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Improving the postharvest shelf life of apricot fruits (*Prunus armeniaca* L. cv. Amal) using preharvest application of spermidine, salicylic acid and sodium nitroprusside

S.M. Abd Elwahab, A.M. Abdallatif*and S.A.E. El-Saeed

*Pomology Department, Faculty of Agriculture, Cairo University, Giza, Egypt. *E-mail: abdo.abdullatif@agr.cu.edu.eg*

Abstract

Maturity at harvest is crucial for determining the quality of apricot fruit, a highly perishable crop with limited storage potential. The study aims to extend the storage life and preserve the quality of "Amal" apricots through various preharvest treatments. Preharvest application of spermidine at 1 mmol, salicylic acid at 1 mmol and sodium nitroprusside at 25µm were done at 15 or 30 days before harvesting. The treated fruits were packed and stored for up to 7 weeks at 5°C and 90–95 % R.H. Fruit quality parameters were evaluated at harvest and every 7 weeks. Results showed that weight loss, total soluble solids, maturity index, total sugars content, respiration rate and total carotenoids increased whereas, firmness, total acidity, and total phenols, decreased by increasing storage periods. The obtained results showed the efficacy of preharvest spermidine treatment followed by salicylic acid and then sodium nitroprusside in delaying fruit maturation and maintaining fruit quality. The study suggests that these treatments might be promising for maintaining apricot fruit quality and extending storage life and marketing of apricot.

Key words: Apricot, spermidine, salicylic acid, sodium nitroprusside, cold storage, fruit quality

Introduction

The apricot (*Prunus armeniaca* L.) is one of the popular and economically important deciduous fruit species belonging to family Rosaceae (Roussos *et al.*, 2011). Apricot is highly appreciated by consumers around the world due to its attractive appearance, flavor, aroma, delicious taste and nutritional value. The fruit pulp is rich with bioactive compounds, *i.e.,* amino acids, carbohydrates, minerals, organic acids, flavonoids, vitamins (A and C), β-carotene, and polyphenolics (Karatas, 2022). The worldwide production of apricots is 3.86 million tons; Mediterranean countries produce more than 60% of world production. Turkey is the world's top apricot producer, contributing with 21% of the global production, followed by Iran, Uzbekistan and Italy; Egypt ranked the 14th in terms of production (FAO, 2023). Fruit ripening is a very complicated process resulting from a change in the taste, color, texture, carbohydrate, phenolic compounds, and organic acids (Prasanna *et al.*, 2007).

Apricots are highly perishable fruit with a very short postharvest life; apricots are rapidly losses there texture, and become susceptible mechanical damaged and microbial decay. Low temperatures, application of ethylene inhibitors and modified-atmosphere storage can reduce fruit decay and extend fruits marketing life (Wu *et al.*, 2015). Moreover, the use of suitable pre harvest treatments may delay these ripening processes, and extended fruit market life. Salicylic acid (SA) play a key role in extending the postharvest life of fruits *via* inhibiting the biosynthesis and action of the ethylene thus maintaining fruits quality (Asghari and Aghdam, 2010). Several studies have recorded the important role of salicylic acid in maintenance of fruit quality parameters delaying fruit ripening through inhibition of ethylene biosynthesis, hence sustain fruit quality, and prolonging the marketable life (Abd Elwahab *et al.*, 2020).

Polyamines (PAs) are biological compounds of low molecular weight with aliphatic nitrogen groups, polyamines are associated with ripening and regulation of fruit quality-related traits and their preharvesting application has been linked with an inhibition of postharvest decay, reduce respiration and ethylene production (Vaka *et al.,* 2020). Sodium nitroprusside (SNP) is the main sources of nitro oxide (NO) which is a natural free-radical gas that can protect against oxidative damage (Wendehenne *et al.*, 2001). SNP treatment has a potential for delaying senescence and keeping the quality of fresh fruit by improving antioxidant capacity and lowering detrimental enzymatic reactions (Hedayati and Sadeghi (2022). SNP was used to suppress ethylene production and maintain fruit quality (Abd Elwahab *et al.*, 2020). The objectives of this study was to evaluate pre harvest application of spermidine, salicylic acid, sodium nitroprusside to delay postharvest decay and improve quality properties during cold storage of Amal apricot.

Material and methods

Fruit material and preharvest treatment: Apricot tress (*Prunus armeniaca*, L. cv. Amal) of eight years old, budded on seedling apricot rootstock and grown in private orchard located in El-Kattatba, Behira governorate were selected for the current experiment. Trees were planted at 5x5 meters in sandy soil under drip irrigation system and received the common cultural practices. Thirty-six trees healthy and as uniform as possible were used in the experiment. Randomized complete block design was followed in this investigation. The apricot trees were sprayed at 30 or 15 days before harvesting, with four treatments, including control (untreated trees), spermidine (Spd) at 1 mmol, salicylic acid (SA) at 1 mmol, sodium nitroprusside (SNP) at 25µm, each treatment replicated three times each replicate had 3 trees. Tween-80 (0.1%) as surfactant was added to all spraying solutions (3 liter for each

tree) and applied directly for the trees with a handheld sprayer until runoff in the early morning.

Fruit storage: Apricot fruits were harvested from each treatment at the predictable maturity date (in the middle of May) based on the fruit color (yellowish green) (Abd Elwahab, 2015). Samples of 15 mature fruits were taken from each replicate of each treatment at the harvest date for determining fruit quality at harvest, for each treatment. Fruits with homogeneous size, and color without any signs of mechanical damage were selected and transported to the postharvest laboratory of the Pomology Department, Faculty of Agriculture, Cairo University. Treated fruits, were rapidly and carefully placed in three perforated cartoon boxes for each treatment; decay percentage, weight loss and fruit quality parameters was evaluated regularly at different sampling time (7, 14, 21, 28, 35, 42, and 49 days) of cold storage. Boxes of all treatments were stored at 5ºC and 90-95% RH.

Fruit quality assessments during cold storage: Fruit samples in all experimented treatments were subjected to series of quality evaluation during cold storage.

Respiration rate: Fruit sample (n=10) for each treatment were weighed and placed in 1-liter jars at 5° C (cold storage conditions). The jars were sealed with a cap and a rubber septum. Servomex Inst. (Model 1450C) was used to measure oxygen content and carbon dioxide production. Respiration rate was calculated as mL CO_2 /kg/h.

Weight loss percentage: The difference between the initial fruits weight (W1) of the fruits and fruits weight at each sampling date (W2) was calculated according to Shah and Hashmi (2020) using the following equation

$$\text{Weight loss\%} = \frac{(W1-W2)}{W1} \times 100$$

Total soluble solids (TSS) %, total acidity (TA) and TSS/ Acids: Sample of apricot fruits pulp were ground and the freshly prepared juice were used for determine soluble solids content using digital refractometer (Pocket refractometer PAL-1, Atago). Total acidity, expressed as malic acid%, was determined by titrating 5-ml of fruit juice with 0.1N sodium hydroxide using phenolphthalein as indicator. TSS/Acids ratio was calculated by divided total soluble solids over total acidity values

$$\text{Total acidity (\%)} = \frac{\text{NaOH used (mL)} \times \text{M of NaOH} \times 0.0064}{\text{Juice used (mL)}} \times 100$$

Decay percentage: Fruits were examined visually for decay symptoms including all of the spoiled fruits resulted from rots, fungus, bacterial and pathogens were assessed and the decay percentage were calculated as follows:

$$\text{Decay (\%)} = \frac{\text{Number of decayed fruits}}{\text{No. of fruits at beginning of storage}} \times 100$$

Fruit firmness: Fruit pulp firmness was measured using a hand pressure firmness tester (L-10, AMETEK Inc.,) and the results were expressed in (kg/cm^2).

Total sugars: Total sugar content was determined using phenol-sulphuric acid method (Dubois *et al.*, 1956). Fruit samples (0.5 g) were homogenized in 20mL of 70% ethanol. 1 mL of the extract was treated with 1mL of 5% phenol and 5mL of 98% sulfuric acid. The absorbance was read at 490 nm. A standard curve was generated using a standard glucose solution, and total sugar content was expressed as mg glucose equivalents per g fresh weight.

Total phenols: Total phenol was determined spectrophotometrically using Folin-Ciocalteu method (Singleton *et al.*, 1999). A 0.5 sample of apricot tissue was extracted with 20 mL methanol (80%). 1mL of this extract was mixed with 1mL of Folin-Ciocalteu reagent than 4mL of 20% sodium carbonate was added. The mixture was incubated for 90min in darkness before the absorbance was measured at 725 nm. Gallic acid was used as a standard. The results were expressed as mg gallic acid equivalent in 100 g fresh weight (mg/ 100 g FW).

Carotenoids content: Fruit pulp samples (0.5g) were homogenized in 20mL of 80% acetone in a dark glass bottle at room temperature. The absorbance was measured using a spectrophotometer at the wavelengths of 480 and 510 nm. Total carotenoid content was calculated according to Hmmam *et al.* (2023) as $\mu g\ g^{-1}$ of fresh weight.

Experimental design and statistical analysis: All results of physio-chemical parameters were performed in triplicate using completely randomized factorial design (Snedecor and Cochran 1967). The homogeneity of variance between the two seasons was assessed using Levene's test (Levene, 1960). Data were subjected to combined analysis using the procedure of MSTAT-C program. When significant differences were detected, treatment means were compared by LSD range test at the 5% level of probability in the two investigated seasons (Duncan, 1955).

Results and discussion

Respiration rate: All preharvest treatments exhibited a gradual increase in respiration rate during storage period (Fig. 1).Pre harvest treatments of Spd, SNP and SA proved the ability in reducing respiration rate at harvest time and after 7 weeks of cold storage compared to control treatment. Respiration rate is a crucial indicator of fruit metabolic activity and a valuable tool for assessing fruit quality and postharvest life. The rate of respiration reflects the ongoing metabolic processes associated with ripening, senescence, and fruit quality (Pott *et al.,* 2020). Those treatments were able to impeding the ripening hormone (ethylene) and respiration rate in such manner thus reduced the whole bioactive reactions of apricot fruits. However, Spd treatment resulted in the least increase of respiration rate compared to the control and other treatments. Fruits treated with SNP displayed a slightly higher respiration rate than Spd but lower than SA. The control group exhibited the highest respiration rate throughout the storage period.

The slower respiration rate in treated fruits may be explained by slowing ripening through pre harvest treatments as spermidine is a polyamine known to influence various processes related to senescence and ripening (Li *et al.*, 2010). Spermidine might reduce respiration and influence the production or signaling of ethylene, a plant hormone known to promote ripening and respiration and might down-regulate the expression of ethylene biosynthesis genes (Mehta *et al.,* 2002), inhibit the activity of enzymes responsible for ethylene production (Li *et al.*, 2010). This could indirectly contribute to a slower decline in respiration rate by preserving cellular machinery involved in respiration. Also, SA application might slightly decrease respiration rate, potentially by influencing ethylene biosynthesis or signaling pathways (Li *et*

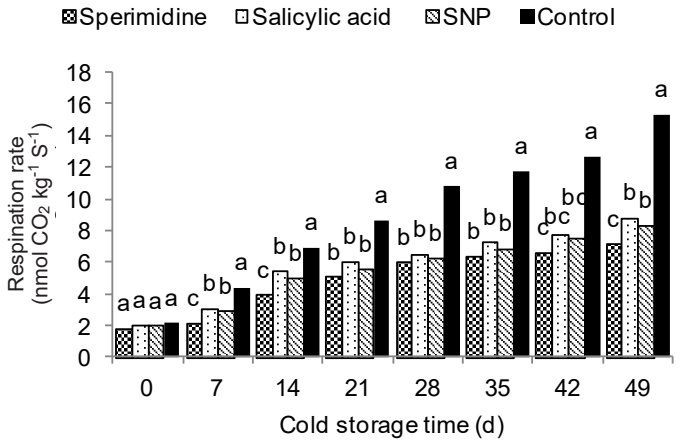

Fig. 1 Effect of per-harvest treatments on respiration rate of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test).

al., 2011). SA might slightly decrease respiration rate by down regulating ethylene biosynthesis or blocking it signaling pathways (Erbaș *et al.*, 2018). Therefore our investigation in agreement with other studies proved that sodium nitroprusside could significantly control fruit ripening *via* reducing the respiration rate and inhibited ethylene production (Saba and Moradi, 2017). SNP might act as nitric oxide (NO) donor, which can impact various physiological processes, potentially including reducing respiration rate (Neill *et al.*, 2002). Similar results showed that preharvest application reduced respiration rate during cold storage (Erbaș *et al.*, 2018) on spermidine (Abd Elahab *et al.*, 2020) on salicylic acid and sodium nitroprusside

Weight loss: Weight loss is a key factor affecting apricot quality, marketability and visual fruit appearance. Data in Fig. 2 show the effect of preharvest applications of spermidine, salicylic acid, and sodium nitroprusside on apricot weight loss during cold storage. Fruit weight loss increased progressively in all treatments, including the control by increased storage period. Spermidine treatment displayed the lowest values of weight loss, followed by SA and SNP treatments compared to the control.

Mature climacteric fruits undergo a series of metabolic processes, such as the increase in transpiration and respiration, the correlation between weight loss and respiration rate was highly positive (Hmmam *et al.*, 2023). The fruit lose weight due to moisture loss and respiration as it is prone to considerable weight loss during storage. The observed effect of Spd on weight loss can be

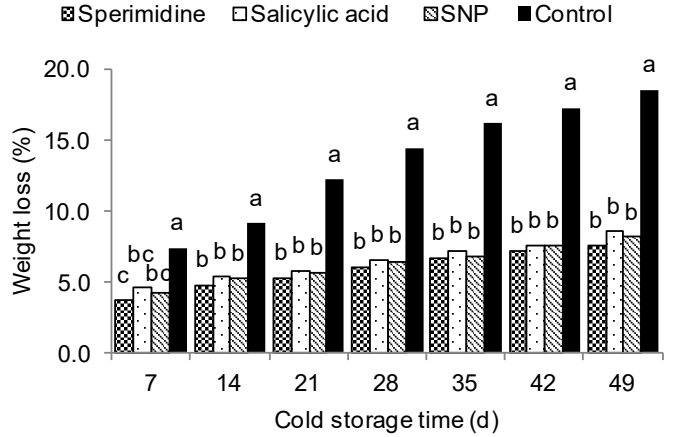

Fig. 2. Effect of per-harvest treatments on weight loss (%) of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test).

explained by influencing water retention in fruits and regulation of enzymes involved in transpiration process (Wang *et al.*, 2018). SA with cold storage reduced transpiration, probably by retarding the rate of respiration in fruits and thus led to minimize the impact of weight loss of apricot fruits and this led to improve storability of apricot fruits. SNP, a donor of nitric oxide (NO), can influence the activity of aquaporins, which are channels that regulate water transport in plants (Aroca *et al.*, 2006). Similar results have been reported by on the effect of spermidine, salicylic acid and sodium nitroprusside (Erbaș *et al.*, 2018; Abd Elwahab *et al.*, 2020)

Total soluble solids: Total soluble solids (TSS) represent the concentration of soluble sugars, organic acids, minerals, and other soluble solids present in the fruit juice. Monitoring TSS during storage helps predict postharvest behavior and maintain the overall quality of apricot fruit.

According to the data illustrated in Fig. 3, the control exhibited the highest initial TSS content at harvest. TSS was lower in apricot fruits treated with spermidine, salicylic acid, and sodium nitroprusside compared with the control fruit. It is evident that TSS increased with the extension of the storage period, reaching the maximum values at the end of the storage period (7 weeks), as previously detected by Abd Elwahab *et al.* (2015). Preharvest treatment slowed down the increment of TSS during cold storage, thereby delaying senescence and maintaining quality, which extends the postharvest life of Amal apricot fruits. Spd treatment displayed the slowest rise in TSS, followed by SA and SNP, compared to the control treatment. Spermidine, salicylic acid, and sodium nitroprusside can influence TSS through various mechanisms, including starch degradation, metabolism,

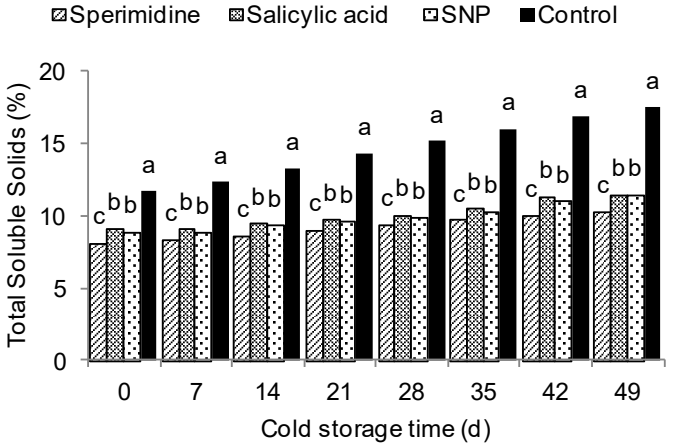

Fig. 3 Effect of per-harvest treatments on TSS of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

and hormonal interactions. Previous studies have shown that Spd treatment can down-regulate the activity of amylase, a key enzyme responsible for starch hydrolysis (Cheng *et al.*, 2018). SA application potentially regulates ethylene biosynthesis, thus reducing hydrolysis enzyme activity (Cheng *et al.*, 2009).

Total acidity: At harvest, the control treatment exhibited the lowest acidity, followed by spermidine, sodium nitroprusside, and salicylic acid, which recorded the highest value of titratable acidity (Fig. 4). The acidity of apricot fruit decreased significantly with increasing storage duration. However, the decrease in acidity of apricot fruit was significantly lower with preharvest application (Spd, SA, and SNP). Preharvest treatments might influence

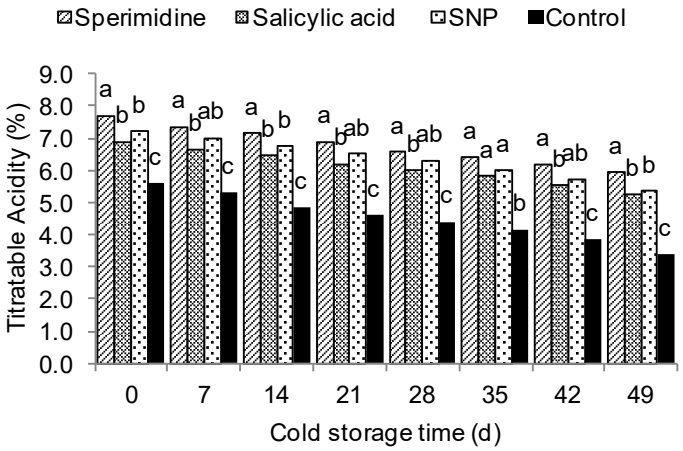

Fig. 4. Effect of per-harvest treatments on tiratable acidity of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

the activity of enzymes involved in organic acid metabolism, potentially slowing down the breakdown of organic acids like malic acid, which contribute to apricot acidity (Cheng *et al.*, 2007).

The acidity of fruits decreases during storage due to the loss of organic acids, especially malic acid, in respiratory metabolism. The application of preharvest treatments slows the rate of respiration and metabolic processes, thus limiting the consumption of organic acids in respiration (Shah and Hashmi, 2020) and maintaining titratable acidity in fruits, which improves the storability of apricot fruits. Similar results were reported with spermidine and sodium nitroprusside (Erbaș *et al.*, 2018; Abd Elwahab *et al.*, 2020).

TSS/Acid ratio: The ripening process of apricot fruit involves a series of biochemical reactions, resulting in increased respiration, ethylene production, and changes in structural polysaccharides, causing the conversion of carbohydrates or starch into sugars and organic acids, thus leading to fruit ripening (Baswa *et al.*, 2001). Increasing the storage duration resulted in a significant increase in the TSS/acid ratio of apricot fruit, as starch is converted to soluble sugars during storage, which increases the TSS content.

It is clear from the data presented in Fig. 5 that the TSS/acid ratio in the fruit juice was markedly increased in the control during storage, mainly due to an increase in total soluble solids and a reduction in juice total acidity percentage. The TSS/acid ratio

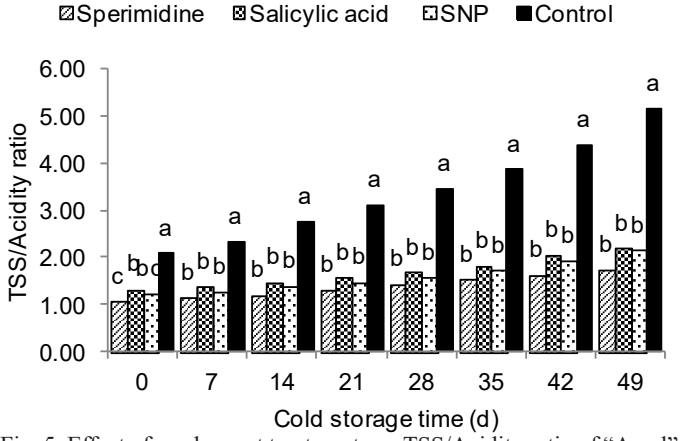

Fig. 5. Effect of per-harvest treatments on TSS/Acidity ratio of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

in the fruit juice was lower in preharvest treatments during cold storage compared to the control treatment. This may indicate that spermidine, salicylic acid, and sodium nitroprusside treatments slowed the respiration rate of the fruits, and the utilization of organic acids was minimal, which slowed down the ripening process (Erbaș *et al.*, 2018; Abd Elwahab *et al.*, 2020).

Decay percentage: Physiological and pathological decay are among the most important factors contributing to postharvest fruit losses of apricot fruits. No decay was observed in any treatment group during the first 3 weeks of storage. The control treatment exhibited initial signs of decay at 4 weeks postharvest. Conversely, all preharvest treatments with spermidine (Spd), salicylic acid (SA), and sodium nitroprusside (SNP) effectively delayed the onset of decay by 1-4 weeks compared to the control (Fig. 6). In the second month of storage, decay development was observed in all treatments. However, the rate of decay differed significantly between groups ($P < 0.05$).

Spermidine (Spd) treatment displayed no decay incidence until the 7th week, followed by SNP and SA. The decrease in decay percentage was probably due to the effect of preharvest treatments on slowing metabolic activity and delaying senescence. Similarly, SA application in some fruits reduces decay by enhancing their defense response (Zhao *et al.*, 2018), and SNP, a nitric oxide (NO) donor, might influence decay through NO signaling pathways known to be involved in defense responses, reducing disease

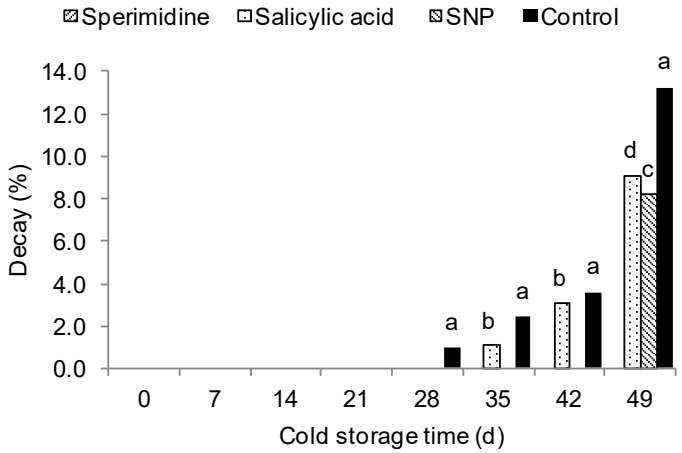

Fig. 6. Effect of per-harvest treatments on decay percentage of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

incidence and delaying senescence (Saba and Moradi, 2017).

Fruit firmness: Firmness can be used to measure the degree of softening and ripening. At harvest, fruits from trees treated with preharvest treatments had the highest firmness values, while the highest fruit softening rate was recorded in the control treatment. The highest firmness value was recorded for Spd, followed by SNP and SA in descending order compared with the control treatment, which exhibited the lowest firmness value (Fig. 7) during the storage period. The loss of firmness during storage is attributed to changes in the primary cell wall during ripening, resulting in textural changes. However, the application of spermidine, salicylic acid, and sodium nitroprusside treatments decreases the rate of respiration and ethylene production, thereby inhibiting the ripening-related cell wall breakdown and thus retaining greater firmness compared to control fruit. SNP maintained fruit firmness by regulating cell wall hydrolysis-

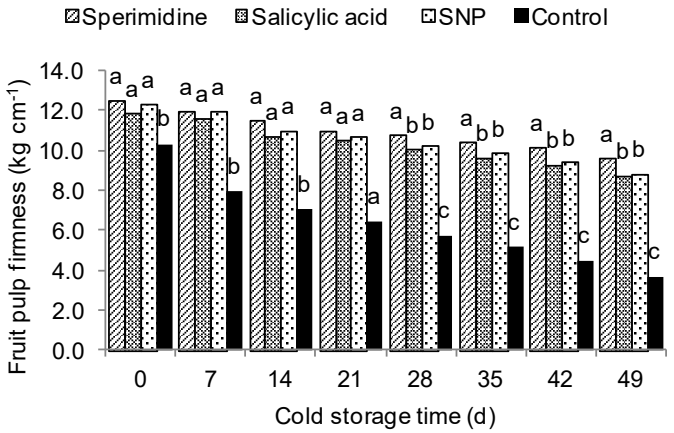

Fig. 7 Effect of per-harvest treatments on firmness of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

related enzyme activity (Zhao *et al.*, 2021).

The effect of spermidine on fruit firmness can be attributed to the cross-linkage of polyamines with –COO groups of the pectic substances in the cell wall (Pandey *et al.*, 2015). This binding also blocks the access of degrading enzymes, which further reduces the rate of fruit softening during storage (Valero *et al.*, 2002). Salicylic acid application increases antioxidant activity (Li *et al.*, 2011), potentially reducing oxidative stress and cell wall degradation, thereby contributing to firmer fruit. Sodium nitroprusside, a donor of nitric oxide (NO), can influence processes related to cell membrane stability in plants (Manjunatha *et al.*, 2010).

Total sugars: Statistical analysis revealed a significant effect of preharvest treatments on total sugar content ($P < 0.05$) of Amal apricot fruits throughout the storage period (Fig. 8). It clearly showed that total soluble sugars increased gradually with the extension of the storage period. The increase in sugar content of fruits could be due to the ripening process, which led to the transformation of polysaccharides into soluble sugars through enzymatic activities (Hmmam *et al.*, 2023). Preharvest treatments of spermidine, followed by salicylic acid, and then sodium nitroprusside, gave the lowest values of total sugars compared with the control treatment. Spd displayed the lowest increase in total sugar content.

On average, total sugar content in Spd-treated apricots increased by 1.42 times compared with the initial value at the beginning of the storage period, while the control treatment increased by 1.96 times during the same period. Spermidine might slow down the rate of starch breakdown (Liu *et al.*, 2010). Studies on apples suggest that Spd application can delay starch degradation and reduce conversion into soluble sugars during storage (Wang *et al.*, 2018). Salicylic acid can influence various aspects of plant metabolism, including sugar signaling pathways (Shi *et al.*, 2014). SNP's role in regulating hormonal signaling pathways (Wang *et al.*, 2015) might indirectly impact sugar metabolism during storage. Sodium nitroprusside maintains total sugars during cold storage (Abd Elwahab *et al.*, 2020).

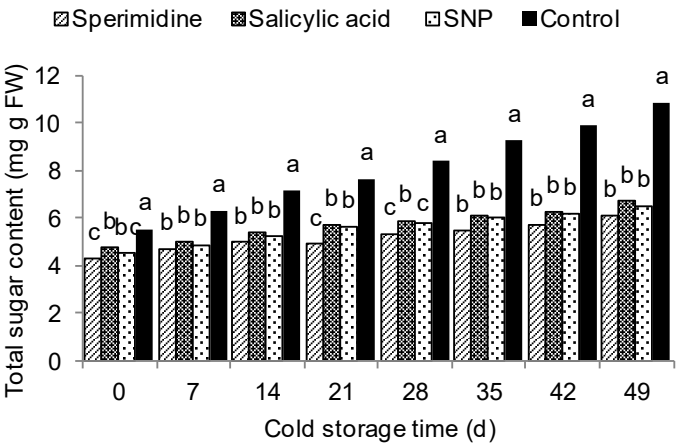

Fig. 8. Effect of per-harvest treatments on total sugar content of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

Total phenols: Statistical analysis revealed a significant effect of preharvest treatments on total phenol content ($P < 0.05$) (Fig. 9). The highest values of total phenols were recorded for apricot fruits treated with spermidine, followed by salicylic acid and sodium nitroprusside in descending order, compared with untreated fruits. There was a significant decrease in total phenol content as the storage period prolonged. The control group displayed the fastest rate of phenol loss; the decrease in total phenols during cold storage might be due to oxidative stress induced by low temperatures, resulting in the degradation of phenolic substances (Khan *et al.*, 2012). Furthermore, preharvest treatments decreased losses of total phenols, which may be due to delayed oxidation of phenolic substances, leading to improved storability of apricot fruits.

Preharvest spermidine application significantly maintained phenolic compound levels during cold storage of peach (Li *et al.*, 2018). Additionally, Spd might modulate the activity of enzymes involved in phenol metabolism, potentially slowing down their degradation (Liu *et al.*, 2010). Salicylic acid has been reported to maintain phenol content during cold storage in apricot fruits (Abd Elwahab, 2015). Also, Adhikary *et al.* (2020) found that sodium nitroprusside maintained higher total phenol content during cold storage.

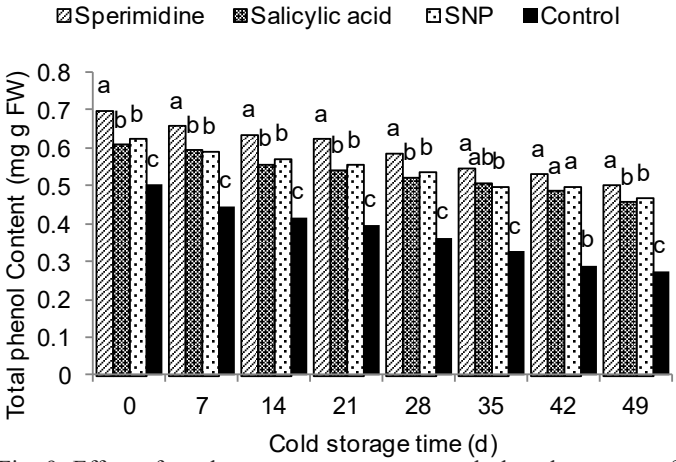

Fig. 9. Effect of per-harvest treatments on total phenols content of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

Total carotenoid content: Carotenoids are the main pigments contributing significantly to the visual appeal of apricots, acting as precursors to vitamin A and possessing antioxidant properties (Zhou *et al.*, 2020). The effects of spermidine, salicylic acid, and sodium nitroprusside have retarded the increase in total carotenoid values compared to the control treatment at harvest. Preharvest treatments had a significant effect on color retention by delaying the development of coloring pigments in apricot fruits. The analysis of carotenoid content in apricots following preharvest

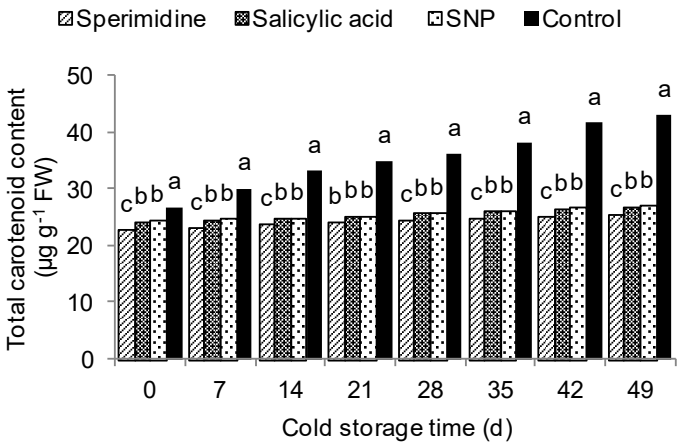

Fig. 10. Effect of per-harvest treatments on carotenoids content of "Amal" apricot fruits during cold storage. Bars with the same letter indicate no significant difference ($P \leq 0.05$, Duncan's test)

treatments revealed a statistically significant effect ($P < 0.05$) due to the treatments (Fig. 10).

Carotenoid content significantly increased with prolonged cold storage. Spermidine, salicylic acid, and sodium nitroprusside treatments reduced color change during cold storage. Apricots pre-treated with Spd displayed a lower increase in carotenoid content compared to the control and other treatment groups during cold storage. Previous studies suggest that Spd might play a role in carotenoid biosynthesis pathways (Li *et al.*, 2019). Moreover, Spd application has been linked to delayed chlorophyll degradation (Zheng *et al.*, 2007). However, SNP's role in regulating hormonal signaling pathways (Wang *et al.*, 2015) might indirectly impact carotenoid biosynthesis. SA can influence various aspects of plant metabolism, including carotenoid biosynthesis (Gupta *et al.*, 2012).

The results presented in this study indicated that preharvest foliar spray of spermidine, salicylic acid, and sodium nitroprusside maintained fruit quality and reduced fruit decay and compositional changes by delaying physical and chemical changes, slowing down the respiration rate at harvest and during cold storage.

References

Abd El Wahab, S.M. 2015. Apricot postharvest fruit quality, storability and marketing in response to preharvest application. *Middle East J. Agric. Res.*, 4: 347-358.

Abd ElWahab, S.M., A.M. Abdallatif, B.M.and Mamdouh, 2020. Maintaining fruit quality of cold stored mango cv. Keitt via exogenous postharvest treatments. *Plant Archives*, 20(2): 9611-9619.

Adhikary, T., P.P.S. Gill, S.K. Jawandha, R.D. Bhardwaj and R.K. Anurag, 2021. Efficacy of postharvest sodium nitroprusside application to extend storability by regulating physico-chemical quality of pear fruit. *Food Chem.*, 346(2): 128934.

Aroca, G., E. Azzarello, J. Saura and J.A. Moreno, 2006. Nitric oxide interaction with other signaling molecules in plants. *J. Expt Bot.*, 57(2): 437-448.

Asghari M. and M.S.Aghdam, 2010. Impact of salicylic acid on post-harvest physiology of horticultural crops. *Trends Food Sci. Technol.*, 21(10): 502-509.

Baswa, M., C.C. Rath S.K., Dash and R.K. Mishra, 2001. Antibacterial activity of Karanj (*Pongamia pinnata*) and Neem (*Azadirachta indica*) seed oil: a preliminary report. *Microbios*, 105: 183–189.

Cheng, G., X. Pang, J. Cao, Q. Wang, W. Yang and Y. Yao, 2009. Salicylic acid alleviates chilling injury of mango fruit by enhancing antioxidant enzyme activity and regulating ethylene biosynthesis. *Food Chem.*, 114(2): 877-882.

Cheng, L., J. Zhan, Y. Li, X. Xu, Y. Wang and Y. Jiang, 2007. Regulation of peach (*Prunus persica* L. Batsch) fruit ripening by malic acid. *J. Agric. Food Chem.*, 55(22): 9292-9297.

Cheng, Y., Y. Jiang, B. Li, Y. Zheng, S. Li and S. Lei, 2018. Spermidine delays 'Cuiguan' pear (*Pyrus pyrifolia* Nakai) postharvest ripening and senescence by regulating ethylene biosynthesis and antioxidant metabolism. *Food Chem.*, 240: 1141-1148.

Dubois, M.K., A. Gilles, J.K. Hamilton, P.A. Reders and F. Smith, 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.*, 28(3): 350-356.

Duncan, D.B. 1955. Multiple Range and Multiple F-Tests. *Biometrics*, 11: 1-42.

Erbaş, D., M. A. Koyuncu and C.E. Onursal, 2018. Effects of pre-and postharvest spermidine treatments on storage life and quality of 'Aprikoz' apricot. *Acta Hortic.*, 1194: 785-791.

FAO, 2023. Food and Agriculture Organization of the United Nations (accessed on 5 June 2024); Available online: https://www.fao.org/faostat/en/#data/QCL

Gupta, D., S. Agarwal, A. Sarkar and Y.P. Singh, 2012. Abscisic acid induces accumulation of lycopene and β-carotene in ripening tomatoes (*Solanum lycopersicum* L.). *J. Expt. Bot.*, 63(14): 5077-5088.

Hmmam, I., M.A.S. Ali and A. Abdellatif, 2023. Alginate-based zinc oxide nanoparticles coating extends storage life and maintains quality parameters of mango fruits "cv. Kiett". *Coatings*, 13(2): 362.

Karatas, N. 2022. Evaluation of nutritional content in wild apricot fruits for sustainable apricot production. *Sustainability*, 14(3): 1063.

Khan, A.S., N. Ahmad, A.U. Malik and M. Amjad, 2012. Cold storage influences the postharvest pericarp browning and quality of Litchi. *Intel. J. Agric. Biol.*, 14(3): 171–178.

Levene, H. 1960. Contributions to probability and statistics: essays in Honor of Harold Hotelling, Olkin I *et al* (eds), *Stanford University Press*, Palo Alto, Santa Clara, CA, USA, pp. 278-292.

Li, H., X. Zhu, X. Guo, H. Li and Y. Zhang, 2019. Spermidine regulates tomato fruit ripening through modulation of ethylene biosynthesis and chlorophyll metabolism. *Plant Physiol. Biochem.*, 143: 252-262.

Li, S., X. Wang, Y. Sun and Y. Liu, 2018. Effects of spermidine preharvest treatment on peach quality and antioxidant capacity during cold storage. *Sci. Hortic.*, 235: 229-236.

Li, S., Z. Wang, H. Gao and J. Wu, 2011. Effects of salicylic acid on postharvest quality and antioxidant capacity of sweet cherry. *J. Sci. Food Agric.*, 76(6): C729-C734.

Li, X., Y. Zheng, Y. Zhang and S. Li, 2010. Spermidine treatment alleviates chilling injury symptoms in postharvest peaches by enhancing antioxidant metabolism and ethylene signal transduction. *J. Sci. Food Agric.*, 90(1): 127-134.

Liu, J.H., S.S. Li, X.M. Li, T.T. Han and M.Z. Bao, 2010. Polyamines regulate polyphenol oxidase gene expression in pear fruit after harvest. *J. Expt. Bot.*, 61(12): 3629-3639.

Manjunatha, G., V. Lokesh, B. Neelwarne, Z. Singh and K.J. Gupta, 2014. Nitric oxide applications for quality enhancement of horticulture produce. *Hortic. Rev.*, 42: 121-156.

Mehta, S., A. Srivastava and L. Saneva, 2002. Effects of polyamines on ethylene biosynthesis and transcript levels of ethylene biosynthetic pathway enzymes in mung bean (*Vigna radiata* L.) seedlings. *J. Plant Physiol.*, 159(12): 1279-1285.

Neill, S., K.S. Gould and J.M. Davies, 2002. Nitric oxide synthesis and signaling in plant defence. *Plant Cell*, 14(6): 1655-1668.

Pandey, R., A. Gupta, A. Chowdhary, R.K. Pal and M.V. Rajam, 2015. Over-expression of mouse ornithine decarboxylase gene under the control of fruit-specific promoter enhances fruit quality in tomato. *Plant Mol. Biol.*, 87: 249-260.

Pott, D.M., J.G. Vallarino and S. Osorio, 2020. Metabolite changes during postharvest storage: effects on fruit quality traits. *Metabolites*, 10(5): 187.

Roussos, P.A., V. Sefferou, N.K. Denaxa, E. Tsantili and V. Stathis, 2011. Apricot (*Prunus armeniaca* L.) fruit quality attributes and phytochemicals under different crop load. *Sci. Hortic.*, 129: 472–478.

Saba, M.K. and S. Moradi, 2017. Sodium nitroprusside (SNP) spray to maintain fruit quality and alleviate postharvest chilling injury of peach fruit. *Sci. Hortic.*, 216: 193-199.

Shah, S. and M.S. Hashmi, 2020. Chitosan–aloe vera gel coating delays postharvest decay of mango fruit. *Hortic. Environ. Biotechnol.*, 61: 279-289.

Shi, H., Y. Mao, Y. Zhong and Q. Jiang, 2014. The roles of abscisic acid and stress-responsive hormones in plant responses to drought, cold and salinity stresses. *Front. Plant Sci.*, 5: 171.

Singleton, V.L., R. Orthofer and R.S. Lamuela-Raventós, 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteau reagent. *Methods Enzymol.*, 299: 152-178.

Snedecor, G.W. and W.G. Cochran, 1967. Statistical methods 6th edition. *Oxford and IBH Publishing Co.*, New Delhi, India, p. 553.

Vaka, D.V., K. Pavani, B. Nirujogi and P.V.K. Reddy, 2020. Role of Polyamines on Post-Harvest Fruit Quality and Storability. *Int. J. Curr. Microbiol. Appl. Sci.*, 9(6): 3519-3529.

Valero, D., D. Martínez-Romero and M. Serrano, 2002. The role of polyamines in the improvement of the shelf life of fruit. *Trends Food Sci. Technol.*, 13(6): 228-234.

Wang, X., S. Li, Y. Sun and Y. Liu, 2018. Effects of spermidine preharvest treatment on quality of 'Fuji' apples during long-term storage. *Sci. Hortic.*, 231: 152-158.

Wang, Y., S. Li, Y. Sun and Y. Liu, 2015. Sodium nitroprusside alleviates drought stress in tomato seedlings by enhancing antioxidant defense and glyoxalase system. *Plant Cell Physiol.*, 56(7): 1322-1334.

Wu, B., Q. Guo, G.X. Wang, X.Y. Peng, J.D. Wang and F.B. Che, 2015. Effects of different postharvest treatments on the physiology and quality of 'Xiaobai' apricots at room temperature. *J. Food Sci. Techn.*, 52: 2247-2255.

Wendehenne, D., A. Pugin, D.F. Klessig and J. Durner, 2001. Nitric oxide: comparative synthesis and signaling in animal and plant cells. *Trends Plant Sci.*, 6(4): 177-183.

Zheng, Y., X. Ding, S. Zhao and Y. Li, 2007. Regulation of chlorophyll metabolism and photosynthesis-related gene expression by spermidine in cucumber leaves under salt stress. *Plant Physiol. Biochem.*, 45(9): 1114-1123.

Zhou, W., Y. Niu, X. Ding, S. Zhao, Y. Li, G. Fan and K. Liao, 2020. Analysis of carotenoid content and diversity in apricots (*Prunus armeniaca* L.) grown in China. *Food Chem.*, 330: 127223.

Zhao, Y., J. Tang, C. Song, S. Qi, Q. Lin, Y. Cui and Y. Duan, 2021. Nitric oxide alleviates chilling injury by regulating the metabolism of lipid and cell wall in cold-storage peach fruit. *Plant Physiol. Biochem.*, 169: 63-69.

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