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Enhancement of Postharvest Life of Fruits by Application of Salicylic Acid

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Salicylic acid (SA), an endogenous plant growth regulator, has been found to produce a wide range of metabolic and physiological responses in plants thereby affecting their growth and development. SA as a natural and safe phenolic compound, which exhibits a high potential in controlling postharvest losses of fruit crops. In this review, various intrinsic biosynthetic pathways and effects of exogenous salicylic acid on respiration, antioxidant systems, ethylene biosynthesis action, oxidative stress, nutritional quality, firmness, disease resistance and postharvest decay have also been discussed. Salicylates (derivatives of salicylic acid) delay the ripening of fruits, probably through inhibition of ethylene biosynthesis or action, and maintain postharvest quality.

Keywords: Biosynthesis; endogenous; ethylene; postharvest quality; salicylic acid.

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1. INTRODUCTION

"The chemical formula for salicylic acid is HOC6H4CO2H. It is a colourless, bitter tasting substance that is both an aspirin precursor and metabolite (acetylsalicylic acid). The word for willow tree in Latin is salix. Salicylates are the name for the salts and esters of salicylic acid. An essential plant chemical called salicylic acid (SA) is often involved in plants" [1]. "Exogenous SA applications have been employed as pre and postharvest treatments recently" [2]. It is also regarded as a naturally occurring plant hormone that slows the synthesis of ethylene and delays fruit senescence. It has also been shown that SA contributes to systemic acquired resistance [3]. "Salicylic acid has recently come to light as a possible natural chemical that might preserve the quality of fruits and vegetables during storage. Salicylic acid is known to be a safe substance to put on fresh fruits and vegetables in lower concentrations . It enhances the chilling injury tolerance in fruit by mediating H_2O2 metabolism" [3]. "It has been reported that fruit quality of peaches was maintained by SA application by retaining its firmness, preventing fruit decay, accelerating the antioxidant enzyme activities and by suppressing ethylene production" [4-11]. "SA is proven beneficial for reducing physiological weight loss of peaches and strawberries in the course of storage. In short, SA may ensure the safety of treated commodities during long term storage and shipment. Salicylic acid (SA), a natural phenolic acid, was first recognised as a defence-related plant hormone, which provides benefits to postharvest storability and alleviation of injury for horticultural commodities" (Baswal et al., 2020). In recent years, researches in the application of SA have suggested a critical role in regulating postharvest quality [12-26]. Exogenous SA treatment exhibits excellent potential in quality control, which may be attributed to –

(1) Preserving nutritional value and boosting antioxidant activity.
(2) Limiting the activity of enzymes that degrade cell walls, retaining the qualities of cell membranes.
(3) Improving fruit flavour, reducing fruit aroma loss, and
(4) Delaying fruit ripening, changing the composition of the fruit's pigments, and reducing fruit browning.

"Salicylic acid acts as natural antioxidants. Therefore, it helps in decreasing respiration rate, increasing antioxidant enzyme activity and maintaining quality attributes. Salicylic acid (SA) has a significant role in disease resistance and plant defence mechanisms. Salicylic acid including its derivatives are safe and natural alternatives for delaying the ripening and softening, retard membrane breakdown and mitigate chilling injury in several horticultural crops" [27]. "This stress hormone (SA) plays a role in induction of resistance related enzymes and has been shown to suppress ethylene production, delaying pericarp browning" (Mustafa et al., 2018). "It reduces stress lignification, and increases chilling tolerance [28] in fruits". "Application of salicylic acid influences the postharvest process by increasing the shelf life of horticultural crops including ornamental fruits and vegetables crops, horticultural crops. Postharvest application of SA has been shown to reduce fruit rot, maintain quality, and increase the antioxidant activity of fruits and vegetables. In horticultural crops, it is an endogenous plant growth regulator that delays the ripening process after harvest" (Baswal et al., 2020). It has been used on a variety of horticultural crops where it has shown the ability for extending shelf life [29-34]. It is related to the ethylene being inhibited during the ripening of fruit (Benati et al., 2021). The quality of horticultural goods, including their appearance, flavour, astringency, and bitterness, can be significantly altered by SA. In this work, we analyse the impacts of SA pre and postharvest applications, as well as its combination with other postharvest technologies, on horticultural commodities with an emphasis on quality control.

1.1 Functions of Salicylic Acid

Salicylic acid plays a crucial role in the growth and development of the plant for important physiological functions, such as increasing the plant's response to stress conditions (biotic and abiotic), increasing the plant's resistance to System Acquired Resistance (SAR), or both. These physiological functions are accomplished by stimulating or altering the internal endogenous signalling to withstand a variety of stresses. Additionally, it has the capacity to form conjugate bonds with certain amino acids, including proline and arginine, which improves the plant's ability to withstand adverse conditions and maintains systemic acquired resistance. Additionally, the SA plays a variety of significant physiological tasks, including promoting protein synthesis, delayed ripening of fruits, seed germination, immune response, nutrition transfer, CO2 representation, ion absorption, blooming, and stomata movement. It also advances the formation of various plant dyes by accelerating up their production and raising their levels, such as chlorophyll and carotene, and contributes to the accumulation of dry matter [35-38]. In contrast to ABA's work, which is responsible for the fall of leaves, it also prevents the representation of ethylene gas. Additionally, it plays a significant part in boosting metabolic rates, which helps the plant save energy by using alternate routes and changing its amount of nucleic and amino acids.

2. EFFECTS OF SALICYLIC ACID TREATMENTS ON PHYSIOLOGICAL LOSS IN WEIGHTS (PLW)

Physiological loss in weight of fruits is due to loss of water as a result of ongoing respiration and transpiration even after harvest. SA has been considered as a possible and effective treatment for senescence related enzyme activity suppression Hanif et al., [39]. This action lowers the rate of fruit respiration during storage, which in turn lowers the physiological loss in weight. Fruits that have lost water during storage not only lose weight but also lose quality and appearance due to shrivelling and withering.Postharvest application of salicylic acid (SA@2mM) was effective in reducing the physiological loss in weight in guava i.e in Allahabad Safeda and Lalit as salicylic acid helps in suppressing the metabolic activity with respect to respiration and ethylene evolution. Madhav et al. [40] Rasouli et al. [41] reported that application of salicylic acid @2mM showed reduction of physiological loss in weight in guava i.e., in Lalit cultivar in Kurdistan University, Sanandaj, Iran. Minimum spoilage and reduction of physiological loss in weight in guava was observed by Kaur et al., [42] application of salicylic acid (200 ppm) treated fruits under cold storage conditions. After 28 days of storage, a minimum PLW of (5.23%) was observed in fruits treated with SA 200 ppm compared with control. The studies were conducted in RRS, PAU, Bathinda, India. Acc Application of salicylic acid @2mM was effective in maintaining the quality of Murcott mandarin fruit during storage, in terms of reducing weight loss. Awad et al., [43] found that postharvest dipping in 2 mM salicylic acid or 0.2 mM was effective in reducing the physiological loss in weight which improved the quality of ‘Sensation’ mangoes at ambient conditions via inhibiting hydrolytic enzymes and enhancing antioxidant system of fruit. The experiment was conducted in a laboratory at King Abdulaziz University in Jeddah, Saudi Arabia. In pre and postharvest experiments, Brar et al., (2014) found that the physiological weight loss (PLW) was also less in SA treated peach (*Prunus persica* L.) cv. “Shan -e-Punjab” compared to untreated ones. According to Hajilou et al., [44] application of SA after harvest decreased the PWL in fruit when compared to the untreated control. SA inhibited the production of ethylene, hence preventing respiration. By closing stomata, salicylic acid may lower PLW and slow down respiration. The experiment was done on "Asgar-Abad," a popular commercial cultivar of Iranian apricot at Tabriz University, Iran. Haider et al., [45] studied that postharvest application of salicylic acid in mandarin orange budded on ‘Rough Lemon’ rootstock was significantly effective to minimize the physiological loss in weight in comparison to control. The study was conducted in University of Agriculture, Faisalabad, Pakistan. Hazarika et al., [46] found that fruits coated with salicylic acid @ 2 mM had considerably lowest PLW after 4, 8, 12 and 16 days of storage, respectively. Also revealed that

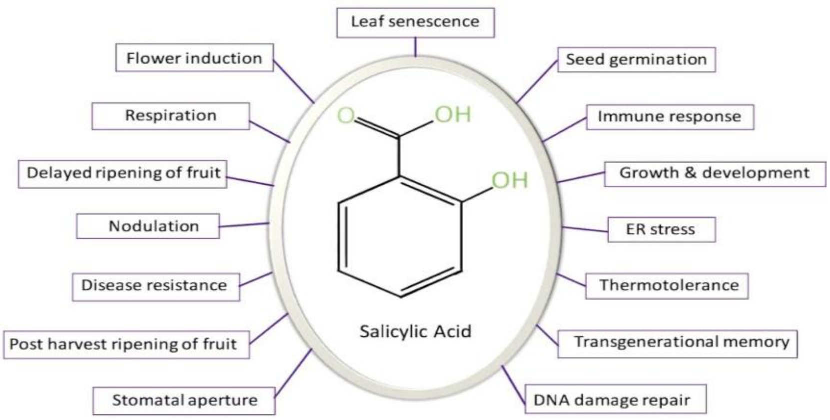

Fig. 1. Functions of salicylic acid in plants

SA is responsible for reduction of weight loss in fruits and their respiration rate by closing stomata. The research was carried out in the Department of Horticulture, Aromatic and Medicinal Plants at Mizoram University, India. Bal et al., (2016) found that after 40 days of storage, the least weight losses were observed in salicylic acid treatments (1.8%). The salicylic acid treatments dramatically inhibited weight loss compared to that of control.

3. EFFECTS OF SALICYLIC ACID TREATMENTS ON FIRMNESS

"Salicylic acid has been found effective in suppressing the wall degrading enzyme" Ahmad et al.,(2020). "It maintains the firmness of the fruits by decreasing the rate of ethylene production and suppressing the cell wall degrading enzymes. Postharvest application of salicylic acid helped to maintain higher firmness in guava" as studied by Venu et al., (2021). SA treated fruits retained their firmness due to inhibition of cell wall and membrane degrading enzymes as polygalacturonase, lipoxygenase, cellulose, and pectin methyl esterase, as well as a lower rate of ethylene production. Kaur et al., [42] reported that "postharvest application of salicylic acid was found effective in maintaining higher firmness on guava in Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab". "Fruit firmness is effectively maintained by postharvest application of salicylic acid in guava as fruit softening was delayed by the SA immersion due to the control of soluble pectin increase and insoluble pectin decrease" as explained by Kaushik et al., (2021). Saba et al., (2019) reported that "postharvest application of salicylic acid could maintain the fruit firmness which was conducted in Kurdistan University, Sanandaj, Iran". "Salicylic acid treatments slowed down fruit softening possibly by suppression of ethylene production and has also shown delay in ripening and suppress ethylene production and respiration rates during ripening at ambient conditions in mango" as studied by Awad et al., [43] conducted at King Abdulaziz University in Jeddah, Iran. According to Brar et al., (2014), salicylic acid therapy applied after harvest at a concentration of 200 ppm was the most successful in slowing the rate of firmness loss in peach fruits. The current studies were conducted on fruit from experimental peach (*Prunus persica* L.) cv. "Shan-e-Punjab" trees that were 6 years old in 2011 at the Regional Research Station, Punjab Agricultural University, Bathinda India.In spite of the treatments, Hanif et al., [47] found that the fruit freshness of stored papaya reduced during cold storage. However, fruit treated with SA at 1.5 mmol L-1 remained more firm throughout storage, indicating that this dosage was most effective in inhibiting the enzyme that breaks down cell walls. The research was carried out in the Postharvest Research Center's lab at the Ayub Agriculture Research Institute in Faisalabad, Pakistan.

4. EFFECTS OF SALICYLIC ACID ON CHILLING INJURY

"Postharvest application of salicylic acid on ripening process helps in curbing the ethylene evolution and senescence further resulting in lower chilling injury of the fruits and less production of free radicals in guava which was studied by Madhav et al., [40]. Sethi et al., (2021) reported that the induction of heat shock proteins in salicylic acid treated guava imparts chilling tolerance". Sayyari et al., [48] found that "postharvest treatment of salicylic acid @ 2 mM was the most effective for reducing chilling injury and for maintenance of ascorbic acid levels in pomegranate".

5. EFFECTS OF SALICYLIC ACID ON COLOUR

Madhav et al., [28] studied that "postharvest application of SA or SSA has delayed the ripening process of guava fruits significantly, probably through inhibition of ethylene production, which was conducted in The Division of Food Science and Postharvest Technology, IARI, New Delhi, India". Lo'ay et al., (2019) found that "hue value decreases less when fruit is treated with salicylic acid @2mM treatment for all fruit maturity stages. The results are due to the effect of the presence of salicylic acid which delay fruit ripening by reducing respiration rate and inhibit ethylene biosynthesis". "Postharvest application of salicylic acid delayed the development of yellow color in guava cultivars signifying a delay in the respiratory processes. The delay in ripening process was mainly due to the inhibitory effect of salicylic acid on ethylene synthesis and the barrier properties of vegetable wax formulation on gaseous exchange further resulting in suppressed activities of enzymes such as ACC synthase and ACC oxidase. Similar effect of delayed transition of color due to salicylic acid treatment has also been reported in guava fruits" by Lo'ay et al., (2011) and wax coated guava by Madhav et al., (2020).

6. EFFECTS OF SALICYLIC ACID ON TOTAL SOLUBLE SOLIDS (TSS)

Postharvest application of salicylic acid @2 mM was effective in decreasing the total soluble solids. The increase in TSS can be attributed to the conversion of starch to sugar during ripening of guava. Since salicylic acid might have suppressed the catabolic processes such as respiration rate and ethylene production in treated guava fruits, the treated fruits showed a slow increase.

7. EFFECTS OF SALICYLIC ACID ON TOTAL PHENOL CONTENT

Postharvest application of salicylic acid was effective in decreasing the total phenol content slightly to inhibit PPO by application of salicylic acid during ripening that reflects to increase fruit color quality as studied by Lo'ay et al., (2011). Adhav et al., (2021) studied that postharvest application of salicylic acid was effective in decreasing the total phenolic content of guava within the storage period. Reduced loss of phenols in salicylic acid treated fruits may be due to delayed oxidation of phenolic substances by polyphenol oxidase (PPO). Similar findings were reported earlier by Khademi et al., [49] in peach and Sahar et al., (2015) in apricot. According to Hajilou et al., [44], apricots treated with 3.0 mM salicylic acid had less phenolic content while being stored. The formation of all significant phenolics, the production of new polyphenols, and the stimulation of phenylalanine ammonia lyase activity in apricot were all produced as a result of salicylic acid treatment. The study was conducted at Tabriz University, and the research was done on "Asgar-Abad," a popular commercial cultivar of Iranian apricot. Khademi et al., [49] found that in comparison to controls, fruits treated with SA at high doses of 2 and 4 mM showed the highest levels of TPC. During the first two weeks of storage, fruits treated with SA at 1 mM were found to contain more TPC than controls, but later on, there was no discernible difference from controls. After storage, total phenols showed a downward trend, and the rate of decline was noticeably greater in SA-treated fruits than in control ones (SA at a concentration of 4 mM). Many enzymatic and non-enzymatic processes have been linked to the loss of phenolic chemicals during storage. The two main enzymes in charge of oxidising phenolic compounds are peroxidase (POD) and polyphenoloxidase (PPO).

8. EFFECTS OF SALICYLIC ACID ON ASCORBIC ACID

Tareen et al., [50,51] found that postharvest application of salicylic acid had a significant effect on maintaining higher content of ascorbic acid in peach fruits. The study was conducted on peach (*Prunus persica* L. Batsch) fruits of cv. 'Flordaking' engrafted on wild rootstock at the Postharvest Laboratory of the Department of Horticulture, Pir Mehar Ali Shah, Arid Agriculture University Rawalpindi, Pakistan.

9. CONCLUSION

Salicylic acid has a significant potential for reducing postharvest losses of horticulture crops since it is a natural and safe phenolic chemical. Following SA treatment, the main outcomes included a reduction in ethylene production and action, induction of disease resistance, prevention of oxidative stresses, induction of crop tolerance to chilling injury, reduction in respiration rate, reduction in ripening and senescence rate, prevention of cell wall degrading enzymes, and maintenance of fruit firmness. SA can be utilised as a suitable substitute for chemicals in horticulture crops postharvest technologies to ensure food safety.Since SA, like any other postharvest treatment, may have different effects on different crops at different circumstances, it is necessary to determine the best and safe concentration for each fruit cultivar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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