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Role of salicylic acid in postharvest management of peach and plum fruits: A review

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Abstract
Salicylic acid (SA) is a naturally occurring phenolic compound that is widely distributed in plants and it is considered as hormone due to its regulatory role in plants. SA has attracted considerable interest because of its role in modulating plant responses to biotic and abiotic stresses during postharvest storage of fruits. SA has been shown to exhibit a high potential in delaying ripening, maintaining fruit quality, and controlling postharvest losses. Use of SA could be a promising technology for enhancing postharvest storability and retaining the nutritional quality of peach and plum fruits after harvest.

Keywords: Postharvest management, peach, plum, salicylic acid

Introduction
Most fruits are perishable due to their physiological properties and cause significant post-harvest loss in developing countries with limited storage options. According to Kader (2005) [1], one-third of all fresh fruits wasted before they reach to customers. The pre-harvest factors such as crop growing environment (weather and climate), tree conditions, light penetration, training pruning, irrigation, nutrient management, insect pest and disease management, use of growth regulators etc. influence overall fruit quality and suitability for storage by modifying physiology, chemical composition, and morphology of fruits. Besides preharvest factors, the main causes associated with the postharvest losses of fruits are poor management of handling and packaging, and storage environment conditions (Kitinoja, *et al.*, 2011) [2]. Due to soft texture of fruits, they are easily bruised or wounded as a result of harvesting, and other post-harvest handling operation such as packaging, transportation and during storage. Mechanically damaged fruits are more susceptible to pathogen attacks thus fruit decay during long distance transport, storage and retail environment causes high losses besides deterioration in fruit quality. The quality of fruits after harvest is largely governed by water content, respiratory rate, ethylene production, endogenous hormones in fruit and exogenous factors such as microbial growth, temperature, relative humidity and atmospheric compositions. Therefore, post-harvest loss of fruits needs to be reduced and their shelf life increased considerably by careful manipulation of pre and postharvest factors associated with the losses. The loss can be reduced by adopting suitable growing environment, implementing the adequate cultural methods, careful harvesting, handling, packaging, transportation and storage. The use of appropriate chemicals at pre and postharvest stage may prolong the availability of fresh produce for a long period of time by protecting them from pathogens and other harmful environmental factors. Also controlled atmosphere storage has been found to be effective in minimising rate of fruit quality deterioration.

Various synthetic chemical compounds have been used for extending the postharvest life and retaining the quality of fruit after harvest. However, concerns about chemicals pesticides being used for postharvest management of fruits are arising among consumers during recent past decades because of their negative consequences on human health as well as environment and also prompted the researchers to look for better fungicide alternatives (Babalar, *et al.*, 2007) [3]. The use of natural compounds in postharvest quality management of fruits has been gained attention during the past few decades. Among others, salicylic acid is one of the natural compounds reported to be beneficial in maintaining the quality of several fruits during storage (Romani, *et al.*, 1989; Zeng *et al.*, 2006; Wang *et al.*, 2006; Mo *et al.*, 2008; Shafiee *et al.*, 2009) [4-8].

Salicylic acid: A Plant hormone with diversified role in plants

Salicylic acid and its derivatives, as one of the plant hormones produced by the plant, belong to the phenolic acids group and are made up of a ring attached to the hydroxyl and carboxyl groups. It is cosmically spread in plant kingdom (Raskin *et al*., 1990) [9] that has been considered as a powerful plant hormone and plays a variety of regulatory actions in plant metabolism (Raskin, 1992) [10]. Because of the key role of salicylic acid in photosynthesis, plant water relations, various enzyme activities, and its effect on plants exposed to various biotic and abiotic stresses, exogenous application of salicylic acid shown to be beneficial to crop growth and biological productivity under constantly changing environmental conditions (Senaratna *et al*., 2000, Horvath *et al*., 2007; Hayat *et al*., 2010) [11-13]. Salicylic acid has recently attained a lot of attention because it regulates the expression of different modalities in plant responses to biological activities (Malamy and Klessig, 1992; Ryals *et al*., 1996; Shah *et al*., 2005) [14-16] and abiotic stressors (Hayat *et al*., 2010; Ding *et al*., 2001, Ding *at al*., 2003) [13, 17-18].

Role of salicylic acid in postharvest management of fruits

Salicylic acid and its derivatives are widely in use to enhance postharvest life of fruits by modifying physiological processes and alleviating the deleterious effects of various biotic and abiotic stresses in fruits. Fruits are exposed to various pathogen attacks after harvest too. To defend themselves from infections plants activating defence mechanisms such as locally acquired resistance (LAR) and systemic acquired resistance (SAR) (Vlot *et al*., 2009) [19]. One of the processes that protect the host from pathogens is the formation of huge levels of salicylic acid. Salicylic acid and its derivatives are considered an important regulator of disease resistance in plants (Klessig and Malamy, 1994) [20]. Salicylic acid is involved in the signal transduction pathway that leads to systemic acquired resistance (Ryals *et al*., 1996; Murphy *et al*., 1999) [15,21], stimulates a number of defence genes, most notably those encoding pathogenesis-related (PR) proteins (Carr and Klessig, 1989; Bowles, 1990) [22,23], and several of these PR proteins have antimicrobial properties, *viz*. chitinase or 1,3-glucanase activity (Schlumbaum *et al*., 1986; Mauch *et al*., 1988; Salzman, *et al*., 1998) [24-26], and have been demonstrated in vitro to suppress the growth of oomycete pathogens and true fungi (Niderman, *et al*., 1995) [27]. Thus, the exogenous administration of salicylic acid and its derivatives plays a significant role in plant signal transduction and disease resistance, as acetylsalicylic acid promotes the expression of pathogenic genes and confers pathogen resistance (Morris *et al*., 1998; Pasquer *et al*., 2005; Makandar *et al*., 2006) [28-30].

It has been demonstrated that salicylic acid maintain flesh firmness of harvested fruits (Wang *et al*., 2006; Li and Han, 1999; Yan *et al*., 1998) [6, 31-32] thereby reducing the fruit quality deterioration during storage. Exogenous salicylic acid's action is influenced by a variety of parameters, including plant type and developmental stage, salicylic acid application method and concentration, and endogenous salicylic acid content in plants under specific environmental conditions (Horvath *et al*., 2007) [12].

Salicylic acid in postharvest management of peach fruits

Peaches are perishable fruits; they ripen rapidly at ambient temperature and require careful and adequate handling after harvest to avoid serious losses. The shelf life of peaches is often limited due to the damage caused by the cold. Susceptible varieties after refrigerated storage (<10 ^{0}C for 2-3 weeks) showing damage symptoms of textural changes and discoloration of the flesh besides rotting especially brown rot and transit rot infections; suitable management practices needed for minimizing the postharvest losses. Salicylic acid considerable role in regulating physiological activities that associated with postharvest losses of fruit. Postharvest Salicylic acid treatment of 'Okuba' peaches @ 0.10 g L^{-1} inhibit the respiration rate and delay the ethylene production peak of ripening (Han *et al*., 2002) [33]. Although, SA-treatment exhibit higher cell membrane electrolyte leakage of fruit during the early days, but lower at the subsequent days (Han *et al*., 2002) [33]. In an immersion treatment with @ SA 0, 0.35, 0.7 and 1 mM to the peach fruits (cv. Beijing 24) fruit at commercial maturity for 5 min and stored at 0 ^{0}C for 28 days, then moved to 20 °C for 3 days; Wang *et al*. (2006) [6] observed that only 1 mM SA significantly maintained higher firmness and lower chilling injury index, decay index, and thiobarbituric acid-reactive-substance content of fruit compared with the control. Further, they also studied whether 1 mM SA alleviated chilling injury by influencing antioxidant systems and/or heat shock proteins of the fruit wherein they observed reduced-to-oxidized ascorbate ratio (AsA/DHAsA) in 1 mM SA treated fruit and alleviated the cold storage induced reduction of a number of volatiles and sugars, and thereby maintained flavor quality of fruit during shelf life after cold storage. According to Awad (2013) [34], SA treatment of 'Flordaprince' peaches maintained a significantly lower enzymes activity (peroxidase and polyphenol oxidase) with increasing SA concentrations. SA treatment also increases phenols, flavonoids, and ascorbic acid contents leading to fruits with higher DPPH and FRAP radicals scavenging capacity with higher antioxidant enzymes catalase, ascorbate peroxidase and superoxide dismutase activity (Razavi *et al.*, 2017) [35]. Peach cv. 'Flordaking' fruit treated with 4 and 6 mM SA exhibited delayed and reduced ethylene production as compared to untreated fruit during fruit ripening, reduced activities of fruit softening enzymes including pectin esterase, endo-1-4 β-Glucanase, endo- and exo-polygalacturonase and reduced ethylene production as compared to untreated fruit during ripening at ambient conditions (Ullah *et al*., 2020) [36].

Postharvest application of salicylic acid has been found effective in maintaining fruits quality during storage. A decreased weight loss of 'Maria Delicia' peaches and lower total soluble solids but a higher titrable acidity and ascorbic acid reported with increased SA concentrations from 0.5 mM to 2 mM compared to untreated control (Abbasi *et al*., 2010) [37]. In 'Flordaking' peaches, Tareen *et al*. (2012) [38] observed that SA @ 2.0 mmol L^{-1} significantly less weight loss compared to other SA doses (0, 0.5, 1.0 and 1.5 mmol L^{-1}). Awad (2013) [34] recorded highest values of fruit losses in weight decreasing SA concentrations from 1.5 to 0.5 mM, and fruits receiving SA treatments produced the firmest fruits.

Salicylic acid application effectively reduce fungal decay (Khademi *et al*., 2013) [39], rate of spoilage and loss of physiological weight total and helpful in obtaining higher fruit firmness, maintenance of fruit TSS and titrable acidity during storage (Awad, 2013; Razavi *et al.*, 2014, Razavi *et al.*, 2017) [34, 40, 35]. Among different postharvest application of SA (0, 2, 4 or 6 mm) to Flordaking peaches fruits at ambient conditions (25±2 ^{0}C and 60-65% RH), 6 mM SA exhibited lowest weight loss of fruits, TSS and highest fruit firmness (Ullah *et al*., 2020) [36]. SA treatment (1 mM) also effective in alleviation of the development of flesh browning, storage-induced reduction of a number of volatiles and sugars and softening thereby maintained fruit flavor quality of ‘Hujingmilu’ peach during shelf-life after cold storage Yang *et al*. (2020) [41].

Pre-harvest SA treatments @ 2 mM in ‘Cresthaven’ peaches found beneficial for better fruit characteristics (fruit weight, fruit flesh firmness, total antioxidant content, total phenol content and acidity) and decreasing the loss of fruit firmness at harvest and after storage at 2 ^{0}C for 8 days and 2 days post storage shelf life at 20 ºC (Deniz and Imail, 2020) [42]. Ali *at al*. (2021) [43] reported that the pre-harvest application of SA @ 3 mM at fruit development stages can improve the harvest quality and storability of ‘Flordaking’ peaches during low temperature storage. They used different concentrations of SA (0, 1, 2 and 3 mM) sprayed on the plants at three growth stages of fruit, i.e., the cell division, cell enlargement and pit-hardening stages and observed that all the SA treatments improved the fruit quality at harvest and maintained higher levels of flesh firmness, titratable acidity and ascorbic acid during storage; however, fruit weight loss, soluble solid contents, membrane leakage, chilling injury, colour development, disease and decay incidence and the climacteric peak of ethylene were lowered by SA treatment after six weeks of low-temperature storage.

Salicylic acid in postharvest management of plum fruits

Plum fruits are perishable and fruit softens quickly after harvest, resulting in a shorter shelf life at ambient temperatures (Menniti *et al*., 2004) [44]. Refrigeration effectively slows fruit ripening and extends the life of plums after harvest, but the beneficial effects may be limited by the development of hypothermia-related diseases, including internal blackening, translucent pulp and/or redness (Crisosto *et al*., 2004; Manganaris, *et al*., 2007) [45, 46]. Chilling injury, disease incidence, electrolyte leakage, MDA content, respiration and ethylene production of control fruit increases during cold storage, therefore, delaying or reducing pulp softening and spoilage at low temperatures should be an important strategy for extending shelf life and maintaining plum fruit quality (Luo *et al*., 2011) [47]. According to Shaaban *et al*. (2020) [48], Fruit weight loss, total soluble solids, total carotenoids content and total phenolics content) increases with advances in storage period while the fruit firmness, lightness (L*), hue angle (h°) of colour, titratable acidity, total flavonoids content and antioxidant activity decreases. Salicylic said to augment the activities of SOD and CAT and maintain lower levels of cell membrane permeability and MDA; thereby, it inhibitory effect on the occurrence of cell membrane lipid peroxidation (Wang *et al.* 2020) [40].

In a preharvest SA spray treatments, Martínez-Esplá *et al.*, 2017) [49] observed enhanced activity of the antioxidant enzymes catalase (CAT), peroxidase (POX), superoxide dismutase (SOD), and ascorbate peroxidase (APX) and higher levels of antioxidant enzymes at the time of harvest in salicylate-treated fruits. Davarynejad *et al.* (2015) [50] evaluated SA dip (0, 1, 2, 3 and 4 mmol/L for 5 min) to the 'Santa Rosa' plum fruits at the mature ripe stage, packed in boxes with polyethylene covers and stored at 4 ^{0}C with 95% relative humidity for 25 days. They observed that weight loss and softening of the plum fruits were decreased significantly by the use of salicylic acid and found to be effective in maintaining titratable acidity, ascorbic acid, total phenolics and antioxidant activity in plum fruits during storage. Martínez-Esplá, *et al*. (2017) [49] also applied foliar spray of SA, acetylsalicylic acid (ASA), and methylsalicylate (MeSA) treatments and advocated that preharvest treatment with salicylates could be a safe, eco-friendly, and new tool to improve and maintain plum quality attributes and especially their content of antioxidant compounds, with an additional effect on delaying the postharvest ripening process through increasing the levels of antioxidant compounds and the activity of the antioxidant enzymes.

In ‘Qadri’ plum, salicylic acid (0, 3, and 6 mmols.l^{-1}) treatment increased titratable acidity, hardness, and moisture content, while water loss, significantly anthocyanin, and total phenols were reduced in fruits stored in a cold room at 2 ±1°C and 90% relative humidity for 60 days. 6 mmols l^{-1} salicylic acid (Kasnazany *et al*., 2017) [51]. In a foliar sprays combinations of SA (3 and 4 mmol/L), putrescine (3 and 4 mmol/L) and moringa leaf extract (5 and 10%) and harvested fruits storage at 0 °C with 85-90% RH for 8 week, the SA @ 3mmol/ L, putrescine @ 4 3mmol/ L and moringa leaf extract @ 10% treatment found to be more effective than other treatments in decreasing the weight loss, softening and maintaining titratable acidity, total carotenoids, total phenolics, total flavonoids and antioxidant activity in plum fruits during storage at 0 °C; hence, preharvest treatment of plum fruits with salicylic acid, putrescine and moringa leaf extract can be effective in delaying the ripening processes and of commercial use to extend the storage life of postharvest plum fruits with acceptable fruit quality (Shaaban *et el*. 2020) [48].

Salicylic acid treatment of ‘Qingnai’ plum fruit said to be useful in suppression of chilling injury and delayed onset of the climacteric peak of respiration besides inhibition of ethylene production during cold storage (Lau *et al*., 2011) [47]. In aqueous dip SA treatments (0.5, 1.0, 1.5 and 2.0 mM) of Santa Rosa plum for 10 min at 20°C, air-dried and packed in plastic punnets followed by storage at 2°C and 90±5% RH, SA (2.0 mM) to be the best for maintaining the fruit quality and overall acceptability, fruit colour; hence, SA dip can be integrated as an effective postharvest practice in the supply chain management to extend their storage life while maintaining fruit quality during storage for 36 days (Sharma and Sharma, 2017) [52]. Salicylic acid also play vital role in cold resistance of postharvest plum fruits and its relationship with ethylene signal as the appropriate concentration of exogenous SA treatment of ‘Bulang’ plum (1.0 mmol L^{-1}) flesh browning and mitigate chilling injury symptoms in fruits stored at 4 ℃ (Wang *et al*., 2020) [53].

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