

Postharvest Salicylic Acid Application Affects the Biochemical Quality and Stability of Strawberry (*Fragaria x ananassa* Duch) cv. Chandler Fruits under Ambient Storage Conditions

ABSTRACT

The present study aimed to determine the effect of postharvest salicylic acid (SA) application on storability and biochemical quality of strawberry fruits cv. Chandler under ambient storage conditions. Freshly harvested fruits were subjected to salicylic acid treatment at 0 (control), 0.5, 1 or 2 mM and fruits were stored at room temperature for 6 days storage studies. Data on physiological loss in weight (PLW), fruit spoilage and biochemical quality of fruits (total soluble solids, titratable acidity, ascorbic acid, reducing and total sugars) were recorded. Results showed that postharvest salicylic acid treatments significantly minimized the PLW and fruit spoilage. At 6 days of storage, the lowest PLW (14.43 %) and fruit spoilage (21.70 %) was observed with SA at 2 mM. All the salicylic acid treatments were effective in retaining the biochemical quality of fruit (total soluble solids, titratable acidity, ascorbic acid, reducing and total sugars). In conclusion, Salicylic acid at 2 mM treatment of strawberry fruits after harvest can be useful in minimizing PLW and fruit spoilage and also maintaining the biochemical quality of fruits during ambient storage conditions.

Keywords: Ambient storage; Fruit quality; Salicylic acid; Strawberry, Storability

1. INTRODUCTION

Strawberry (*Fragaria x ananassa* Duch.; Family *Rosaceae*) is most important berry fruit [1] and widely cultivated in temperate, the **mediterranean** and subtropical regions of the world [2]. Strawberry is a popular fruit due to its appealing fruits shape, pleasant aroma, juicy texture, and nutritional and health benefits. Globally China is leading in production, followed by USA, Mexico, Egypt, Turkey and Spain among others countries are major producers of strawberries [3]. It has been witnessed that worldwide, strawberry production has expanded substantially in recent decades [4]. India's temperate regions of Jammu Kashmir, Himachal Pradesh, and Uttarakhand are widely renowned for commercial strawberry growing long back; but its commercial cultivation has increased substantially in subtropical and tropical plains in recent decades. Growers of Haryana, Punjab, Maharashtra, Karnataka, Uttar Pradesh and in vicinity of Delhi are successfully growing strawberries in the winter using planting materials from the Himachal Pradesh and Uttarakhand [5].

Strawberry is a non-climacteric and highly perishable fruit. Highly perishability fruits have very short storage and shelf-life which is one of the primary bottlenecks the strawberries fresh market supply chain. The postharvest management practices greatly influence the shelf life and quality of strawberry fruits. **The respiration** rate and ethylene production does not increase sharply during ripening [6]. After harvest, mechanical damage, physiological

deterioration, water loss, and microbial spoilage rapidly decrease the quality of the fruit, resulting in post-harvest losses [7]. The most efficient approach for maintaining strawberry fruit quality is postharvest fast cooling and storage at low temperatures (0-4 °C) [8]; although, ensuring optimal storage and temperature control after harvest is not always achievable because of the short storage life of fruit, insufficient cold storage and cold chain facilities.

Fruit postharvest treatment solutions focus primarily on limiting water loss, preserving biochemical quality, and extending fruit shelf life while preventing the emergence of postharvest infections. Several synthetic compounds have been used to extend the postharvest life of various fruits; nonetheless, public concern over fungicide residues is growing. Because of the negative impacts of pesticides on human health and the environment, it is critical to focus on better fungicide alternatives [9]. Use of natural compounds in postharvest storage and quality control of fruits has attracted attention among the scientific community and end users during the last few decades. Salicylic acid (SA), a natural plant molecule that has the key role in photosynthesis, plant water relations, various enzyme activities and its effect on the plants exposed to various biotic and abiotic stresses [10]. Salicylic acid has been shown to play an important function in the expression of pathogenic genes and to impart resistance to infections [11, 12]. It has been demonstrated that use of salicylic acid to be effective in preserving the quality of numerous fruits during storage [13-16]. In furtherance, the current study sought to determine the effect of postharvest salicylic acid spray on strawberry storability and fruit quality under ambient environments.

2. MATERIAL AND METHODS

The experiment was conducted at the Division of Horticulture, Faculty of Agriculture (SKUAST-K), Wadura Campus, Sopore, J&K (India) during the year 2017 & 2018. Freshly harvested strawberry cv. Chandler fruits were used for postharvest salicylic acid treatment. experiment was laid out in Complete Randomized Design where each treatment was replicated five times. The fruits with uniform color and size were individually picked from Strawberry farm at the Faculty and immediately transferred to the laboratory. The salicylic acid at 0 (control), 0.5, 1 and 2 mM concentration was used for postharvest treatment of fruits. In each treatment, 50 fruits were treated with respective SA concentration and the treated fruits were kept in polypropylene terephthalate (PET) packaging under ambient conditions for storage studies. One another lot of 10 fruits was also used for initial data recording on physio-chemical parameters of un-treated fruits. Observations on physiological loss in weight (PLW), decay percentage and biochemical quality attributes of fruits were assessed at 2, 4 and 6 days of storage.

The PLW was worked out by subtracting the final weight fruit from initial weight fruit weight and then divided by initial fruit weight in each treatment on specified days after storage using following formula:

$$\text{PLW (\%)} = \frac{(\text{Initial weight} - \text{Final weight}) \times 100}{\text{Initial weight}}$$

The Fruit spoilage percentage was worked out by subtracting the number of decay fruit from the total number of fruits kept for storage in each treatment at specified days after storage and the divided by total number of stored fruits using following formula:

$$\text{Spoilage (\%)} = \frac{(\text{No. of fruits} - \text{No. of decay fruits}) \times 100}{\text{Total no. of stored fruits}}$$

The total soluble solid (TSS) was determined using a hand refractometer (Erma, Japan). Titratable acidity was determined using phenolphthalein as an indicator, ascorbic acid with 2,6-dichlorophenol indophenol indicator, and sugars (total and reducing sugars) using Fehling's solutions [17].

The podded data of two years study were analysed using the Complete Randomized Design methodological approach [18]. The significance of the difference in treatment means a 5% level of significance was assessed using the critical differences (CD).

3. RESULTS AND DISCUSSION

Data revealed that PLW in strawberry cv. Chandler was increased with increase in storage duration and recorded the highest in untreated fruit at all three dates of observations (Fig 1). Postharvest Salicylic acid treatment found effective in reducing the PLW of fruits (Fig 1). Highest PLW at 2, 4 and 6 days storage was recorded in control fruits (4.36, 11.04 and 15.94 %, respectively). At 6 days of ambient storage, 2 mM salicylic acid provided the minimum PLW of 13.76 %. This might possibly be due to the fact that salicylic acid reduces transpiration and consequently weight loss by inhibiting stomatal reactions [19]. Wolucka *et al.*, 2005 [20] has demonstrated that salicylic acid, as an electron donor, produces free radicals that disrupt normal respiration, leading in reduced weight loss in fruits. Salicylic acid prevents softening and weight loss by decreasing ethylene levels during storage. Our results are consistent with those of Mahsa *et al.* [21], who observed that the salicylic acid decreased weight loss in strawberry.

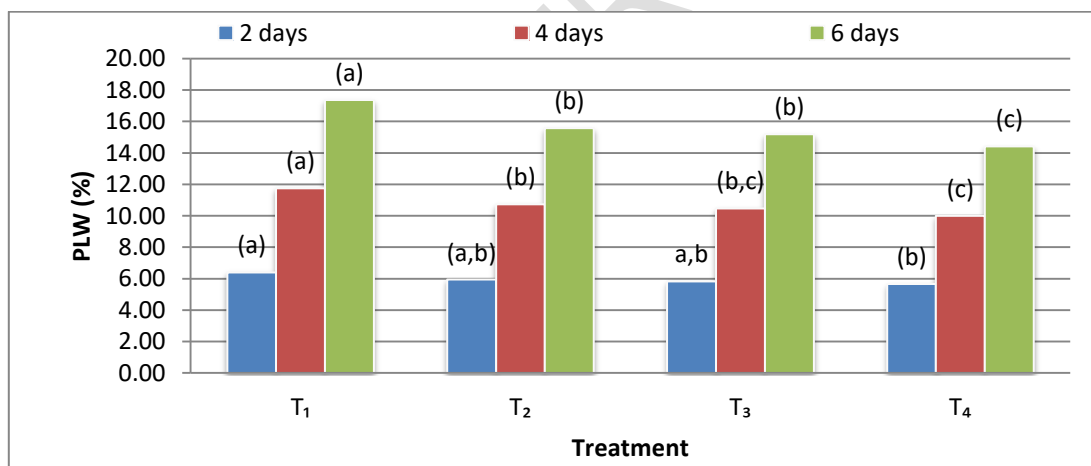


Fig 1: Physiological loss in weight (PLW) of strawberry cv. Chandler fruits as affected by postharvest salicylic acid treatments. Salicylic acid concentration:- T₁: 0 mM (control), T₂: 0.5, T₃: 1.0 mM T₄: 2.0 mM.

Fruit spoilage was observed to be increased with increase in storage duration and recorded the highest in un-treated fruit at all tree dates of observations (Fig 2). The fruit spoilage was greatly minimized with the salicylic acid treatment at 6 days of storage (Fig 2). The highest spoilage of fruits at 2, 4 and 6 days storage was recorded under control (4.36, 11.04 and 15.94 %, respectively). At 6 days of storage, control fruit showed 32 % spoilage while salicylic acid treated fruit with 0.5, 1 and 2 mM exhibited significantly lower spoilage i.e. 27.60, 24.10 and 21.70 %, respectively. Lower rotting percentage in SA treated fruits in our study may be attributed to the potential of salicylic acid in triggered defense enzymes

chitinase, POD, and PAL to minimize fungal and bacterial infections that cause rotting of fruits [10, 22]. According to Xu and Tian [23], salicylic acid stimulated the defense system by increasing the activity of antioxidant enzymes, resulting in better resistance to fungal assault in treated sweet cherry fruits.

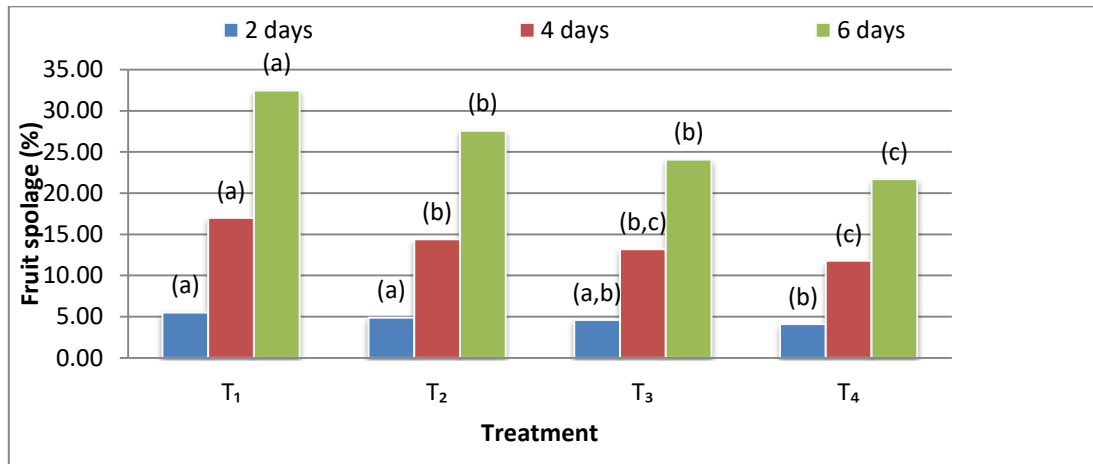


Fig 2: Fruit spoilage (%) of strawberry cv. Chandler as affected by postharvest application of salicylic acid treatments. Salicylic acid concentration:- T₁: 0 mM (control), T₂: 0.5, T₃: 1.0 mM T₄: 2.0 mM. Bars with same alphabets within same date of observation have no-significant difference.

Fruit TSS at harvest ranged from 12.02 to 12.08 °Brix (Fig 3). It increased with the progression of storage duration and rate of increase was higher in control fruits compared to salicylic acid treated fruits (Fig 3). At 6 days of storage, control fruits had 13.65 °Brix TSS while it was 13.09, 12.77 and 12.63 °Brix in the 0.5, 1 and 2 mM salicylic acid treated fruits, respectively. Results also indicated that all three salicylic acid doses had similar effects on TSS determined at 2, 4 and 6 days of storage study. The higher value of total soluble solids in control fruits might be due to the decrease in fruit water content and the conversion of cell wall components such as starch, protein, pectin, and hemicelluloses into simple soluble sugars during storage, resulting in the higher TSS value. Wills *et al.* [24] reported that starch is hydrolyzed into mono and disaccharides, resulting in an increase in the soluble solid content of tin fruits. Salicylic acid is an ethylene inhibitor; which slow down the ripening process by lowering respiration rates and metabolic activities [25, 26]. Our findings are consistent with those of Sayyari *et al.* [27] and Salari *et al.* [28] who found that salicylic acid treatment, resulted in a considerably sluggish increase in total sugar content in pomegranate fruit during storage. Awad [29] recorded that the total sugar of Flordaprince peaches in cold storage settings reduced due to the application of a higher salicylic acid concentration. Use of salicylic acid have also been reported to slow down the rate of respiration, prolonging the increase in SSC content in strawberry [9] and banana [30].

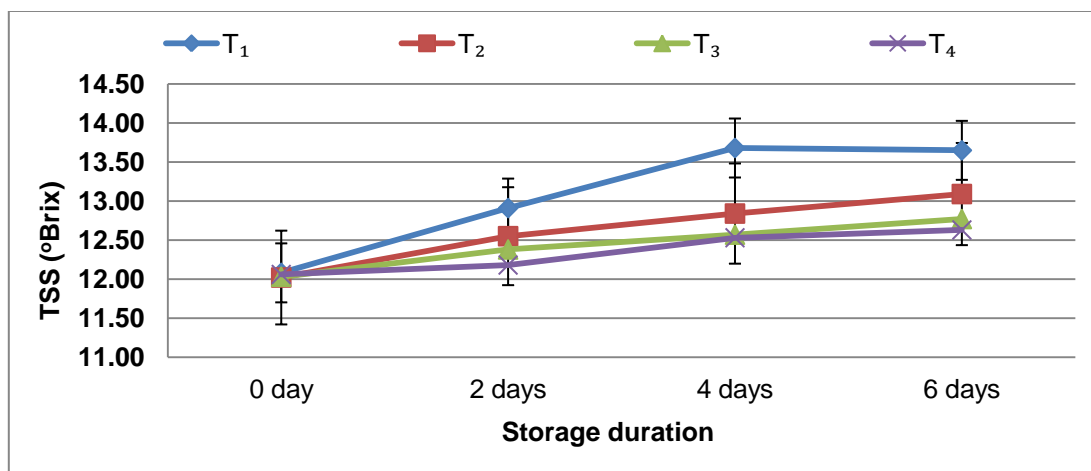


Fig 3: Total soluble solids (TSS °Brix) of strawberry cv. Chandler as affected by postharvest application of salicylic acid treatments. Salicylic acid concentration:- T₁: 0 mM (control), T₂: 0.5, T₃: 1.0 mM T₄: 2.0 mM.

Titrateable acidity in fruits at harvest ranged from 0.419 to 0.429 °Brix (Table 1). It decreased with the progression of storage duration and rate of decrease was slow in salicylic acid treated fruits compared to control (Table 1). At 2 day of storage, no significant different was found in fruit acidity due to salicylic acid treatment. At 6 days of storage, 0.5, 1 and 2 mM salicylic acid treated fruits had 0.292, 0.307 and 0.316 % titrateable acidity while control fruits showed the lowest acidity of 0.269 %. The effect of salicylic acid at 1 and 2 mM on acidity was statistically at par at both 4 and 6 days of storage (Table 1). It has been reported that fruit uses the acids during maturity, hence organic acids in fruits diminish while storage [31]. Because salicylic acid inhibits ethylene biosynthesis [33], it aids in slowing the rate of respiration and the conversion of acids into sugars while storage. Our findings correspond with those reported in banana [30] and apple [34].

Table 1: Effect of postharvest application of salicylic acid on titrateable acidity and ascorbic Acid of strawberry cv. Chandler fruits

Treatment	Titrateable acidity (%)				Ascorbic Acid (mg 100g ⁻¹)			
	0 day	2 days	4 days	6 days	0 days	2 days	4 day	6 days
T ₁ -0.00 mM	0.429	0.379	0.331	0.269	61.17	54.26	49.73	41.48
T ₂ -0.50 mM	0.420	0.379	0.346	0.292	60.05	55.38	53.01	46.56
T ₃ -1.00 mM	0.419	0.379	0.357	0.307	60.30	57.58	54.46	46.83
T ₄ -2.00 mM	0.424	0.399	0.365	0.316	60.74	59.42	56.30	49.25
SEd±	0.13	0.120	0.10	0.008	1.88	1.76	1.54	1.42
CD(0.05)	NS	NS	0.022	0.019	NS	3.91	3.36	3.10

Fruit ascorbic acid content at harvest ranged from 60.05 to 60.74 mg 100 g⁻¹ (Table 1). It decreased with the increase in the storage duration and rate of decrease was higher in control fruits compared to salicylic acid treated fruits. Data revealed that the salicylic acid treatment significantly minimized decrease of ascorbic acid in fruit (Table 1). Salicylic acid at 2 mM resulted the significantly the highest ascorbic acid content (59.42, 56.30 and 49.25 mg 100 g⁻¹) at 2, 4 and 6 days of storage, respectively. The lowest ascorbic acid content at all three dates of study was noted in control fruits (54.26, 49.73 and 41.48, respectively). According to Awad *et al.* [29], changes in fruit ascorbic acid concentration during storage dropped rapidly as storage duration increased. Earlier reports also reveal that post-harvest salicylic acid treatments have been shown to be beneficial in maintaining ascorbic acid in

fruits [35]. Salicylic acid slow down the drop of ascorbic acid content and prevent ascorbic acid dissolution in pineapple [36], hence high ascorbic acid amounts in treated fruit might improve fruit quality.

Reducing sugar in fruit at harvest ranged from 4.50 to 4.63 % (Table 2). It increased with the progression of storage duration and rate of increase was higher in control than salicylic acid treated fruits. The salicylic acid treatment didn't influenced the reducing sugars in fruits at 2 days of storage, but it had substantial impact later on 4 and 6 days on storage studies (Table 2). At 4 days of storage, the reducing sugars estimated in salicylic acid at 0.5, 1 and 2 mM treated fruits were statistically at par. At 6 days of storage, the highest reducing sugars in fruits was estimated in control fruits while 0.5, 1 and 2 mM salicylic acid treated fruits had reducing sugar value of 5.72, 5.49 and 5.32 %, respectively (Table 2). Total sugars in fruit at harvest ranged from 7.93 to 8.03 % (Table 2). It also increased with the progression of storage duration and rate of increase was higher in control than salicylic acid treated fruits. The effect of salicylic acid significantly influenced the total sugars in fruits at 2, 4 and 6 days of storage studies (Table 1). At 2, 4 and 6 days of storage, the highest total sugars 9.42, 10.05 and 10.24, respectively were observed in control fruits followed by salicylic acid treatment at 0.5 mM, 1 mM and 2mM. At 6 days of storage, total sugars in fruits treated with 0.5, 1 and 2 mM salicylic acid were 10.15, 10.15 and 9.44 %, respectively Table 2.

Table 2: Effect of postharvest application of salicylic acid on reducing sugars and Total sugars of strawberry cv. Chandler fruits

Treatment	Reducing sugars (%)				Total sugars (%)			
	0 day	2 days	4 days	6 days	0 days	2 days	4 day	6 days
T ₁ -0.00 mM	4.50	5.19	5.73	6.00	8.03	9.42	10.05	10.24
T ₂ -0.50 mM	4.51	5.11	5.33	5.72	7.93	9.02	9.84	10.15
T ₃ -1.00 mM	4.62	4.96	5.23	5.49	7.93	8.85	9.27	9.94
T ₄ -2.00 mM	4.63	4.87	5.13	5.32	7.96	8.29	8.92	9.44
SEd±	0.14	0.15	0.16	0.18	0.24	0.28	0.28	0.31
CD(0.05)	NS	NS	0.34	0.38	NS	0.63	0.62	0.68

Respiration process breakdown the acids into sugars thereby titrable acidity in fruits diminishes and sugars increases during storage [32]. Bhattatai and Gautam [31] also pointed out that fruit uses the acids during maturity and organic acids in fruits diminish in storage. Because salicylic acid inhibits ethylene production [33], it slows the rate of respiration and acid-to-sugar conversion during storage. Our findings are in accordance with the results reported in apple [34].

CONCLUSION

Postharvest salicylic acid treatments on strawberry cv. Chandler fruit considerably reduced the PLW and fruit spoilage. After 6 days of storage under ambient conditions, SA at 2 mM had the lowest PLW and fruit spoilage. Also, the SA treatment found effective in maintaining the biochemical quality (TSS, acidity, ascorbic acid, reducing sugars and non-reducing sugars) of the fruits during storage. Hence, postharvest salicylic acid treatment of strawberry fruits at 2 mM can help to reduce PLW and fruit spoilage while also maintaining the biochemical quality of the fruits under ambient storage conditions.

REFERENCES

1. Stewart PJ. *Fragaria*: history and breeding. In: Folta KM, Kole C, Editors. Genetics, Genomics and Breeding of Berries. Science Publishers, New Hampshire, USA; 2011 pp. 114-137.
2. Hancock HF. Strawberries. In: Erez A, Editor. Temperate fruit crops in warm climates. Dordrecht: Kluwer Academic Publishers; 2020.
3. FAOSTAT. 2021. Food and Agriculture Organization, Italy: Rome; 2021. Available: <http://faostat.fao.org>. [Accessed: November 17, 2021].
4. García-García I, García-Parrilla MC, Santos-Dueñas IM, Mas A, Cañete-Rodríguez AM. Strawberry. Editor(s): Charis M. Galanakis, Valorization of Fruit Processing By-products; London: Academic Press, pp.281-300, 2020.
5. Pramanick KK, Kishore DK, Sharma SK, Das BK, Murthy BNS. Strawberry Cultivation under Diverse Agro-Climatic Conditions of India, International Journal of Fruit Science. 2013;13:36-51
6. Perkins-Veazie PM, Huber DJ, Brecht JK. *In vitro* growth and ripening of strawberry fruit in the presence of ACC, STS or propylene. Annals of Applied Biology. 1996;128:105-116.
7. Cordenunsi BR, Genovese MI, Nascimento JRO, Hassimotto NMA, Santos RJ, Lajolo FM. Effects of temperature on the chemical composition and antioxidant activity of three strawberry cultivars. Food Chemistry. 2005;91:113-121.
8. Tahir HE, Zou X, Jiyong S, Mahunu GK, Zhai X, Mariod AA. Quality and postharvest-shelf life of cold-stored strawberry fruit as affected by gum arabic (*Acacia senegal*) edible coating. J. Food Biochem., 2018;42(3):e12527.
9. Babalar M, Asghari M, Talaei A, Khosroshahi A. Effect of pre and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of Selva strawberry fruit. Food Chemistry. 2007;105:449-453.
10. Hayat Q, Hayat H, Irfan M, Ahmad A. Effect of exogenous salicylic acid under changing environment: A review. Environmental and Experimental Botany. 2010;68:14-25.
11. Pasquer F, Isidore E, Zarn J, Keller B. Specific patterns of changes in wheat gene expression after treatment with three antifungal compounds. Plant Molecular Biology. 2005;57:693-707.
12. Makandar R, Essig JS, Schapaugh MA, Trick HN, Shah J. Genetically engineered resistance to Fusarium head blight in wheat by expression of *Arabidopsis NPR1*. Molecular Plant-Microbe Interactions. 2006;19:123-129.
13. Romani RJ, Hess BM, Leslie CA. Salicylic acid inhibition of ethylene production by apple discs and other plant tissues. Journal of Plant Growth Regulator. 1989;8:63-69.
14. Zeng KF, Cao JK, Jiang WB. Enhancing disease resistance in harvested mango (*Mangifera indica* L. cv. Matisu) fruit by salicylic acid. Journal of the Science of Food and Agriculture. 2006;86:694-698.
15. Wang L, Chen S, Kong W, Li S, Archbold DD. Salicylic acid pre-treatment alleviates chilling injury and affects the antioxidant system and heat shock proteins of peaches during cold storage. Postharvest Biology and Technology. 2006;41:244-251.
16. Mo Y, Gong D, Liang G, Han R, Xie J, Li W. Enhanced preservation effects of sugar apple fruits by salicylic acid treatment during postharvest storage. Journal of the Science of Food and Agriculture. 2008;88:2693-2699.
17. Ranganna S. Handbook of analysis and quality control for fruit and vegetable (2nd edition). New Delhi: Tata McGraw-Hill; 1986.
18. Panse VG, Sukhatme, PV. Statistical Methods for Agricultural Workers, 4th Edn. ICAR Publication: New Delhi; 1985.

19. Manthe B, Schulz, Schnable MH. Effects of salicylic acid on growth and stomatal movement on *Vicia faba* L., evidence for salicylic acid metabolism. *Journal Chemistry Ecology*. 1992;18:1525-1539.
20. Wolucka BA, Goossens A, Inze D. Methyl jasmonate stimulates the de-novo biosynthesis of vitamin C in plant cell suspensions. *Journal of Experimental Botany*. 2005;56:2527-2538.
21. Mahsa G, Sadegh S, Vahid A. Extending postharvest longevity and improving quality of strawberry (*Fragaria ananassa* Duch cv. 'Gaviota') fruit by postharvest salicylic acid treatment. *Journal of Agricultural Studies*. 2015;3(2):17-36.
22. Jiankang C, Kaifang Z, Vand-Weibo J. Enhancement of postharvest disease resistance in Ya Li pear (*Pyrus bretschneideri*) fruit by salicylic acid sprays on the trees during fruit growth. *European Journal of Plant Pathology*, 2006;114: 363-378.
23. Xu X, Tian S. Salicylic acid alleviated pathogen-induced oxidative stress in harvested sweet cherry fruit. *Postharvest Biology and Technology*. 2008;49:379-385.
24. Wills RBH, Bambridge PA, Scott KJ. Use of flesh firmness and other objective tests to determine consumer acceptability in Delicious apples. *Australian Journal of Experimental Agriculture and Animal Husbandry*. 1980;20:252-58.
25. Pila N, Gol NB, Rao TVR. Effect of postharvest treatments on physico-chemical. *American-Eurasian Journal of Agricultural and Environmental Science* 2010;9(5):470-479.
26. Rademacher W. Effects on gibberellin biosynthesis and other metabolic pathways. *Annual Review of Plant Physiology and Plant Molecular Biology*. 2000;512:501-531.
27. Sayyari M, Babalar M, Kalantari S, Serrano M, Valero D. Effect of salicylic acid treatment on reducing chilling injury in stored pomegranates. *Postharvest Biology and Technology*. 2009;53(3):152-154.
28. Salari N, Bahraminejad A, Afsharmanesh G, Khajehpour G. Effect of salicylic acid on post-harvest quantitative and qualitative traits of strawberry Cultivars. *Advances in Environmental Biology*. 2013;7(1):94-99.
29. Awad RM. Effect of post-harvest salicylic acid treatments on fruit quality of peach cv. Flordaprince during cold storage. *Australian Journal of Basic and Applied Science*. 2013;7(7):920-927.
30. Srivastava MK, Dwivedi UN. Delayed ripening of banana fruit by salicylic acid. *Plant Science*. 2000;158:87-96.
31. Bhattarai DR, Gautam DM. Effect of harvesting method and calcium on postharvest physiology of tomato. *Nepal Agriculture Research Journal*. 2006;7:37-41.
32. Ball, JA. Evaluation of two lipid based edible coating for their ability to preserve post-harvest quality of green bell peppers. Master Diss., Faculty of the Virginia Polytechnic Institute and state University. Blacksburg, USA: Virginia; 1997.
33. Leslie CA, Romani RJ. Inhibition of Ethylene Biosynthesis by Salicylic Acid. *Plant Physiology*. 1988;88:833-837.
34. Han T, Li LP. Physiological effect of salicylic acid on storage of apple in short period. *Plant Physiology Communications*. 1997;33:347-348.
35. Shafiee M, Taghavi TS, Babalar M. Addition of salicylic acid to nutrient solution combined with postharvest treatments (hot water, salicylic acid, and calcium dipping) improved postharvest fruit quality of strawberry. *Scientia Horticulturae*. 2010;124:40-45.
36. Lu X, Sun D, Li Y, Shi W, Sun G. Pre- and post-harvest salicylic acid treatments alleviate internal browning and maintain quality of winter pineapple fruit. *Scientia Horticulturae*. 2011;130:97-101.

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