMYB10 and the majority of anthocyanin biosynthesis genes belonging to the same cluster. They discovered that low temperature storage significantly increases anthocyanin biosynthesis in pears (*Pyrus communis* cv. 'Wujiuxiang'). Shi et al. [31] isolated cDNA from a pear (*Pyrus pyrifolia*) that encoded a putative 14-3-3 protein and named it Pp14-3-3a. Pp14-3-3a, they hypothesised, was involved in pear fruit ripening and senescence in response to salicylic acid and ethylene signalling.

In plant species, the activity of the key enzyme 1-aminocyclopropane-1-carboxylic acid (ACC) synthase (ACS) determines the level of ethylene. Shi and Zhang [32] isolated and named PpACS1a a gene encoding an ACC synthase protein from the pear (*Pyrus pyrifolia*), encoding a protein of 495 amino acids that shared high similarity with other pear ACC synthase proteins. Furthermore, salicylic acid (SA) and indole-3-acetic acid (IAA) regulated PpACS1a gene expression in fruit, and it was up-regulated in diseased pear fruit, implying that it may be involved in fruit ripening and response to salicylic acid, IAA, and disease.

Shi et al. [33] investigated the expression and regulation of PpEIN3b in *Pyrus pyrifolia* Nakai fruit ripening and senescence. Cv. Whangkeumbae was cloned by combining SA, glucose, and ACC signalling, and a gene encoding an EIN3 was named PpEIN3b. PpEIN3b was discovered to be preferentially expressed in fruit and to be developmentally regulated during ripening and senescence. PpEIN3b transcripts were repressed by salicylic acid (SA) in pear fruit and diseased fruit, implying that PpEIN3b may integrate SA, glucose, and ACC signalling to regulate fruit ripening and senescence in pear, providing a candidate gene for this regulation and providing a candidate gene for this regulation to obtain fruit with a long shelf life and improved economic value.

3.2 Plant Growth and Fruit Yield

Nimbolkar et al. [34] sprayed Salicylic acid (50 ppm and 100 ppm) after fruit set and two more sprays at fifteen-day intervals on Gola Pear (*Pyrus pyrifolia*). In comparison to untreated control trees, they observed increased shoot growth, number of leaves per shoot, leaf area, leaf chlorophyll content, and fruit number. Hafez et al. [35] found that spraying salicylic acid (20 ppm) on Le Conte pear trees twice (in mid-May and June) resulted in higher leaf contents of N, P, Ca, Mn, and Cu when compared to control trees sprayed with water. They advocated for the use of foliar applications of 20 ppm salicylic acid to improve the performance of the Le Conte pear in newly reclaimed soil conditions.

Three foliar applications of salicylic acid (50 ppm and 100 ppm) after fruit set, followed by two sprays at fifteen days intervals and increased the number of fruits and yield compared to untreated control trees [34]. Fayek et al. [36] discovered that three foliar applications of 200 ppm salicylic acid, combined with compost tea, increased fruit yield of the 'Le-Conte' pear.

3.3 Fruit Firmness and Weight Loss

Spraying salicylic acid (0, 0.5, 1.0, and 1.5%) on pear (*Pyrus Communis* L.) cvs. Spadona and Compote resulted in increased fruit weight and firmness compared to the control treatment [37]. According to Hafez et al. [35], Le Conte pear trees were sprayed with salicylic acid (20 ppm) twice (in the middle of May and June). Le-Conte treatment with salicylic acid (100 and 200 ppm) followed by cold storage of harvested fruits at 0^0C and 90-95 percent RH for 12 weeks and shelf-life at 22 0C for 12 days was effective in maintaining fruit quality and lowering weight loss percentages when compared to the control. Khedr [38] found that Salicylic acid at 200 ppm treatments increased fruit firmness in LeConte pear fruits. Guan et al., [39] discovered no significant effect of salicylic acid on fruit firmness. According to Adhikary et al. [40], salicylic acid-treated fruits demonstrated that SA application slowed the rate of weight loss.

Researchers have also tested the fruit quality and post-harvest quality of pear fruits using salicylic acid in combination with other materials. Fayek et al. [36] investigated the effects of compost tea, three foliar antioxidant treatments containing 1000 ppm ascorbic acid, 200 ppm thiamin, and 200 ppm salicylic acid, as well as combinations of compost tea and antioxidants, on fruit quality. When compared to soil compost application, they discovered that salicylic acid application improved fruit quality, antioxidants, ascorbic acid, and higher N, P, and K contents.

3.4 Alleviation of Chilling Injury

Low temperature storage has been the primary method used in postharvest technologies to extend shelf life and preserve fruit quality. Low-temperature storage reduces metabolic activity, including respiratory rate, and inhibits the spread of fungal infections. Chilin injury reduces fruit quality by causing irregular ripening, pitting, or browning, and if severe, the produce suffers significant deterioration, lowering its final market value. Chilling injury (CI) is a common occurrence in pear storage at low temperatures, and it is characterised by a brown spot on the fruit surface. Guan *et al*. [39] has elaborated the mechanism of chilling injury in ‘Huangguan’ pear fruit treated with Salicylic acid that 5 mM SA treatment increases the content of SA in peel, enhancement in the activities of ascorbic acid peroxidase (APX), glutathione reductase (GR) and superoxide dismutase (SOD), reduction in the accumulation of phenols in the later stage, decreasing the activity of polyphenol oxidase (PPO) before the occurrence of CI, inhibiting the expression of PPO1 and PPO5 genes in peel, and significantly down-regulating the expression of LOX1 and PLD4.

Postharvest soaking of 'Huangguan' pear with salicylic acid (5 mM and 10 mM) followed by storage at 0 ^{0}C results in a significant reduction of chilling injury index (CI) compared to the control, but no significant effect on fruit firmness, soluble solids content, or titratable acid content of the fruits [39]. They proposed that the SA treatment increases the antioxidant capacity of the peel, inhibits the degradation of cell membrane lipids, reduces the appearance of brown spots on the fruit surface, and alleviates CI during fruit cold storage.

3.5 Alleviation of Postharvest Diseases

Sprays of salicylic acid at a concentration of 2.5 mM on Ya Li pear (*Pyrus bretschneideri*) inoculated with *Penicillium expansum* at 30, 60, and 90 days after full flowering and harvested fruit at commercial maturity (about 120 days after full flowering) exhibit remarkable enhancement in resistance to the pathogen of the mature pear fruit [41]. In salicylic acid's effect on disease severity and plant defence enzymes in *Pyrus bretschneideri* cv. Yali and *Physalospora piricola,* [42] found that treating pear with 0.2 mM SA increased resistance to *P. piricola* significantly. The mechanism of pear resistance to ring rot induced by SA reveals that plant defence responses in pear leaves were induced using marker enzymes such as superoxide dismutase (SOD), peroxidase (POD), phenylalanine ammonia-lyase (PAL), polyphenol oxidases (PPO), -1,3-glucanase, and chitinase. The SA treatment increased the activities of POD, PAL, PPO, -1,3-glucanase, and chitinase in the inoculated leaves. The PR-proteins reacted quickly to pathogen infection, demonstrating that SA could induce systemic acquired resistance and boost pear's antiviral capability against *P. piricola.*

3.6 Alleviation of Browning

Khedr [38] found that salicylic acid at 200 ppm was effective in lowering the rate of decay incidence. Arshad [43] reported that postharvest treatment with salicylic acid (1.5 mM L^{-1}) in combination with calcium chloride (1.5 and 3 5%) effective in decreasing ethylene content and browning of fruit and thus increasing fruit quality during storage. According to Adhikary et al. [40], the Salicylic acid-treated fruits exhibited slower oxidation of total phenol content by inhibiting PPO action and retaining total phenolic content, resulting in a lower incidence of browning.

3.7 Postharvest Fruit Quality

Jalili and Shafaie [44] investigated the salicylic acid at 0, 1, and 2 mmol L^{-1} and in different combinations with citric acid in a concentration dependent postharvest treatment of pear cv. Sardrod fruits, followed by fruit storage at 00.5 ^{0}C for 90 days. The researchers discovered that salicylic acid (2 mmol L^{-1}) treatments had a significant effect on total phenolics, total antioxidants, total acidity, and ascorbic acid, as well as preventing fruit softening during storage. The results showed that using salicylic acid as a postharvest technology for the Pear cv. Sardrud fruit can be an effective and successful strategy. Quality of European pear cv. Sardrod fruits after postharvest treatment with salicylic acid (1 and 1.5 mM L^{-1}) in combination with calcium chloride (1.5 and 3 percent) studied by Arshad [43] post treatment storage for 30, 210, and 240 days reveals that Salicylic acid application @ 1.5 mM L^{-1} with calcium chloride @ 3 percent significantly effective in decreasing ethylene content and browning of fruit and thus increased fruit quality during storage.

Khedr [38] emphasised that a preharvest spray of salicylic acid (100 and 200 ppm) on Le-Conte pear twice at full bloom and at the initial fruit set stage was also effective in maintaining fruit quality and lowering weight loss percentages in cold storage of fruits at 0 ^{0}C and 90-95 percent RH for 12 weeks shelf-life at 22 ^{0}C for 12 days. Salicylic acid at 200 ppm was found to be useful in maintaining fruit firmness, higher h° value of fruit peel, ascorbic acid concentrations, total phenols content, and antioxidant capacity values of LeConte pear fruits. According to Adhikary et al. [40] salicylic acid treated fruits demonstrated that SA application reduced the rate of weight loss and respiration while maintaining ascorbic acid content, total soluble solids, titratable acidity, ascorbic acid, and pH.

4. CONCLUSION

Pear (*Pyrus* sp.*)* is an important fruit of temperate and sub-temperate regions of the world. Some classical plant growth regulators, such as auxin, gibberellin, and cytokinin, have been widely used in pear production; however, in recent years, salicylic acid has received considerable attention due to its regulatory role in physiological processes of plant, especially in alleviating the biotic and abiotic stress effects. In pear, salicylic acid application found to be beneficial in increasing the plant growth and fruit yield, reducing chilling injury to the fruits, retaining fruit firmness, reducing weight loss, controlling postharvest disease and browning, and maintaining post-harvest quality of fruit.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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