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Effect of pre-and or post-harvest application of salicylic acid and ascorbic acid on post-harvest quality of horticultural crops: A review

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Abstract
Salicylic acid and ascorbic acid application influence in post-harvest process by increasing the shelf life of horticultural crops-ornamental, fruits and vegetables. Both salicylic and ascorbic acid act as natural anti-oxidants. Therefore, help in decreasing respiration rate, increasing anti-oxidant enzyme activity and maintaining quality attributes. Salicylic acid (SA) is a plant chemical that has a role in disease resistance and plant defense mechanisms. In different horticultural crops, post-harvest application of SA has been shown to reduce fruit rot, maintain quality, and increase the antioxidant activity of fruits and vegetables. An endogenous, phenolic nature plant development controller is salicylic acid (SA). It expands plant force under biotic and abiotic conditions and has significant physiological roles in plant control development. SA has a fundamental role in modifying the quality of organic products, such as their appearance, flavour, astringency and bitterness. SA has the potential to reduce fruit respiration and ethylene biosynthesis rates, as well as fruit water loss, microbiological contamination, and fruit firmness during storage and the usable shelf life. Ascorbic acid has been utilized as an anti-browning, antibacterial and ant oxidative ingredient in edible coatings. With antioxidant characteristics, ascorbic acid has a cyclic and enediol-lactone resonant structure. It is effective at removing free radicals.
This review article delivers key information as how pre and post-harvest application of salicylic acid and ascorbic acid influenced the storage quality and shelf life of selected horticultural crops at different concentrations.

Keywords: SA, AA, pre-harvest and post-harvest

Introduction

India holds second rank in the fruit production worldwide. Crop storage loss is faced during post-harvest life of horticultural crops due to internal or external factors which leads to serious loss of quality, nutrition and sensory quality. Chilling injury as an abiotic stress during storage which increases susceptibility to decay leads to economic losses (Yang *et al*., 2013) [113]. Salicylic acid (SA) is a mixture of phenolic chemicals that is widely dispersed in plants and plays an major role in a wide range of variables physiological mechanisms (Zavala *et al*., 2004) [15].

In order to maintain shelf-life and quality to prevent post-harvest losses use environmentally friendly technologies such as application of SA salicylic acid SA is natural analog acetyl salicylic. (SA) has shown to exhibit a high potential in delaying ripening, quality enhancing and controlling post-harvest losses (Asghari and Aghdam, 2010) [14]. Salicylic acid (SA) is an endogenous plant growth regulator that retards the post-harvest ripening process in horticultural crops (Baswal *et al*., 2020) [20]. Its application has already been applied on several different horticultural crops where it showed an optimum potential in increasing shelf life aspects. SA is related to inhibition of ethylene in ripening process of fruit (Benati *et al*., 2021) [22].

Ascorbic acid is a natural antioxidant that helps in maintaining the post harvest quality of horticultural crops due to its anti- pathogenic actions (Jayachandran *et al*., 2007) [49]. Fruit quality cannot be enhanced while storage of fruits. Fruit varieties should be so selected that their market value, quality and yield is not deteriorated. This can be mitigated by use of antioxidants for increase in fruit quality and shelf life. Contributing to this, ascorbic acid can be used as a protectant which helps in maintaining the fruit quality and enhanced shelf life by keeping the properties of fruit intact for a longer period.

Effect of SA on pre-and/or Post harvest quality of horticulture crops

(A) Pre-harvest application of salicylic acid

Pre-harvest application of SA has been tested and done already on several horticultural crops such as ber fruit (Z*iziphus Mauritania*), sweet orange, Thompson novel orange and the observations made were that SA application directly or indirectly affects the oxidative metabolism of fruit crop thus helped in preserving the nutritional value during storage. In ber, the fruit length, diameter color and weight were significantly higher in SA sprayed fruits compared to non-treated (Kanwal *et al*., 2021) [52]. In sweet orange the pre-harvest spray of SA effectively minimized the losses of post-harvest storage by maintaining the contents of SSC, TA, individual sugars and organic acid in treated fruits (Ahmad *et al*., 2013) [7].

Sweet cherry

Salicylic acid (SA) significantly reduced lesion diameters on sweet cherry. Fruit treated with SA on before harvest significantly lowered disease percentages in storage (Tian *et al*., 2005) [117]. With the application of salicylic acid, (Gholami *et al.*, 2010) [38] observed a significant increase in anthocyanin content, flesh firmness, and stem freshness of fruits in the 'Mashhad' sweet cherry (*Prunus Avium* L).

Strawberry

SA treatments has been effective in preserving strawberry fruit quality and extending storage life throughout pre-harvest management (Babalare *et al*., 2007) [16]. According to (Salari *et al.*, 2013) [87], 'Paros' strawberries treated with salicylic acid out performed the other cultivars in most quantitative and qualitative parameters.

Applications of SA preserved fruit against ascorbic acid (AsA) loss, total phenolic compounds (TPC) and anthocyanin concentrations in all pre-harvest applications remained greater than control over the penultimate storage period (Darwish *et al*., 2021) [32].

Pear

Salicylic acid spray before harvest, the fruit developed resistance to pathogens and infections in pear (Jiankang *et al*., 2006) [50]. During 5 months of cold storage, dipping pear fruit in SA solution significantly reduced fruit degradation (Asghari *et al*., 2007) [16].

Pepper

The effectiveness of SA bulk materials and SANPs induced instimulating initiated immune responses in pepper plants (Abdel-Rahman *et al*., 2020) [2]. Similarly by (Lee *et al.*, 2009) [57], it was reported that pre-treating unripe pepper fruits with SA totally protected them from *C. Gloeosporioides.*

Grapes

Pre-harvest spraying of SA on grape cv. Flame Seedless improved quality and extended post-harvest life by efficiently maintaining peel colour, increased firmness, decreased pectin methyl esterase activity, and electrolyte leakage, as well as suppressed TSS and TA degradation during cold storage (Ranjbaran *et al*., 2011) [84].

Tomato

Pre-harvest application of salicylic acid led to an increase in total yield per plant therefore maintained fruit quality attributes such as TSS firmness and better shelf life (Baek *et al*., 2021) [17].

(B) Post-harvest application of SA on Horticultural crops

Fruits

Winter pineapple

Lu *et al*., (2011) [67] reported that post-harvest application of salicylic acid treatments significantly reduced internal browning (IB) intensity in pineapple. The pineapple fruit when treated with SA shows positive effect as it reduces the incidence of IB intensity. However, the soluble solid content (SSC), treatable acidity (TA) and total phenolic content remained unaffected. SA delayed the decline of ascorbic acid content hence maintained post-harvest life (Lu *et al*., 2011) [67].

Cherry

With the application of salicylic acid, (Gholami *et al*., 2010) [38] observed significant increase in anthocyanin content, flesh firmness, and stem freshness of fruits in the 'Mashhad' sweet cherry (*Prunus Avium L.*). Ripening process significantly delayed, the acidity was lowered and the firmness losses were estimated. Total phenolics, anthocyanin with DPPH scavenging activities increased during storage (Dokhanieh, *et al*., 2013) [33].

Peach

SA effectively resulted in preserving guava fruits from GBS disease during shelf life as it had an overall effect on fruit quality, delay in ripening TSS and WL along with other quality attributes (Arafat *et al.*, 2019) [13]. SA treatments boosted the activity of antioxidant enzymes in plant cells, delayed the ripening process in peaches (Tareen *et al*., 2012) [106].

Blood Orange

The fruit treated with salicylic acid showed the significantly lower incidence of post-harvest degradation of the catastrophic fungal pathogen *Penicillium Digitatum* Sacc, the cause of blood orange green mould disease (Aminifard *et al.*, 2013) [11]. Also, fruits treated with salicylic acid exhibited significantly highest higher acidity, anthocyanin, and antioxidant content, as well as greater storability (Aminifard *et al*., 2014) [37].

Banana

Exogenous SA had shown to be effective at delaying the ripening and firmness of bananas in recent years when applied to fruits at nontoxic concentrations (Srivastava and Dwivedi, 2000) [101]. Salicylic acid-treated fruits, according to (Manoj and Upendra, 2000) [71], showed an increase in decreasing sugar levels in a concentrated manner.

Guava

SA effectively resulted in preserving guava fruits from GBS disease during shelf life as it had an overall effect on fruit quality, delay in ripening TSS and WL along with other quality attributes (Arafat *et al*., 2019) [13]. 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 (Khademi and Ershadi

2013) [54]. These results had previously been observed in guava and other fruits by (Loay and Khateeb, 2011) [64].

Kinnow

SA application resulted in maximum antioxidant activity, total phenolic content activities of (POD) AND (SOD). SA level had significant effect to prevent fungal attack in storage of fruit thus enhancing the shelf life and reduced weight loss in Kinnow mandarin (Baswal *et al*., 2020; Haider *et al*., 2020; Tavallali and Moghadam, 2015) [20, 43, 107].

Apple

SA in optimal concentration significantly was able to increase the antioxidant enzyme activities while decreasing the respiration rate and TSS. (Han and Li, 1997) [44] found that when apple fruits were treated with salicylic acid, soluble solids increased without reducing firmness.

Kiwi

SA treatment resulted in increased TSS, TA, ascorbic acid and antioxidant content and had the lowest decay and acidity along with inhibiting grey mould growth at SA applied concentrations. SA reduced wound-induced transcription and ACS activity, as well as LOX activity, in kiwifruit discs, resulting in a reduction in free radical generation and ethylene biosynthesis.

Grape

SA application effectively inhibited development of decay infection and delayed rachis browning maintained berry appearance. Concentration of quercetin and catechin were increased by SA treatment (Ranjbaran *et al*., 2011) [84]. SA as a therapy for grapevine berries slowed or inhibited ripening (M. Salam 2016) [6]. SA slows down respiration and ethylene biosynthesis (Srivastava *et al*., 2000) [101], which delayed ripening-related changes.

Strawberry

Fruits dipped in SA solution had less weight loss, decay and higher firmness (Shafiee *et al*., 2010) [93]. SA treatments had been reported to be effective in preserving strawberry fruit quality and extending storage life throughout post-harvest management (Babalare *et al*., 2007) [16]. According to (Salari *et al*., 2013) [87], 'Paros' strawberries treated with salicylic acid outperformed the other cultivars in most quantitative and qualitative parameters.

Qingnai plum

SA resulted in suppression of chilling injury with reducing leakage, MDA content, delayed activities of PPO and POD and enhanced PA accumulationalong with delaying the onset of climacteric peak of respiration during cold storage (Luo *et al*., 2011) [68].

Lemon

The effects of SA resulted in increasing the antioxidant enzyme catalase, peroxidase, ascorbate peroxidase, lower weight and firmness losses, respiration rate, production of ethylene control, sugar and organic acids were maintained at higher concentration in flavedo and juice (Escolano *et al.*, 2021) [92].

Cornelian Cherry Fruits

SA treatment on cornelian fruit salicylic acid (SA) on total phenols (TP), flavonoids (TF), anthocyanin's (TA), ascorbic acid (AA) contents, resulted in increasing the DPPH scavenging activity of cornelian cherry fruits (Dokhanieh AY *et al*., 2013) [33].

Jujube

SA dipping treatmet resulted in reduced rate and index of decay and catalysis activities, whereas ascorbic content increased (Cao *et al*., 2013) [26].

Vegetable

Cucumber

Dipping cucumbers in salicylic acid was the most efficient method for preventing chilling injury and maintaining significantly higher fruit firmness (Cao *et al*., 2009) [27].

Asparagus

Effect of SA resulted in improved colour and maintained chorophyll, phenolic, flavonoid and ascorbic acid content, induced concentration of phenolics in post-harvest asparagus, increase in total flavonoids (Wei *et al*., 2011) [112].

Flower

Chrysanthemum

SA resulted in increased shelf life by lowering the electrolyte leakage, increase in reducing sugar contents, improving membrane stability and decreasing lipid peroxidation (Mansouri 2012).

Rose

The vase solution containing SA significantly helped in increasing shelf life by reducing the malondialdehyde accumulation and ACC-oxidase activity in same solution and improving membrane stability along with other positive effects on age-related change associated with rose petal senescence (Zamin *et al.*, 2011).

Herb

Parsley

Parsley dipped in SA exhibited delayed loss of fresh weight in cold storage conditions along with maintenance of green color and sensory quality (Öztürk and Koyuncu, 2021) [108].

Chestnut

Ye and Xu (2011) [118] discovered that post-harvest treatments with salicylic acid reduced the percentage of chestnut deterioration.

(C) Effects of ascorbic acid on pre and post-harvest quality

Pre-harvest application of Ascorbic acid

Various researchers have reported ascorbic acid as effective measure in controlling enzymatic browning of fruits and vegetables (Santerre *et al*., 1988; Sapers *et al*., 1989) [89, 90]. Various kinds of molds (Fungi) in different nuts that are already roasted can be removed by application of ascorbic acid solution along with water (H Clark 2015) [29]. Ascorbic acid is a powerful antioxidant that prevents fruit from browning and aids bacteria killing while drying. Ascorbic acid is a water-soluble vitamin that aids in the detection of reactive oxygen species (Alvarez *et al*., 2000) [10].

Strawberry

AA treatment resulted in delaying,ripening and lowering of microbial populations hence preserved strawberry fruit quality after harvest (Sogvar *et al.*, 2016) [99].

Apricot

Ascorbic acid resulted in increased fruit weight, yield, and maintained quality parameters by slowing respiration rate. Ascorbic acid had been identified as a good option for preserving fruit quality and extending post-harvest life (Batool *et al.,* 2021) [21].

Washington Navel orange

Ascorbic acid treatmentsprays increased fruit length, diameter, leaf nitrogen, potassium, and calcium, V.C., TSS, and TSS/Acidity therfore, extending the fruit crop's post-harvest fruit quality and shelf life (El-Khayat 2020) [35].

(D) Post-harvest application of Ascorbic acid on Horticultural crops

Fruits, Litchi

Ascorbic acid play a role in preventing pericarp browning, dehydration, and microbial attack, as well as maintaining membrane integrity, resulting in better litchi storability (Sun *et al.*, 2010) [102]. During storage, (Duan *et al*., 2009) [34] discovered AsA coated fruit, resulted in decreased anthocyanin synthesis activity. Ascorbic acid enhanced the shelf life of litchi fruit (Sun *et al.,* 2010) [102].

Pear

Application of ascorbic acid effectively resulted in delaying the increase of weight loss, retained greater firmness by increasing the antioxidant property of the fruit (Lin *et al.*, 2008). The firmness of 'Yali' pear fruit treated with ascorbic acid was increased as a result of reduced membrane lipid peroxidation, enzyme activity, and delayed ripening due to increased cell ability to scavenge reactive oxygen species (Ling *et al*., 2007) [61].

Strawberry

Combination of AA and CH application suppressed the fruit softening by reducing cell wall degrading enzyme i.e. polygalacturonase, cellulase and pectin methyl esterase activities. AA treatment maintained the fruit and sensory quality under cold storage (Saleem *et al*., 2021) [88]. Similarly the AA had potential to increase the storage life by reducing the water loss therefore maintaining the fruit quality attributes (Nazoori *et al*., 2020) [79].

Apples

AA significantly induced the metabolic pathways of *P. Caribbica* thereby potentially enhanced the biological control efficacy to post-harvest disease of apple. Using ascorbic acid to boost *P.caribbica*'s oxidative stress tolerance and biocontrol efficacy on apples (Li *et al*., 2014) [62]. As is a water-soluble antioxidant that aided in the detoxification of active oxygen molecules (Noctor and Foyer, 1998) [80] such as fruits like apples (Javdani *et al*., 2013) [48].

Ber

Banik *et al*., (1988) [18] used ascorbic acid in Ber fruits stored at low temperature which reduced physiological weight loss and soil age. TSS levels increased in ascorbic acid-treated 'Umran' Ber fruits maintained at room temperature (Siddiqui and Gupta 1995) [94].

Guava

Ascorbic acid was the effective therapy in extending the storage life of guava fruits in storage (Gill *et al*., 2014) [39]. Because of the delayed ripening, fruits treated with ascorbic acid maintained a higher acidity value during storage (Jayachandran *et al*., 2007) [49].

In guava, (Singh and Pal 2008) [96] found a decreasing trend in phenolic content after storage.

Baladi Mandrin

AA during cold storage, inhibited the generation of O2 radical and H2O2 and increased scavenging activities (DPPH and ABTS). Hence resulted, the ascorbic coating treatment for mandarin fruits made them more resistant to cold storage stress (Loay *et al*., 2019) [64].

Pomegranate

Ascorbic acid coating on pomegranate arils ‘Shishe-Kab’ exhibited prolonged lag time of microorganisms and overall sensory scores found higher at storage (Moradinezhad *et al*., 2020) [78].

Plum

Cell wall modification, particularly changes in cell wall mechanical strength and cell-to-cell adhesion (Valero and Serrano, 2010) [110]. The AsA coatings significantly delayed the loss of firmness.

Flower

Gerbera L.

Ascorbic acid having antibacterial properties, helped to lower bacterial populations while also increasing channel conductivity and uptake of water. (Xing *et al*., 2010) [113] observed that treating fresh-cut lotus root with ascorbic can help minimise browning and extend storage life.

Vegetable

Lettuce

AA increased damage index (hydrogen peroxide and lipid peroxidation). AA decreased yeast and molds counts during storage hence was able to preserve the quality attributes (Xylia *et al*., 2021) [114].

Legume

Mung beans

Ascorbic acid inhibited as a therapy instrument for enzymatic browning suppression. Hence Mung bean sprouts nutraceutical quality improved. (Sikora and Swieca 2018) [95].

Nut

Walnut

In ascorbic acid treatment on walnut the values of TP, AC, colour, and sensory qualities are largely retained. AA edible coatings can be utilised to prolong the shelf life of FKs in a dry environment (Habibie *et al.*, 2019) [40].

Conclusion

In horticultural crops, AA and SA have had a considerable impact in ways that go beyond the scope of this analysis, which was required to focus on a limited number of AA and SA features. There are numerous opportunities for combining them with current technology to provide consumers with high-quality horticultural output while also reducing post-harvest losses, particularly for perishable fruits, vegetables, and ornamental. The scientific community can use AA and SA to look into the biochemical and physiological reactions of horticultural produce. In order to allow safe usage of the technology, more research is needed to understand the diverse responses inside different horticultural crops.

Table 1: Effect of Salicylic acid concentration, time and temperature on Horticultural crops

Commodity	Concentrations of SA	Temperature	Effects	Reference
Liliumcut Flower	SA at 50ppm	24±4°C	Increased morphological characteristic along with flowering quality	Hajizadeh *et al.*, 2013 [43]
'*Cresthaven*' peach cultivar	SA at 2mM	Storage at 2°C Shelf life 20°C	Reduction in loss of fruit firmness and acidity loss	Erogul *et al.*, 2020 [36]
Wax apple *Syzygium samarangenese cv 'Taaptipjaan'*	SA at 0.05mM	13±1°C	Delayed the loss of firmness and maintained physicochemical quality	Supapvanich *et al.*, 2017 [103]
Vitis vinifera L. 'Superior seedless' grape	SA at 4mM	20°C	Lower weight loss,delayed ripening process	Lo'ay*et al.*, 2019

Table 2: Effect of Salicylic acid concentration, time and temperature on Horticultural crops

Commodity	Concentration of SA	Time	Temperature	Effects	Reference
Kinnow	4mM SA	5 minutes	5±1°C	Minimised decay % and maintained the highest level of bioactive compounds for three months.	(Haider*et al.*, 2020)
Apple	0.8 mmol L^{-1} SA	15 minutes	15°C	Increase in antioxidant enzyme activity and decrease in respiration rate	(Mo *et al.*, 2008)
Peach	2-6 mM SA	10th day of harvesting	20°C	Maintained fruit pulp firmness	(Benati *et al.*, 2021) [22]
Mango	1.5-2.0 mM SA	5minutes	12°C	Minimum weight loss, maintained ascorbic acid and maximum shelf life	(Mandal *et al.*, 2018) [70]
Parsley	2 mM SA	5 minutes	1°C	Preserve green colour, suppressed respiration rate and ethylene production.	(Öztürk and Koyuncu., 2021) [108]
Peach cultivar robin	2 mmol SA	5 minutes	4°C	Preservation of preliminary conditions TSS and pH	(Salyari *et al.*, 2021)
Lemon	0.5mM SA	20Minutes	18°C	Sugar and organic acid remain intact	(Escolano *et al.*, 2021) [92]

Table 3: Effect of Pre-harvest application of Ascorbic acid

Commodity	Concentration	Effect	Reference
Apricot (*Prunus Americana* cv. "Canino")	4mM	Preserved fruit quality after harvest and extended post-harvest life	(Batool M. *et al.*, 2021) [21]
Sweet orange (*Citrus sinensis* cv.	400ppm	Extended the fruit's post-harvest quality and shelf life.	(El-Khayat H.H., 2020) [35]

Table 4: Effect of Ascorbic acid concentration, time and temperature on Horticultural crops

Commodity	Ascorbic acid concentration	Time	Temperature	Effect on post harvest treatment	Reference
Guava	100 ppm	5 minutes	6-8°C	Retained fruit quality attributes and enhanced market value	Gill*et al.*, 2014
Plum	40mM	15 minutes	5±1°C	Maintained tissue firmness and lowered respiration rate	Liu *et al.*, 2014
Persimmon	2%	2 minutes	18-24°C	Minimum weight loss, maximum fruit firmness and minimum disease incidence	(Noor *et al.*, 2021) [81]
Mung bean sprouts	20mM	2 hours	4°C	Enzymatic browning inhibited and enhancing nutraceutical quality of sprouts	(Sikora and Swieca, 2018) [95]
Litchi	40mmol/l	15 minutes	5°C	Increase in total soluble solids, soluble sugar, titrable acidity. Hence,lowering the decay rate.	(Sun *et al.*, 2010) [102]
Pelargonium	20µM Fe and 1mM AsA		22-23°C	Highest chlorophyll content in plants.	(Nejad *et al.*, 2019)

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