Review Article

Salicylic Acid Alleviates Postharvest Fruit Decay of Strawberry (*Fragaria* x *ananassa* Duch.-A mini review

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ABSTRACT

Strawberry (*Fragaria* x *ananassa* Duch.) fruits are highly perishable~~;~~ and fruit quality decrease rapidly after harvesting, thereby it has a limited scope of long duration storage. Among several synthetic chemicals suggested for minimizing postharvest losses of fruits, Salicylic acid (SA) is a natural phenolic compound widely distributed in plants and considered as a hormone because of its regulatory role in plants and has received ~~a~~ particular attention because of its role in the modulation of the plant response to biotic and abiotic stresses. Current scientific knowledge on the salicylic acid application in postharvest management of strawberry fruits suggests that SA has a potential role in minimizing fruit decay and maintaining ~~the~~ fruit quality. These predictors, however, need further work to validate reliability in postharvest management of strawberry fruits in a larger perspective.

Comment [PK1]: It would be better to rewrite this sentence into two seperate sentences. (too lengthy)

Keywords: Fragaria x ananassa Duch., Fruit decay, Postharvest, Salicylic acid, Strawberry

1. INTRODUCTION~~)~~

Modern cultivated strawberry (*Fragaria* x *ananassa* Duch.) is an octaploid (2n=8x=56) hybrid species in the Family *Rosaceae* [1], that arose during the mid-1700s in France from two New World species *F. chiloensis* and *F. virginiana* [2]. Worldwide, strawberries are grown in a broad range of climates including temperate, grassland, Mediterranean, and subtropical regions [3], and globally stands most important berry fruit [4]. In India, temperate Jammu Kashmir, Himanchal Pradesh, and Uttarakhand have been known for strawberry cultivation, but in the recent decades, there has been an expansion in area and production of strawberry in plains of subtropical regions and North-Eastern states of India [5]; however, the runner production in plains are very poor [6]. Strawberries are the most preferred berry fruit due to ~~its~~ their pleasant aroma, colour, taste, flavor, and bioactive compounds [7,8]. Strawberry fruits are rich in nutritional content, phenolic compounds, anthocyanins, tannins, phenolic acids, and have potential health benefits [9].

The strawberry fruits are highly perishable; it has limitations in ~~long~~ long-distance transport in the conventional system of fruit growing. Besides fruit maturity, method of packaging and distance of transportation influence the postharvest losses in strawberry [10,11], also postharvest management practices and storage conditions affect~~s~~ the shelf life and quality of fruits [12,13]. Strawberry is a non-climacteric fruit, implying its respiration rate and ethylene production do~~es~~ not increase during ripening [14,15]. During the ripening phase, the fruit continues to ~~grow in size~~grow [16,17] and exhibits tissue softening rate, water loss, and susceptibility to physical damage during postharvest handling [12,18]. Due to the high metabolic activity of the fruit, the susceptibility to mechanical damage, physiological deterioration, water loss, and microbial spoilage, the quality of the fruit drops rapidly after

~~harvest~~harvest, and it tends to post-harvest losses [19]. Fruit softening occurs due to the disassembly of the cell wall as a result of the dissolution of middle lamellae during ripening [20]. Strawberry postharvest methods attempt to reduce respiration and water loss, while also preserving fruit firmness and limiting disease development. Various synthetic compounds have been used to extend strawberry postharvest life, however public concerns about fungicide residues have arisen. The negative consequences of pesticides on human health and the environment have prompted scientists to look for better fungicide alternatives [21]. In the past few decades, ~~researches~~research on the use of natural compounds in postharvest quality management of fruits have been gained attention among the scientific community and the ~~end~~ end-users. Among others, salicylic acid is one of the natural compounds that has been found beneficial in maintaining the quality of several fruits including ~~strawberry~~ strawberries during storage [22-26]. ~~Present~~ The present review encompasses the use of salicylic acid on postharvest fruit decay control of ~~strawberry~~ strawberries by salicylic acid applications.

Salicylic acid: a hormone with a diverse regulatory role in plants

Salicylic acid is considered a potent plant hormone because it has a variety of regulatory effects in plant metabolism [27]. Salicylic acid (SA) and methyl salicylate (MeSA) play a central role in plant development, regulating stress response and disease resistance [28]. Under constantly changing environmental conditions, exogenous application of salicylic acid has been proven to be beneficial to crop growth and biological productivity, because of the key role of salicylic acid in photosynthesis, plant water relations, various enzyme activities, and its effect on the plants exposed to various biotic and abiotic stresses [29-31]. Plants are attacked by various pathogens, but plants protect themselves by activating certain types of defense mechanisms, such as locally acquired resistance (LAR) and systemic acquired resistance (SAR) against pathogens [32]. The effect of exogenous salicylic acid depends on many factors, such as plant type and developmental stage, application method and concentration of salicylic acid, and the endogenous content of salicylic acid in plants under given environmental conditions [30]. Salicylic acid has recently attracted special attention because it plays a key role in regulating the expression of multiple modes in plant responses to biological activities [33-35] and abiotic stresses [31,36,37]. The accumulation of large amounts of salicylic acid in the host is one of the mechanisms to protect it from pathogens. Therefore, salicylate plays an important role in the signal transduction pathway of plants and plays an important role in disease resistance [38] as the exogenous application of salicylic acid or acetylsalicylic acid induces the expression of pathogenic genes and confers resistance to pathogens [39-41].

Salicylic acid in mitigation of postharvest fruit decay

Salicylic acid plays a key role in the signal transduction pathway leading to systemic acquired resistance (SAR), an enhancement of resistance against a broad spectrum of pathogens [34,42]. One reason for this is that salicylic acid induces a range of ~~defence~~ defense genes, most notably those encoding the pathogenesis-related (PR) proteins [43,44] and several of these PR proteins possess antimicrobial activities such as chitinase or β-1,3-glucanase activity [45-47]. Others, including members of the well-studied PR^{-1} family, have no known biochemical activity but have been shown to inhibit the growth of oomycete pathogens and true fungi in vitro [48]. It has been established that ~~the~~ Salicylic acid also activates defense responses against pathogens and plays a role in the development of systemic acquired resistance [49,50]. According to Asghari and Aghdam [51], the application of salicylic acid, especially preharvest, for inducing the defense resistance systems against postharvest diseases may be a useful and promising measure for controlling postharvest decay on a commercial scale.

Strawberry fruit ~~are~~ is very delicate; they can get bruised during harvest and postharvest handling. Bruising is the most undesirable damage that seriously limits not only the appearance of fruits but also such fruits easily affected by fungal pathogens leading to decay and shorter shelf life. Fungi *Botrytis cinerea, Rhizopus stolonifer, Mucor* spp., *Colletotrichum* spp., *Penicillium* spp. are the main pathogens that cause post~~-~~harvest rot of strawberry fruits [52], and the gray mold caused by *Botrytis cinerea* is the most serious disease after harvest when conditions become favo~~u~~rable to disease development [53,54]. Although~~,~~ a lot of effort has been put in by researchers for minimizing decay losses of fruits, the ~~low~~ low-temperature conditions around 1°C are considered an effective tool in postharvest quality prolongation. Different fungicides, soil fumigants, and bio~~-~~agents have been used to control the diseases [54-58] but most of these approaches have an unsavory impact due to the increment safe strains of pathogens against different chemical fungicides. Recently, few researchers worked on the improvement in plant defense mechanisms in fruits after harvest against the decay through the salicylic acid application.

Salicylic acid application in evaluated by researchers has advocated that the effective concertation is variable with doses, method of application, and the time of application. Postharvest dip treatment of fruit with salicylic acid has been found most effective than preharvest foliar sprays. Bablar *et al*. [21] studied the effect of foliar applied salicylic acid (1, 2, and 4 mmol L^{-1}) on postharvest fungal decay and overall quality index in strawberry fruits and they observed that the application of salicylic acid at vegetative and fruit development stages followed by postharvest treatment of fruits effectively reduced fungal decay and retained postharvest storage quality of fruits when applied at with 1 or 2 mmol L^{-1} while the postharvest treatment at 4 mmol L^{-1} slightly damaged the fruits and less effective in retaining fruit quality. Shafiee *et al*. [26] studied the strawberry cv. Camarosa fruit quality after 7 days storage at 2 °C as influenced by salicylic acid addition to nutrient solution (0.03 mM) and postharvest treatments of salicylic acid. They observed that SA in their nutrient solution had less fruit decay and higher firmness of fruits. In ~~an~~ another trial conducted by Abolfazl *et al.* [59], pre- or postharvest application of salicylic acid (0, 3, 5, and 7 mM) resulted in less weight loss of fruits and delayed onset of the climacteric peak of respiration and also inhibited ethylene production, which intern enhanced the quality of fruit. Lolaei *et al*. [60] observed delayed ripening of strawberry cv. Camarosa by pre and postharvest salicylic acid application. Salari *et al*. [61] examined five levels of salicylic acid (0, 1, 2, 3, and 4 mM) on three cultivars (Paros, Kamarosa, and Selva) on the postharvest durability of fruits stored in the refrigerator at 3°C±1°C for 12 days. ~~Highest~~ The highest rotten fruits percentage was obtained from control and the effect of SA was independent with cultivars for healthy fruits and rotten fruits percentage. Mahsa *et al*. [62] tested methods of application (spray SA on fruits and paper disk method) and variable concentration of salicylic acid (0, 25, 50, and 100 μ L^{-1}) on the postharvest durability and quality characteristics of strawberry fruit wherein fruits treated with salicylic acid resulted in lower decay as compared to control and the paper disk method showed a higher effect on fruit decay and quality resulted in the longer storability.

Salicylic acid as a foliar spray at 3-4 leaf stage in the spring growth of strawberry and again 15 days after 1st spray found that salicylic acid treatments were effective in improving storability of fruits compared with control as it resulted in a significantly minimum physiological loss in weight and rotting percent~~,~~ and retained higher values for biochemical parameters of fruits at 2, 4 and 6 ~~day~~days of storage at ambient conditions [64]. Yousif [65] emphasized that ~~the~~ salicylic acid can be considered one of the ~~most safe~~safest~~ty~~ ways with ~~less~~ fewer environmental hazards to improve the postharvest life and maintaining the quality of ~~strawberry~~ strawberries and reducing the rate of rachis browning during postharvest storage. Preharvest foliar sprays of salicylic acid are also reported to be effective in postharvest quality management of fruit. SA 2 mM as pre- and postharvest application was found to be effective in prolonging the storage life of strawberry fruits by reducing the fruit spoilage and fungal decay up to 16 days of storage [65]. Postharvest dipping of dipping strawberry fruits after harvest in salicylic acid solution (2 and 4 mM) was found effective in suppression of the fungal growth on fruit [66]. Salicylic acid treatment with calcium was also found beneficial in postharvest quality retention of fruits. Niazi *et al*. [67] examined postharvest dip of fruits in 1 mM salicylic acid along with 2% calcium chloride, and a combination of salicylic acid and calcium chloride at two water temperatures of 20°C (cold water treatment) and 45°C (hot water treatment) for 5 min and then stored at 4°C for 14 days. They observed that the Salicylic acid and $CaCl_2$ along with hot water treatment maintained the fruit quality more efficiently during storage.

CONCLUSION

Salicylic acid is a potential plant hormone having a variety of regulatory effects in plant development, regulating stress response and disease resistance. Exogenous application of salicylic acid has been proven to be beneficial in minimizing fruit decay and maintaining the fruit quality suggests that it has a potential role in postharvest management of strawberry fruits. Further research works in this direction are needed to validate the reliability of the applicability of applicability on a commercial scale.

CONSENT

Not applicable

ETHICAL APPROVAL

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