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POSTHARVEST APPLICATION OF MORINGA LEAF EXTRACT MAINTAINS THE QUALITY OF PERSIMMON FRUITS DURING EXTENDED STORAGE

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ABSTRACT

Persimmon (*Diospyros kaki* L.), native to subtropical to temperate regions, has highly perishable fruit. Cell wall degradation and microbial invasion during prolonged storage reduce the storage potential and commercial value of the product. Therefore, this study was designed to assess the potential of moringa leaf extract (MLE) (0%, 15%, 30%, and 45%) to enhance storage potential and postharvest quality of persimmon fruits at 0±1 °C and 90±5% relative humidity for 60 days. The results demonstrated that prestorage application of 30% MLE to persimmons significantly delayed the increase in weight loss and disease incidence in coated fruits compared to the control. Additionally, persimmon fruit treated with MLE substantially reduced metabolic changes such as soluble solids content and ripening index, while maintaining maximum titratable acidity and preserving maximum ascorbic acid content compared to untreated fruit. Moreover, application of MLE noticeably maintained higher levels of bioactive compounds, including total phenolic content and antioxidant radical scavenging activity, compared to untreated fruit. Subsequently, the application of MLE regulated oxidative stress by reducing the maximum levels of hydrogen peroxide and malondialdehyde, while maintaining the maximum activity of antioxidant enzymes such as superoxide dismutase, peroxidase, and catalase during prolonged storage. Furthermore, fruits coated with MLE treated with 30% MLE notably maintained maximum firmness and mitigated deterioration by inhibiting the activity of cell wall-degrading enzymes such as polygalacturonase, cellulase, and pectin methylesterase. They also maintained quality traits compared to the control until the end of storage. Consequently, this study highlights the potential of MLE as a sustainable and eco-friendly way to maintain postharvest persimmon fruit quality during extended storage.

Key words: *Diospyros kaki*, climacteric fruit, cell wall degradation, metabolic alternation, antioxidant enzymes, postharvest quality

INTRODUCTION

Persimmons are a significant climacteric fruit of subtropical to temperate regions. They are rich in vitamins (A, C, E, and B-complex – B_1, B_2, B_6, and folate), as well as minerals such as potassium, manganese, and copper. They contain high levels of antioxidants, dietary fiber, and bioactive phytochemicals that support immunity, improve digestion, reduce oxidative stress, and lower the risk of cardiovascular disease (Saleem et al. 2020). Their high perishability and short shelf life reduce their commercial value. Inadequate temperature control and the occurrence of microbial diseases contribute to significant losses for persimmon growers, distributors, and consumers (Khademi et al. 2012). Postharvest losses of persimmons are estimated at 20–50%, depending on the cultivar, stage of maturity at harvest, and the effectiveness of supply chain management (Bagheri & Esna-Ashari 2022).

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To improve the postharvest quality of persimmon fruit, numerous techniques have been used, including hexanol (Öz et al. 2023), calcium chloride (Liu et al. 2023), arginine (Nasr et al. 2022), hydrogen sulfide, along with γ-aminobutyric acid (Niazi et al. 2021) and nitric oxide (Shahkoomahally et al. 2015), to effectively improve membrane disintegration and quality during storage. Combining these methods with adequate storage conditions helps preserve the overall quality and shelf life of persimmon fruit, improves its marketability, and slows senescence during storage.

Recently, numerous eco-friendly methods have been adopted to preserve postharvest quality (Daisy et al. 2020). These coatings create semipermeable barriers to O_2/CO_2 and water vapor, inhibit the maturation process, and help extend the storage life of horticultural produce. Furthermore, growing consumer concerns about food safety have significantly impacted the food industry, ensuring food security and sustainability, particularly in the postharvest management of fruits and vegetables (Salehi 2020). Consequently, integrating these interventions notably helps decrease dependence on synthetic strategies, regulate oxidative stress and texture decomposition, and extend shelf life. The use of plant extracts in fruit preservation has gained recognition as a sustainable alternative to synthetic preservatives. These naturally derived substances effectively inhibit microbial growth and extend shelf life without posing a risks to human health or the environment (Shahbaz et al. 2022).

Moringa oleifera L. is a plant with documented bioactive compounds useful in postharvest management due to its nontoxic nature, including a high content of natural antioxidants, phenolic compounds, vitamins, and antimicrobials (Arif et al. 2022). In recent years, moringa extract has been used to inhibit microbial growth, delay ripening, and enhance the natural antioxidant capacity of fruits. It plays a significant role in regulating physiological and metabolic alterations by reducing ethylene production, oxidative stress, and pathogen proliferation in horticultural products (Nasibi et al. 2025). Previously, it was used to extend the shelf life of many fruits, including tomato (Liamngee et al. 2019), mango (Abd El-Razek et al. 2019), avocado (Kubheka et al. 2020), plum (Mahmoud et al. 2020), and strawberry (Shafique et al. 2023), by preserving the biochemical properties, bioactive components, and defensive capabilities of the fruit during storage. However, the effectiveness of MLE in enhancing defense mechanisms by modulating softening enzymes and mitigating oxidative stress in persimmons has remained unclear. Consequently, this experiment was conducted to evaluate the effect of postharvest MLE on mitigating the occurrence of disease and chilling injury by preserving the antioxidant metabolism of persimmons during cold storage.

MATERIALS AND METHODS

Persimmons were harvested at commercial maturity, characterized by a total soluble solids (TSS) content of 10–12°Brix, 50% titratable acidity (TA), and 35% color break. The fruits were obtained from a commercial orchard located at the Barani Agriculture Research Institute, Chakwal, Pakistan. Immediately after harvest, the fruits were placed in corrugated fiberboard boxes and transported to the Postharvest Research Center, AARI, Faisalabad, under controlled conditions. After transport, all persimmons were carefully examined for their appearance and physical integrity. Fruits with visible defect, mechanical injuries, or pathological symptoms were excluded from the experimental material to ensure uniformity and maintain the reliability of subsequent assessments. All initial quality parameters were assessed on the day of harvest to establish reference values for subsequent storage evaluations. Before treatment, the selected fruits were thoroughly rinsed with tap water and immersed in a 0.2% NaClO solution for 5 minutes to minimize external microbial contamination. They were then air-dried at room temperature.

Approximately 400 fruits were selected for this experiment, divided into four treatments, replicated three times. Treatments included four concentrations of MLE: 0 (distilled water control), 15%, 30%, and 45%. Application was carried out by immersing the fruits in their respective solutions for 5 minutes to ensure uniform contact and absorption. After dipping, the fruits were drained adequately and subsequently stored in cold storage at 0±1°C and 90±5% relative humidity for 60 days. Physiological and qualitative characteristics were evaluated at 15-day intervals (0, 15, 30, 45, and 60 days) during the storage period. At each sampling point, 10 fruits per replication were selected for analysis. Fruit samples were stored in liquid nitrogen at −20°C until further analysis. Data were recorded systematically at each interval to monitor the changes during storage.

A coating of fresh MLE was formulated by mixing MLE powder with distilled water at 40°C for 15 minutes with connstant stirring. The pH of the resulting solution was set to 5.6 with 1N NaOH. Additionally, glycerol (1.5%, v/v) was added as a plasticizer to increase the mechanical strength and flexibility of the coating. Various concentrations of MLE were prepared accordingly. Only distilled water was used in the control samples.

The weight loss of persimmons was determined using the technique of Saleem et al. (2020). Results were calculated as a percentage by comparing the weight in each interval with the initial weight. To assess disease incidence, the method by Dutot et al. (2013) was used. Disease incidence was calculated as a score. To estimate soluble solids content, a few drops of filtered persimmon juice were placed on the prism of a digital refractometer (RX 5000, Atago, Japan), and the reading was recorded and expressed in degrees Brix. Furthermore, titratable acidity was assessed using the method by Li et al. (2023), which involved a phenolphthalein titration process, and the results were expressed as a percentage. Ripening index was measured by comparing the soluble solids content with the titratable acidity, and the results were expressed as a percentage.

Ascorbic acid content in persimmons was evaluated using the procedure of Singh and Mirza (2018) using 2,6-dichlorophenolindophenol and recorded in mg per 100 mL FW.

Total phenolic content (TPC) was assessed according to the method of Khademi and Ershadi (2013) using the Folin–Ciocalteu reagent. For this purpose, persimmon pulp tissue of (1 g) was homogenized and then centrifuged at 15,000 g for 20 minutes at 4°C. Then, 0.5 mL of the supernatant was mixed with Folin–Ciocalteu reagent (0.6 mL of 10%) and Na_2CO_3 (2.5 mL of 700 mM), and the absorbance of the supernatant was measured. Results were expressed as mg of GAE per 100 mL. Furthermore, antioxidant activity was estimated according to the protocol described by Khademi and Ershadi (2013), with minor modifications, and the results were expressed as a percentage.

Malondialdehyde (MDA) content was determined using the thiobarbituric acid (TBA) assay described by Tareen et al. (2012). Results were expressed in nmol per g FW. Moreover, hydrogen peroxide (H_2O_2) was used, following the method of Wang et al. (2019) with slight modifications. Briefly, 1 g of persimmon pulp was homogenized in 5 mL of precooled acetone and centrifuged (10,000 × g, 10 min, 4°C). The resulting precipitate was dissolved in 3 mL of 2 M H_2SO_4, and the absorbance was recorded at 412 nm. Results were expressed in μmol per g.

To measure the antioxidant activity of enzymes, an enzymatic extract was obtained using frozen pulp (1 g), potassium phosphate buffer (2 ml of 50 mM, pH 7.0), and Na-EDTA (2 mM). Superoxide dismutase (SOD) activity was assessed using a modified method of Li et al. (2023). The absorbance of the mixture was measured at 560 nm, and the results were represented as U per mg of protein. Peroxidase (POD) activity was measured according to the protocol of Jia et al. (2018) with slight modifications. The absorbance of the mixture was observed at 470 nm and expressed as U per mg of protein. Catalase (CAT) activity was determined using the method of Asghari and Hasanlooe (2015). The absorbance of the solution was detected at 240 nm. Catalase activity was expressed in U per mg of protein.

Fruit firmness (FF) was assessed at three random locations using a handheld fruit firmness tester (FR-5120, Norfolk, Virginia, USA) equipped with a 3 mm diameter tip. Firmness was recorded as the highest peak force measured in Newtons (N).

Polygalacturonase (PG) in persimmons was estimated using the method of Khan et al. (2008) with citrus pectin, and the results were expressed in U per kg FW. Moreover, pectin methylesterase (PME) activity was determined using the procedure of Jawandha et al. (2012), and the results were expressed in U per kg FW. Cellulase (CL) activity was determined using the technique of Girardi et al. (2005), which involved 100 μl of enzyme extract, 500 μl of 0.1 M sodium acetate buffer, and 400 μl of 1% carboxymethyl cellulose, and the values were expressed in U per kg.

Sensory quality was assessed according to Liu et al. (2020). A well-trained panel of 15 members (different ages and genders) evaluated the aroma, taste, and overall acceptability of treated and untreated persimmons using a 9-point hedonic scale (1 – remarkably dislike, 5 – neither like nor dislike, 9 – extremely like).

All data collected during storage were analyzed using a repeated measures ANOVA in Statistix 8.1 (Analytical Software, Tallahassee, USA). Treatment was considered as a between-subjects factor and storage time as a within-subjects factor to account for repeated measurements in the same experimental units. Means were compared using the LSD test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Weight loss and disease incidence

During the 60-day cold storage period, a substantial increase in weight loss observed for all persimmons, both treated and untreated (Fig. 1A). Weight loss and disease incidence increased with storage time. MLE application noticeably delayed the increase in weight loss compared to the control. At the 30% concentration, weight loss and disease incidence were lowest, significantly different from other concentrations during 30, 45, and 60-day storage

(Fig. 1A). Similar to weight loss, application of 30% MLE significantly reduced disease incidence at all storage periods except 15 days.

The maximum weight loss of horticultural produce during storage is primarily attributed to moisture loss through transpiration. The results of the present study showed that treatment with MLE significantly reduced the increase in weight loss compared to the control. Generally, postharvest application of MLE indicates a substantial role in reducing water loss, dehydration, and shrinkage by creating a barrier on the fruit surface that regulates transpiration (Opara et al. 2015). Similarly, Thanaa et al. (2017) reported the effect of MLE on reducing weight loss of plums during storage and prolonging their shelf life. Furthermore, previous studies have shown that MLE can markedly reduce the moisture content of tomatoes during storage (Basra & Lovatt 2016).

Postharvest decay of fresh fruits is a significant issue for the fruit industry, contributing to increased economic losses, a decline in fruit quality, and a decline in the commercial value of stored produce (Hala & Nabila 2017). The underlying mechanism of disease involves microbial invasion of fruit tissues, which disrupts their structural integrity, promotes tissue softening, and increases susceptibility to further deterioration (Wang et al. 2019). Numerous methods have been used to mitigate postharvest decay, including the use of biocontrol agents and natural compounds such as MLE, which specifically enhance fruit resistance to microbial pathogens while preserving quality during storage. Previously, the use of MLE significantly maintained fruit quality by reducing the incidence of disease in navel oranges (Abo El-Enien et al. 2015) and strawberries (Mohammed & Majeed 2023).

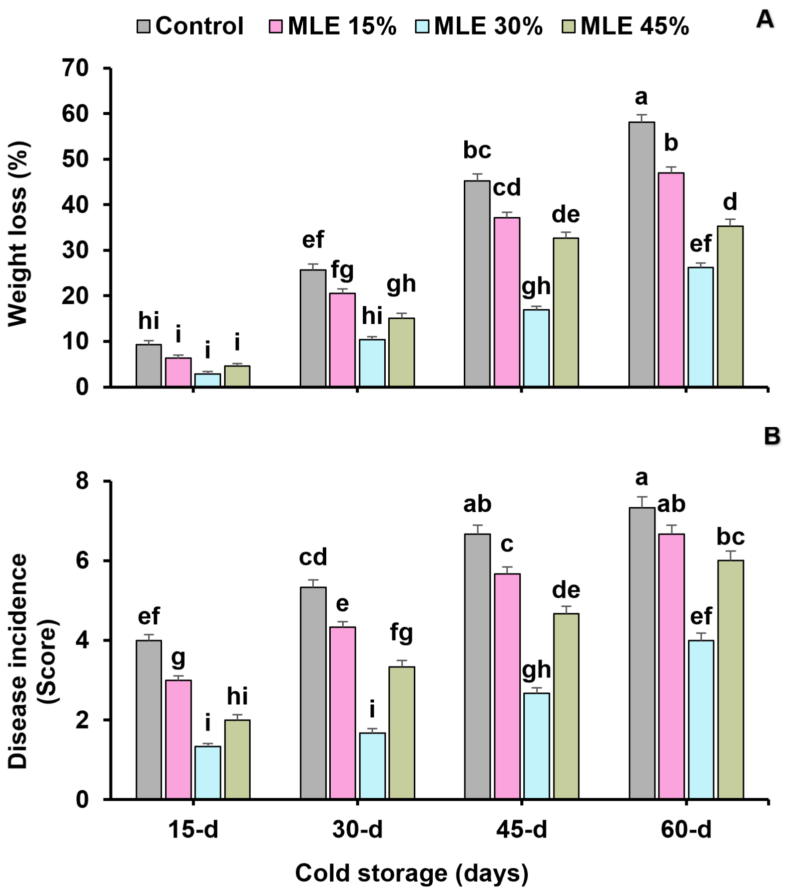

Figure 1. Effect of postharvest moringa leaf extract (MLE) application on weight loss (A) and disease incidence (B) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test (P ≤ 0.05)

Soluble solids, titratable acidity, and ripening index
Soluble solids content (SSC) and ripening index were significantly elevated during storage (Fig. 2A, C). SSC was highest in the group of fruits untreated with MLE. Application of MLE resulted in a decrease in SSC. For fruits treated with 30% MLE, the decrease was significantly smaller after 30, 45, and 60 days of storage. A similar trend was observed for ripening index. Application of 30% MLE was most beneficial in delaying fruit ripening.

Titratable acidity (TA) decreased with storage time (Fig. 2B). MLE application delayed this decline compared to the untreated control. The highest protection, significantly different from other concentrations, was observed with 30% MLE.

A maximum increase in SSC intensifies the ripening process and contributes to postharvest deterioration, ultimately shortening the storage life of the fruit. As fruit matures, SSC levels increase due to the hydrolysis of starch to sugars, which enhances sweetness but also makes them susceptible to decay and quality loss (Thanaa et al. 2017). It has been suggested that elevated SSC levels are associated with increased respiration rates and ethylene production, thereby accelerating the ripening process and potentially promoting physiological disorders. Subsequently, regulating SSC accumulation is crucial for preserving quality traits and extending fruit shelf life during storage, as excessive sugar accumulation leads to rapid deterioration and reduced marketability (Fan et al. 2018). The results showed that the application of 30% MLE maintained lower SSC synthesis in persimmons compared to the control. These results support previous research indicating that the use of MLE significantly improved fruit quality by reducing sugar accumulation in tomatoes (Mthembu et al. 2019). Similarly, Shaaban et al. (2020) reported that the use of MLE improved the quality of plums and increased their storability.

Organic acids play a key role in maintaining fruit acidity during storage, which is essential for preserving quality and extending shelf life. Organic acid content decreases significantly during storage due to metabolic processes. However, several treatments have been shown to enhance persimmon postharvest quality by stabilizing acidity levels and minimizing weight loss (Zhang et al. 2023). In the current study, fruits treated with 30% MLE showed a smaller reduction in TA with a minimum ripening index compared to other treated and untreated controls during storage (Fig. 2B–C). Nevertheless, a previous study showed that the use of MLE extended shelf life, demonstrating maximum acidity in ‘Eureka’ lemons (Rikhotso et al. 2019). A high ripening index can deteriorate fruit quality and shorten the shelf life of stored fruit (Salehi 2020). These results align with earlier findings that applying MLE preserved strawberry quality by maintaining higher acidity and delaying ripening (Ahmed et al. 2024).

Ascorbic acid content, total phenolic content, and total antioxidant activity
Ascorbic acid (AsA), total phenolic content (TPC), and total antioxidant activity (TAO) decreased with storage time (Fig. 3A–C). The metabolism of these compounds was fastest in fruits not treated with MLE. Application of MLE before storage delayed this process. The most effective was 30% MLE. The results were similar for each compound.

Ascorbic acid (AsA) acts as a detoxifying agent for reactive oxygen species (ROS) and substantially inhibits the production of free radicals. It acts as a potent antioxidant, directly scavenging various types of ROS, thereby mitigating oxidative stress in cells (Akram et al. 2017). Ascorbic acid significantly reduces the accumulation of ROS, which is vital for maintaining cellular integrity and preventing oxidative damage. It is oxidized to dehydroascorbic acid (DHA) by reaction with ROS, facilitating detoxification (Khan et al. 2011). Maximum AsA content was observed in persimmons treated with 30% MLE compared to the control. The results confirmed previous study that MLE protected AsA, thereby enhancing the shelf life of strawberries (Ismail & Ganzour 2021).

The reduction in TPC and TAO in persimmons during storage is mainly due to oxidative degradation and enzymatic oxidation of phenolic compounds, catalyzed primarily by peroxidase (POD) (Arif et al. 2022). However, prolonged storage, primarily under low-temperature stress conditions, significantly causes cell dissimilation, which increases oxidative stress, browning reactions, and loss of antioxidant capacity. Moreover, phenolic biosynthesis pathways reduce metabolic activity, accelerate phenolic degradation, and reduce the commercial value of the fruit (Umeohia & Olapade 2025). These combined biochemical and physiological changes result in a significant reduction in both TPC and antioxidant activity, thus reducing the nutritional and functional value of persimmons during extended storage. The results showed that the application of 30% MLE maintained the maximum TPC and TAO activity compared to other treatments and the control during storage (Fig. 3B–C). It has been previously observed that the application of MLE substantially preserved the physiochemical properties of kinnow during storage (Nasir et al. 2016).

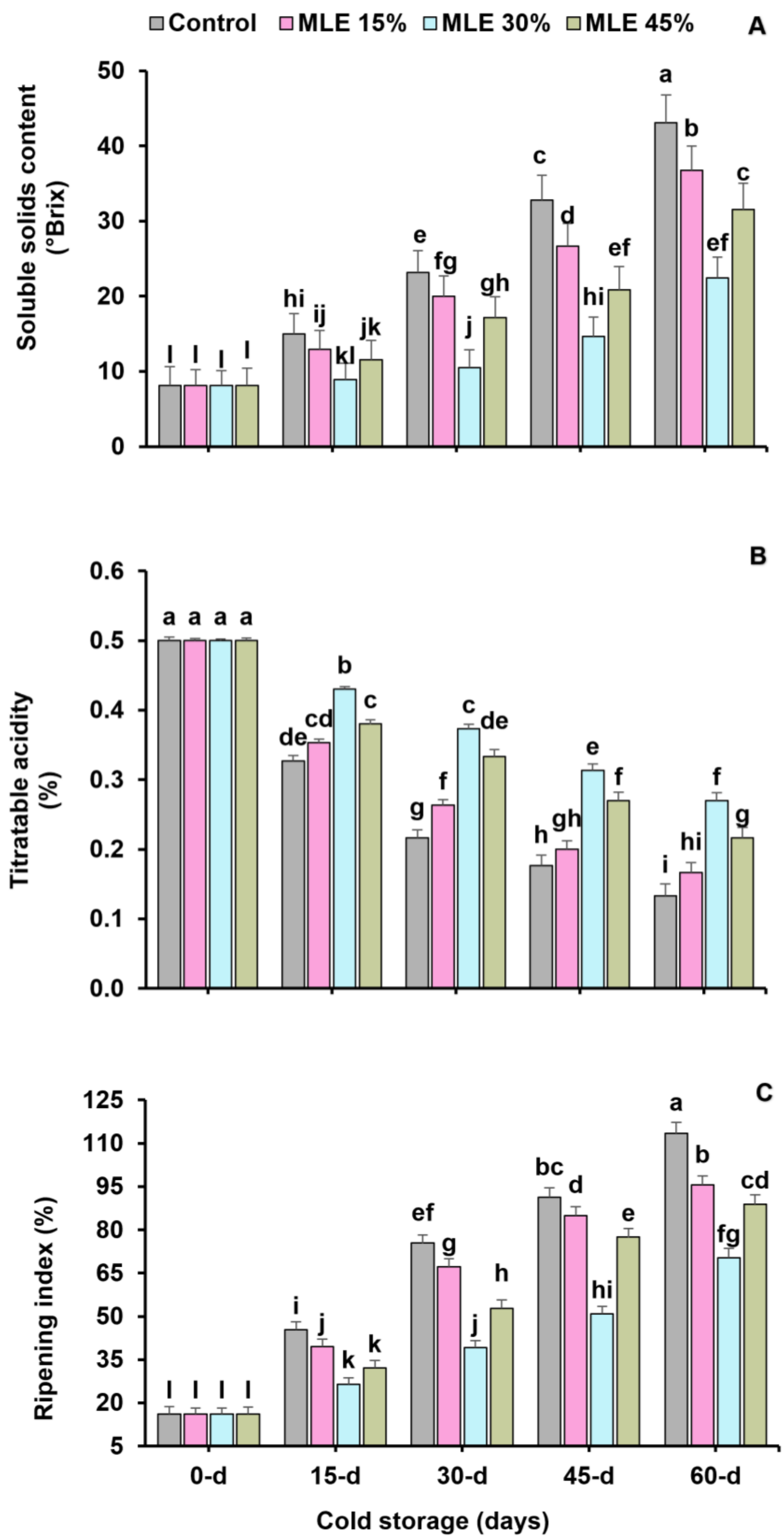

Figure 2. Effect of postharvest moringa leaf extract (MLE) application on soluble solids content (A), titratable acidity (B), and ripening index (C) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

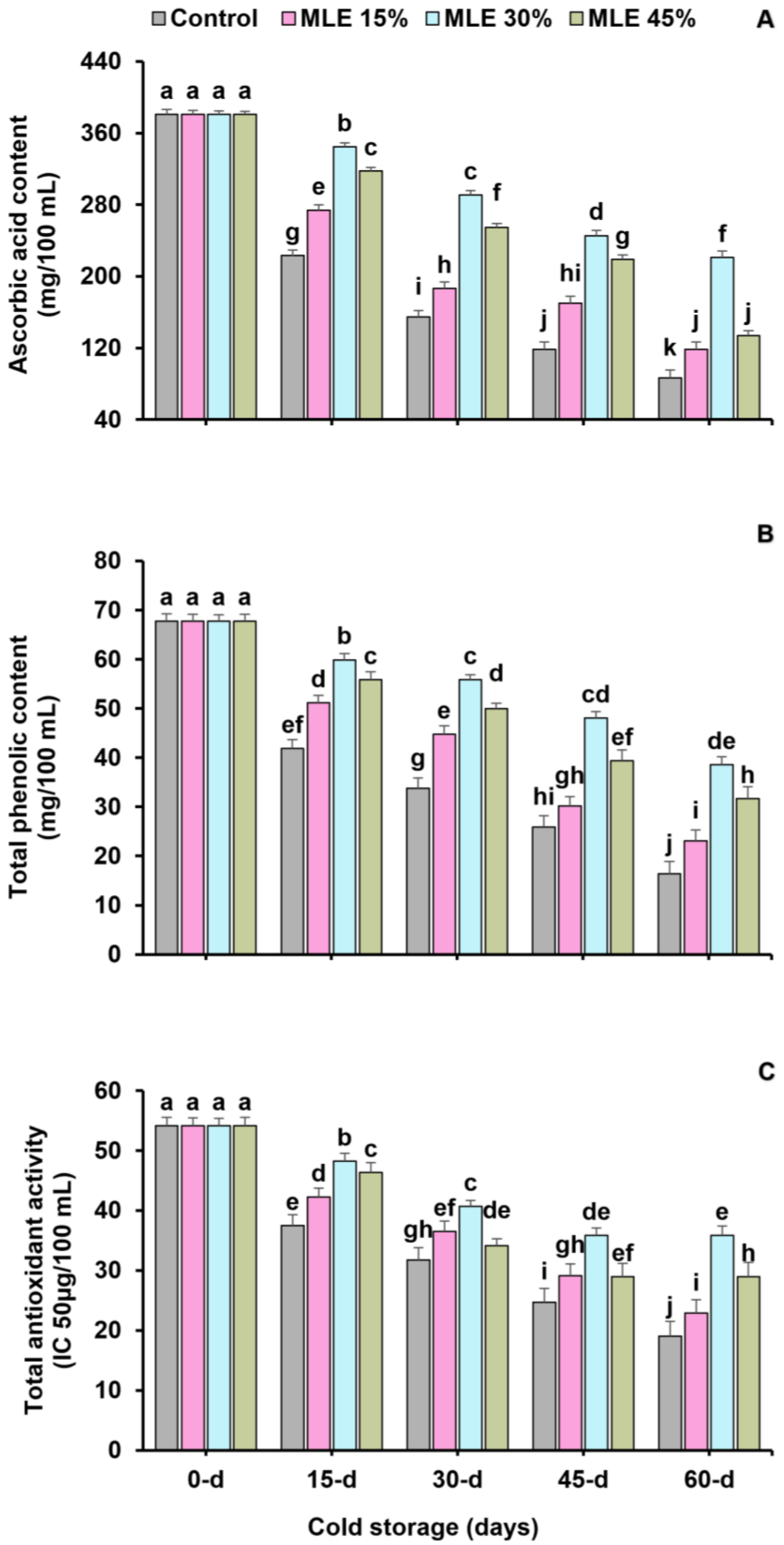

Figure 3. Effect of postharvest moringa leaf extract (MLE) application on ascorbic acid content (A), total phenolic content (B), and total antioxidant activity (C) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

Malondialdehyde and hydrogen peroxide accumulation

Malondialdehyde (MDA) synthesis gradually increased during storage (Fig. 4A). The highest MDA concentration was always in untreated fruit during each storage period. Application of MLE reduced MDA levels compared to the control. The MDA content in fruit treated with MLE was significantly lower during each storage term. The most effective concentration of MLE was 30%, which was significantly lower than other concentrations.

Hydrogen peroxide (H_2O_2) levels were markedly heightened in treated and untreated fruits during storage (Fig. 4B). Nevertheless, prestorage MLE application effectively helped regulate the maximum H_2O_2 accumulation compared to the control. Generally, H_2O_2 content was significantly lower during the first 30 days of storage but increased substantially with increasing storage from 15 to 60 days. Nonetheless, fruit treated with 30% MLE exhibited a 29.71% lower H_2O_2 content compared to the control (51.74%) after 60 days of storage.

During storage, the accumulation of MDA and H_2O_2 promotes cell membrane oxidation and tissue damage, thereby reducing fruit quality and shortening its shelf life. MDA serves as a marker of oxidative stress and membrane integrity, and elevated levels indicate extensive membrane damage (Thanaa et al. 2017). Concurrently, H_2O_2 is a ROS that remarkably exacerbates oxidative damage, promoting further lipid peroxidation and protein denaturation. Results showed that the application of 30% MLE maximally reduced the accumulation of oxidative stress during all storage periods. The accumulation of these compounds reflects fruit quality deterioration, leading to symptoms such as softening, discoloration, and increased susceptibility to decay (Wang et al. 2019). A previous study demonstrated that the use of MLE significantly reduced oxidative stress and maintained the quality of postharvest strawberries during storage (Shafique et al. 2023).

Antioxidant enzyme activity

The activity of superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) decreased during storage Fig. 5A–C). Treatments with MLE before storage maintained the metabolism of these enzymes at all concentrations. Although the activity of antioxidant enzymes gradually decreased with storage time, the treatment with 30% MLE was more effective than other concentrations of MLE at all storage periods.

Antioxidant enzymes play a crucial role in alleviating oxidative stress by scavenging ROS, thereby protecting membranes. Key enzymes such as SOD, POD, and CAT counteract free radicals and limit cellular damage (Li et al. 2023). The activity of these antioxidant enzymes is essential for maintaining cellular homeostasis and protecting against oxidative damage (Jia et al. 2018). The results of the present study showed that the application of 30% MLE before storage significantly preserved the maximum activity of SOD, POD, and CAT during fruit storage. Therefore, MLE notably inhibited senescence and degradation of persimmons and maintains its quality during storage (Wang et al. 2019). These results are in accordance with the above study, which showed that MLE specifically preserved the antioxidant enzyme activities of table grapes during storage (Aly et al. 2020).

Fruit firmness, softening, and enzyme activity

The firmness (FF) of persimmons gradually decreased during storage (Fig. 6A). Postharvest application of MLE substantially preserved FF during storage compared to untreated fruit. Persimmons treated with 30% MLE before storage exhibited the highest firmness compared with the control and other fruit treated with lower or higher concentrations of MLE. Softening is a consequence of the activity of enzymes metabolizing polygalacturonase, pectin methylesterase, and cellulose, the activity of which increases with storage time (Fig. 6 B–D). The activity of softening enzymes was mitigated by MLE. MLE at 30% concentration had the highest power, especially for polygalacturonase and pectin methylesterase (Fig. 6 B–C).

Reduced fruit firmness during storage is mainly due to degradation of cell wall polysaccharides (pectin, hemicellulose, cellulose) mediated by increased activity of softening enzymes such as PG, PME, and CL (Jiang et al. 2020). These enzymatic activities reduce cell adhesion and middle lamella integrity of the, contributing to fruit softening and accelerating senescence. During prolonged storage, several factors, including maximum ethylene production and oxidative stress under suboptimal storage conditions, can reduce fruit firmness and quality (Li et al. 2023). Recent studies have shown that the use of 30% MLE maintained maximum fruit firmness, reducing fruit softening during storage. Therefore, the use of MLE was investigated to mitigate firmness loss and extend shelf life by slowing enzymatic activity and reducing respiration rate, thereby preserving desirable fruit textural characteristics (Moradinezhad et al. 2013). Our results are consistent with those of Bakhsh et al. (2020), who documented that the application of MLE suppressed cell decomposition and retained greater firmness in peaches during storage. Likewise, the application of MLE considerably maintained higher firmness, reduced metabolic alterations and prolonged the storage potential of mango (Abd El-Razek et al. 2019) and papaya (Langa 2018) by inhibiting cell wall degradation.

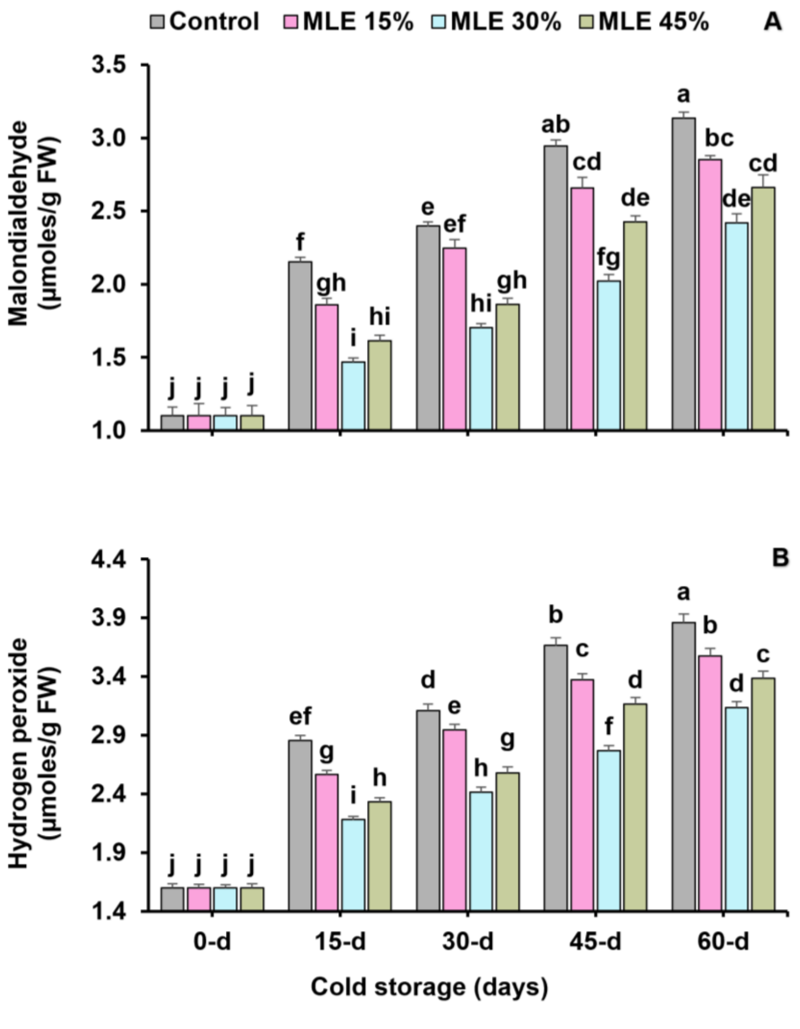

Figure 4. Effect of postharvest moringa leaf extract (MLE) application on malondialdehyde content (A) and hydrogen peroxide (B) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

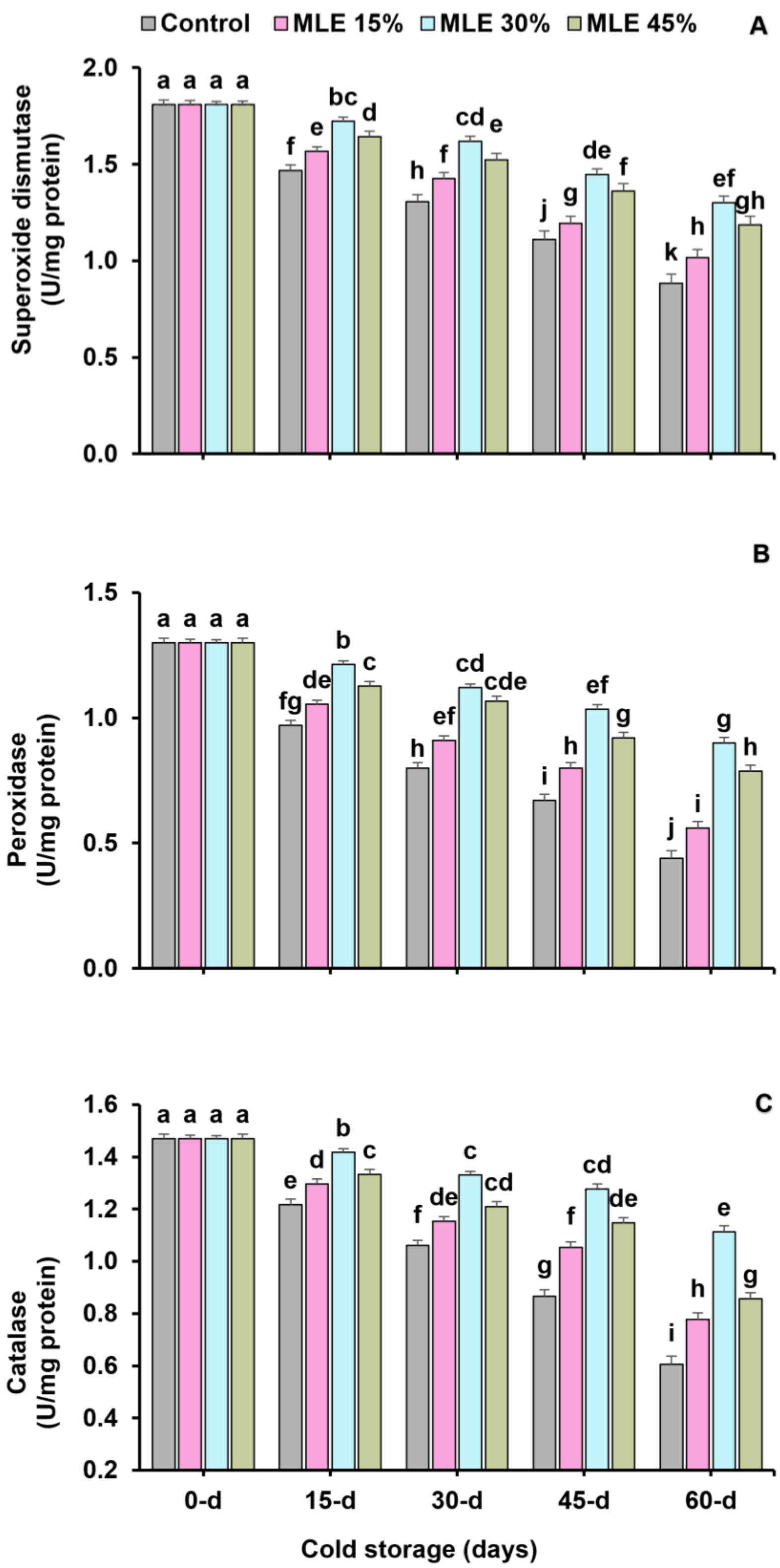

Figure 5. Effect of postharvest moringa leaf extract (MLE) application on superoxide dismutase (A), peroxidase (B), and catalase (C) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

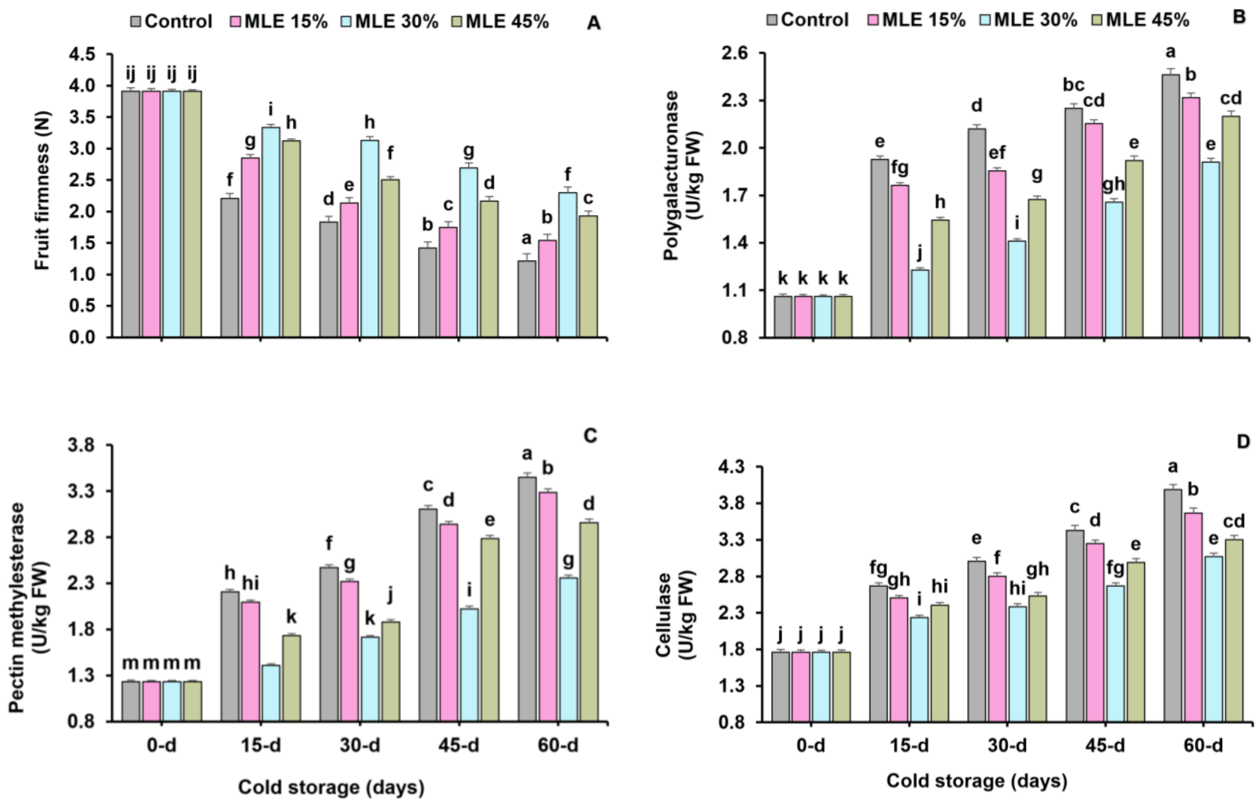

Figure 6. Effect of postharvest moringa leaf extract (MLE) application on fruit firmness (A), polygalacturonase (B), pectin methylesterase (C) and cellulase (D) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

Fruit aroma, taste, and overall acceptability

The softening process negatively impacts marketability and consumer acceptance. During storage, the aroma, taste, and overall acceptability of the fruit gradually decrease, irrespective of the treatments. Treatments with MLE effectively maintained the maximum aroma, taste, and overall acceptability of the persimmons compared with the untreated control. Persimmons treated with 30% MLE before storage showed maximum fruit aroma, taste, and overall acceptability compared with untreated control (Fig 7).

The quality attributes, phytochemical composition, and nutrient content of stored fruit decrease significantly during storage, contributing to lower consumer evaluation. The degradation process is clearly influenced by many factors, such as temperature fluctuations, which remarkably accelerate respiration, deplete carbohydrates, and diminish quality attributes. Moreover, the accumulation of oxidative stress negatively affects phytochemical and nutritional values (Fallik & Ilić 2021), which can be mitigated by applying 30% MLE before storage. The results of this study were consistent with those of Abd El-Razek et al. (2019), who reported that the use of MLE preserved the biochemical quality traits of mango. In addition, the use of MLE combined with chitosan, salicylic acid, and putrescine maintained higher plum quality during storage (Shaaban et al. 2020).

The higher efficacy of the 30% MLE could be attributed to its optimal balance of bioactive constituents, such as phenolics, flavonoids, and antioxidants, which collectively reinforce the defense system of the fruit. At this concentration, the extract likely formed a uniform, semipermeable coating that moderated gas exchange, slowed metabolic activity, and restricted microbial proliferation without inducing anaerobic conditions. Conversely, it is possible that the lower concentration (15%) provided insufficient bioactive protection, while the higher concentration (45%) could have delayed regular physiological exchange due to the excessive coating thickness. Therefore, the 30% MLE appears to provide the most physiologically compatible conditions for preserving fruit firmness, antioxidant metabolism, and overall quality of postharvest persimmons during storage.

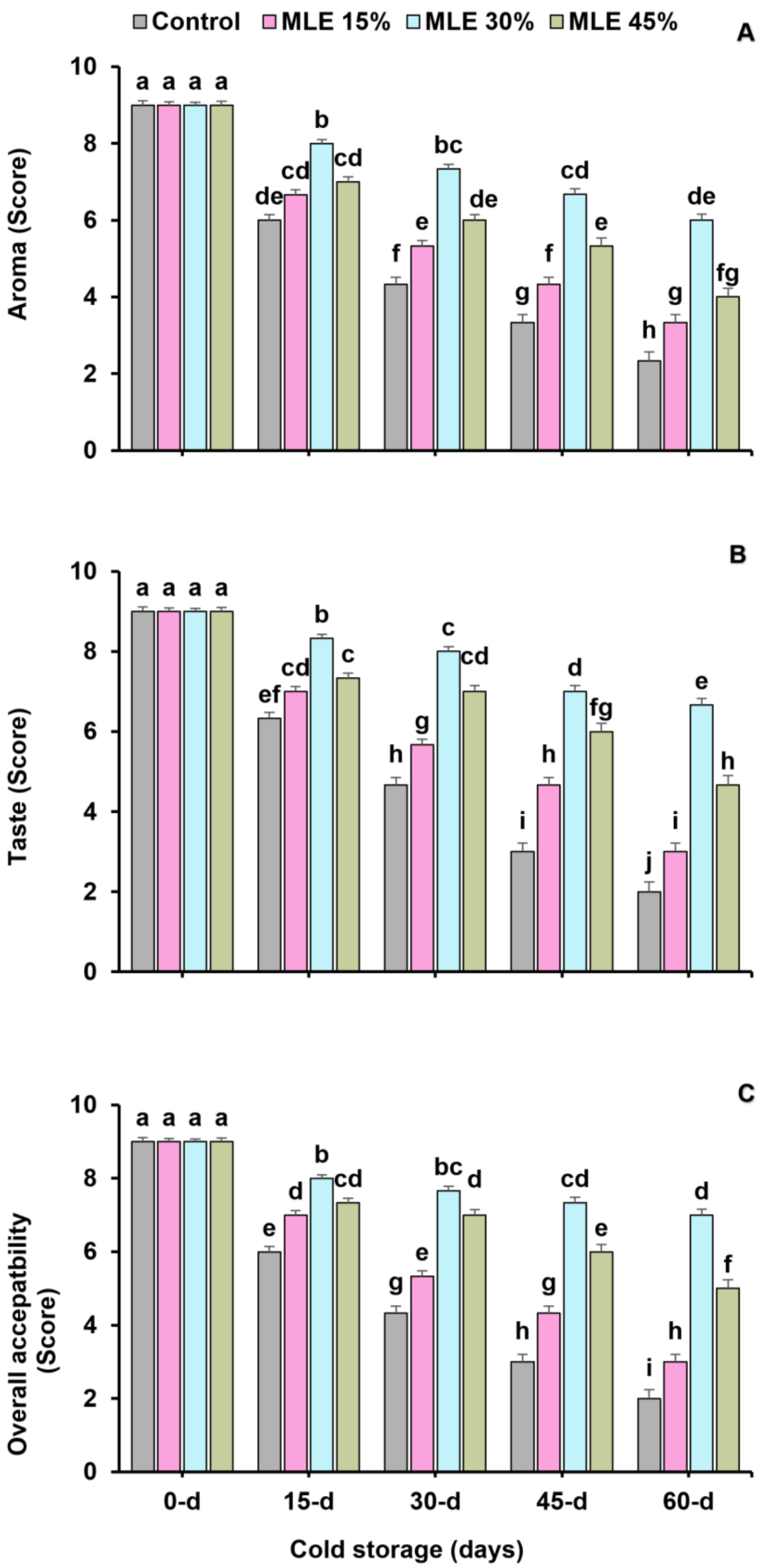

Figure 7. Effect of postharvest moringa leaf extract (MLE) application on fruit aroma (A), fruit taste (B), and overall acceptability (C) of persimmons during cold storage

Vertical bars represent the standard error of the means for data that are averages of three replicates; Different letters indicate substantial variances in the means, while the same letters indicate statistically insignificant differences according to the LSD test ($P \leq 0.05$)

CONCLUSION

Application of 30% moringa leaf extract substantially helps maintain the bioactive properties and prolongs the storage potential of persimmons for 60 days. Persimmons subjected to moringa leaf extract retained higher levels of titratable acidity, ascorbic acid, total phenolic content, antioxidant activity, and the activity of antioxidant enzymes such as superoxide dismutase, peroxidase, and catalase compared with the control. The use of moringa leaf extract reduced the accumulation of oxidative stress markers, including malondialdehyde and hydrogen peroxide. This indicates a substantial reduction in the activity of pectin methylesterase, polygalacturonase, and cellulase during 60 days of cold storage, while preserving fruit firmness, aroma, and taste. Subsequently, the postharvest application of moringa leaf extract could prove to be a sustainable and eco-friendly solution that delays senescence, alleviates physiological modifications, preserves bioactive characteristics and extends the storage potential of persimmons during cold storage.

Author contribution statement

MH – A – Research concept and design, D – Writing the article, F – Final approval of the article
MAUR – B – Collection and/or assembly of data
HR – E – Critical revision of the article
HH – C – Data analysis and interpretation

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