Effects of Packaging Materials and Storage Temperature on the Postharvest Quality of Lady's Finger (*Abelmoschus esculentus* L. Moench) Treated with Aqueous *Moringa oleifera* Leaf Extract

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ABSTRACT

Fresh lady's finger (*Abelmoschus esculentus* L.), commonly known as *okra* in the Philippines, is highly perishable, typically losing marketability within two to three days due to rapid moisture loss and physiological deterioration. This study evaluated the effectiveness of *Moringa oleifera* leaf extract (MLE), combined with different packaging materials and storage conditions, in extending okra's postharvest shelf life. A completely randomized design (CRD) was employed to evaluate six treatments involving MLE application, packaging materials, and storage temperatures under ambient (25°C) and refrigerated (5°C) conditions. Results revealed significant differences in weight loss, shriveling index, visual quality rating, and shelf life from Day 2 to Day 6. The untreated ambient control (T_1) exhibited the highest weight loss (73.22%) and a 100% shriveling index by the end of the storage period. In contrast, MLE-treated okra packaged in plastic film and stored under ambient conditions (T_3) demonstrated the best overall performance, recording the lowest weight loss (6.39%), a shriveling index of 33.33%, and the highest visual quality rating. Furthermore, T_3 extended shelf life to 8.00 days, compared with only 3.00 days for the untreated control. Interestingly, refrigerated treatments showed greater deterioration than their ambient counterparts when combined with MLE, suggesting possible moisture-related physiological stress under the tested conditions. The study concludes that MLE application combined with plastic film packaging under ambient conditions is a promising, environmentally friendly, and potentially cost-effective postharvest management strategy for maintaining okra quality. This approach may help smallholder farmers reduce postharvest losses, extend marketability, and improve the economic value of harvested produce.

Keywords: *Edible coating, Moringa olefiera, CRD, storage temperature, packaging materials*

INTRODUCTION

Abelmoschus esculentus (L.), commonly known as lady's finger or *okra*, is an economically significant vegetable crop cultivated extensively throughout tropical and subtropical regions worldwide (Ali et al., 2024). Despite its agricultural and nutritional importance, fresh okra is highly perishable following harvest which commonly causes high post-harvest losses. According to Jia et al., (2025), the harvested pods experience rapid physiological and biochemical deterioration, including elevated respiration rates, excessive transpiration resulting in moisture loss, and accelerated degradation of chlorophyll pigments. Hence, managing this rapid deterioration is critical to bridging the extensive gap between vegetable supply and demand (Jahan, 2020). Despite of this vulnerabilities, postharvest science has shifted toward sustainable preservation technologies, such as edible coatings and specialized packaging. Edible coatings serve as a physical barrier on the fruit's surface, significantly reducing moisture transfer, gas exchange (O2 and CO2), and oxidation (Tesfay & Magwaza, 2017). Aqueous extract of *Moringa oleifera* leaves represents an ideal candidate for this purpose due to its exceptional phytochemical profile. Moringa leaves are naturally rich in proteins, B-carotene, vitamins, phenolics, flavonoids, and isothiocyanates, giving the extract powerful antioxidant and antimicrobial properties that actively inhibit food spoilage organisms (Kubheka et al., 2020).

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However, the efficacy of these natural coatings is heavily dependent on the surrounding microclimate, making postharvest packaging and temperature management critical secondary defenses. Proper packaging seals the produce against physical friction, chemical alterations, and airborne microbial contamination while serving as a vital marketing tool by displaying the product cleanly to consumers (Neelima, P., 2019). When combined with temperature manipulation, specifically comparing ambient storage to refrigeration, the packaging material regulates the internal relative humidity and respiration rate of the coated fruit. Therefore, evaluating the interaction between *Moringa oleifera* leaf extract coatings, diverse packaging materials, and storage temperatures (ambient versus refrigerated) provides a comprehensive, multi-hurdle approach to maximizing the postharvest life and quality retention of fresh lady's fingers.

This study aids a practical value for smallholder farmers and postharvest handlers by providing a low-cost, eco-friendly preservation protocol that directly reduces on-farm and transit losses of lady's finger. By establishing how a natural Moringa leaf extract coating interacts with specific packaging materials and storage temperatures, this research offers the vegetable industry a concrete strategy to maintain the crop's green color, prevent ridge blackening, and stop surface shriveling. This intervention ensures a safer, chemical-free supply of highly marketable and bridge a critical gap in agricultural literature by delivering a scalable, multi-factor postharvest model that reduces aesthetic food waste and promotes sustainable food supply chains.

Generally, the study evaluated the effect of packaging materials and storage temperature on the postharvest quality of lady's finger *(Abelmoschus esculentus L.)* applied with aqueous moringa leaf extract (MLE) as an alternative biodegradable coating in postharvest handling. Specifically, this study aims to: identify which packaging materials and storage temperature, have a higher rate of extending the shelf life of lady's finger *(Abelmoschus esculentus L.);* evaluate which treatment has visible signs of storage damage, such as chilling injury (surface pitting) and shriveling or surface wrinkling of the okra pods; and determine which combination of packaging material and storage temperature that maintains the highest visual marketability score and acceptability of aqueous MLE-coated lady's finger.

MATERIALS AND METHODS

Location and Duration of the Study

The study was conducted at the Crop Protection Laboratory of Monkayo College of Arts, Sciences, and Technology (MonCAST), located in Poblacion, Monkayo, Davao de Oro, Philippines. The laboratory provided a suitable environment for the preparation of the treatments, application of postharvest treatments, packaging, and evaluation of the quality parameters of lady's finger fruits under controlled conditions. Storage of the treated fruits was carried out under ambient laboratory conditions to simulate the typical postharvest handling and storage practices commonly employed by local producers and vendors. The experimental work, including the preparation of materials, application of treatments, storage, periodic data collection, and laboratory analyses, was conducted during the month of June 2026.

Experimental Design and Treatments

The study was conducted using a Completely Randomized Design (CRD) consisting of six (6) treatments, each replicated three (3) times with five (5) lady's finger (*Abelmoschus esculentus* L. Moench) fruits per replication, for a total of ninety (90) experimental units. Three factors were considered in formulating the treatment combinations: (1) the application of *Moringa oleifera* leaf extract (MLE) to evaluate its efficacy as a natural postharvest treatment, (2) the type of packaging material, namely plastic film and polyethylene bag (Figure 1c-1d), and (3) the storage condition, consisting of ambient storage (25°C) and refrigerated storage (5°C). These factors were combined to determine their influence on the postharvest quality and shelf life of lady's finger fruits.

The treatments were as follows: T_1 – Control (no packaging, without *Moringa oleifera* leaf extract, and stored under ambient conditions); T_2 – Control (no packaging, without *Moringa oleifera* leaf extract, and stored under refrigerated conditions at 5°C); T_3 – Plastic film packaging with *Moringa oleifera* leaf extract under ambient conditions; T_4 – Plastic film packaging with *Moringa oleifera* leaf extract under refrigerated conditions at 5°C;

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T_5 – Polyethylene bag packaging with *Moringa oleifera* leaf extract under ambient conditions; and T_6 – Polyethylene bag packaging with *Moringa oleifera* leaf extract under refrigerated conditions at 5°C. Plastic film and polyethylene bag packaging were non-perforated. The experimental units were randomly assigned to the treatments to minimize experimental error and ensure that each experimental unit had an equal probability of receiving any treatment.

Preparation of Lady's Finger Fruits

Freshly harvested, and homogenous lady's finger (*Abelmoschus esculentus* L. Moench) fruits of the 'Lega C' variety were used as the experimental materials in this study. The fruits were carefully selected based on uniformity in size (10-12 cm long), maturity (harvested after 4 days from flowering), color (dark green), and the absence of physical damage, disease symptoms, and insect infestation. The packaging materials used in the study, including plastic film and polyethylene bags (Figure 1), were purchased from local commercial stores in Monkayo, Davao de Oro, Philippines.



Figure 1. Experimental materials used in the study: (a) fresh, healthy, and uniformly sized lady's finger (Abelmoschus esculentus L. Moench) fruits of the 'Lega C' variety, (b) styrofoam container, (c) polyethylene bags, and (d) plastic film used as packaging materials for the postharvest treatments.

Preparation of Moringa Leaf Extract

Fresh leaves of *Moringa oleifera* were collected from Libuton, Poblacion, Monkayo, Davao de Oro. The leaves were thoroughly prewashed under a gentle stream of tap water for one to two minutes to remove dirt and other contaminants. They were then rinsed three times with distilled water to ensure cleanliness. The cleaned leaves were crushed using a sterilized mortar and pestle to obtain the leaf macerate. The macerate was transferred into sterile beakers containing 100 mL of distilled water and allowed to stand for three hours to facilitate extraction. After extraction, the mixture was filtered through a sterile muslin cloth to obtain the crude leaf extract. Following the method of Liamngee et al. (2019), 20 mL of the crude *Moringa oleifera* leaf extract was diluted with 100 mL of distilled water to prepare the treatment solution (Figure 2).

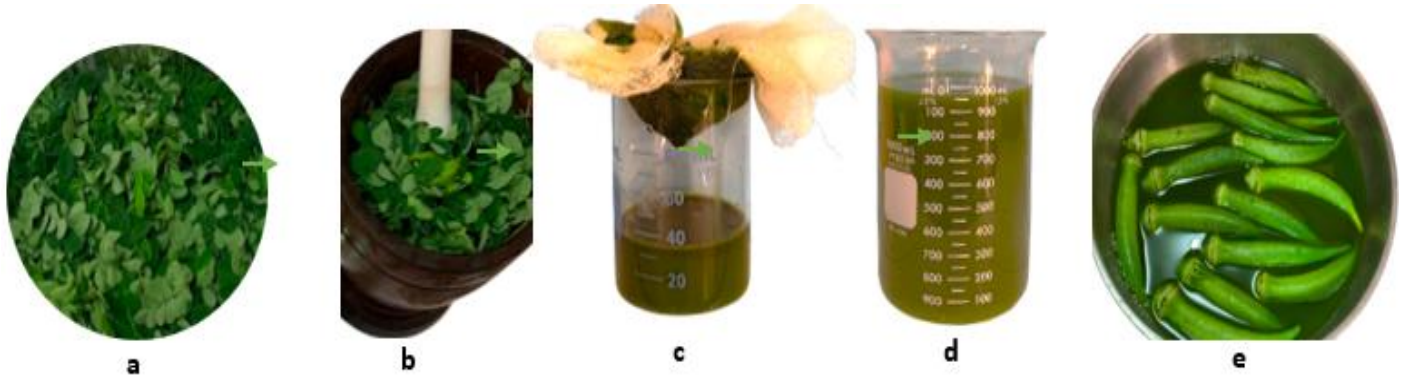


Figure 2. Preparation of Moringa oleifera leaf extract (MLE): (a) collection of fresh leaves, washing and rinsing of leaves, (b) crushing using a sterilized mortar and pestle, (c) maceration in distilled water and filtration through a sterile muslin cloth, and (d) preparation of the treatment solution by dilution of the crude extract, and (e) dipping of the lady's finger fruits in the MLE.

Treatment of Lady's Finger fruits with Moringa leaf extracts

The lady's finger fruits were thoroughly washed with tap water to remove dirt and then air-dried before the application of the treatments. The treated fruits were dipped once in a 200 mL/L concentration of Moringa leaf extract (MLE), while the control fruits were dipped in distilled water only. After treatment, all fruits were air-dried and subsequently stored under ambient temperature conditions, and the refrigerated samples were stored in a refrigerator set at the highest cooling level (Setting 7), maintaining an approximate storage temperature of 0–2°C (Figure 3).



Figure 3. Experimental setup of the lady's finger fruits following the application of Moringa oleifera leaf extract (MLE): (a) air-drying after treatment, (b) storage under ambient conditions (25°C), and (c) storage under refrigerated conditions (2°C).

Data Gathered

A. Fruit Weight Loss (%)

Fruit weight loss was determined by measuring the weight of the lady's finger (*Abelmoschus esculentus* L. Moench) fruits using a calibrated digital weighing scale. The initial weight of each experimental unit was recorded before the application of treatments and storage (Day 0), while the final weight was recorded at the end of the storage period. The percentage of fruit weight loss was calculated by comparing the difference between the initial and final weights relative to the initial weight, following the method described by Ali et al. (2016). Fruit weight loss was computed using the following formula: $Fruit\ Weight\ Loss = Initial\ weight\ before\ storage - Final\ weight\ after\ storage / Initial\ weight\ before\ sorage\ x\ 100.$

B. Shriveling Index

The shriveling index of the lady's finger (*Abelmoschus esculentus* L. Moench) fruits was assessed through visual evaluation throughout the storage period. Each experimental unit was examined daily for the presence and severity of surface shriveling, and a corresponding rating score was assigned based on the extent of moisture loss and fruit wrinkling. The shriveling index (SI) of the lady's finger (*Abelmoschus esculentus* L. Moench) fruits was evaluated following the methods described by Fawole et al. (2020) and Arif et al. (2024). Shriveling symptoms were assessed through daily visual inspection throughout the storage period. Each fruit was classified according to the degree of shriveling using the following rating scale: 0 = no shriveling; 1 = less than 25% shriveling; 2 = 25–50% shriveling; 3 = 50–75% shriveling; and 4 = more than 75% shriveling. The shriveling index was expressed as a percentage and calculated using the following equation: *Shriveling Index*

(SI) = ∑ (Shrivel Scale Score × Number of Fruits in that Score) / Total Number of Fruits Evaluated × Highest Score on the Scale × 100.

C. Visual Quality Rating

The visual quality of the lady's finger (Abelmoschus esculentus L. Moench) fruits was evaluated through visual inspection throughout the storage period. Assessments were conducted on Day 0 and at daily intervals until the sixth day of storage. Each experimental unit was assigned a visual quality rating based on its overall appearance, including color, freshness, firmness, and the presence of defects such as shriveling, discoloration, or decay. The visual quality of the fruits was scored using the rating scale adapted from Tayobong et al. (2024) (Table 1), with higher scores indicating better overall marketability and postharvest quality.

Table 1. Visual quality rating scale used for evaluating the postharvest quality of lady's finger (*Abelmoschus esculentus* L. Moench) fruits during the storage period, adapted from Tayobong et al. (2024).

Rating Score	Description
9	No symptoms of deterioration; ideal bright green color, turgid, and no mechanical damage.
7	Minor symptoms of deterioration; slight yellowing or minor dehydration/wrinkling.
5	Deterioration evident, but not serious; some shriveling or spotting. This is typically considered the limit of marketability.
3	Serious deterioration; extensive discoloration (browning/blackening), shriveling, or signs of fungal decay. Reaching the limit of usability.
1	Complete loss; heavy rotting, extremely dark surface spots, or soft-rotting pathogens present.

D. Postharvest Life

The postharvest life of the lady's finger (*Abelmoschus esculentus* L. Moench) fruits was determined by recording the number of days from the start of storage until the fruits reached a Visual Quality Rating (VQR) of 5, which represents the end of marketable quality. Each treatment was evaluated daily, and the postharvest life was expressed as the total number of days the fruits remained acceptable for marketability based on the established visual quality rating scale.

Statistical Analysis

The data collected from the experiment were subjected to Analysis of Variance (ANOVA) using a Completely Randomized Design (CRD) to determine the significant differences among the six treatment combinations. Statistical significance was evaluated at the 5% level of significance ($\alpha = 0.05$). When the ANOVA indicated significant treatment effects, and Tukey's Honest Significant Difference (HSD) Test was employed as a post hoc analysis to compare the treatment means. All statistical analyses were performed using the Statistical Tool for Agricultural Research (STAR) software.

RESULTS AND DISCUSSION

Fruit Weight Loss (%)

The study resulted that no significant differences among treatments were observed on Day 1 ($P = 0.3283$). However, highly significant differences ($P < 0.01$) were detected from Day 2 to Day 6, indicating that the treatments effectively influenced fruit weight loss as storage progressed (Table 2).

The untreated control stored under ambient conditions (T_1) recorded the highest fruit weight loss throughout the storage period, reaching 73.22% on Day 6, followed by the refrigerated control (T_2) with 48.34%. In contrast, fruits treated with MLE and packaged with plastic film (T_3 and T_4) or polyethylene bags (T_5 and T_6) exhibited significantly lower weight loss, ranging from 6.39% to 13.14% on Day 6. Among all treatments, T_3

(MLE + Plastic Film–Ambient) recorded the lowest fruit weight loss (6.39%), although it was statistically comparable with the other MLE-treated treatments.

Table 2. Mean fruit weight loss (%) of lady's finger (*Abelmoschus esculentus* L. Moench) fruits as affected by *Moringa oleifera* leaf extract (MLE), packaging material, and storage temperature over a six-day storage period.

TREATMENTS	DAYS OF OBSERVATION					
	Day 1^{ns}	Day 2**	Day 3**	Day 4**	Day 5**	Day 6**
T_1-Control–Ambient	11.64	21.96^{c}	34.33^{b}	49.06^{a}	59.99^{c}	73.22^{c}
T_2-Control–Refrigerated	6.38	16.78^{bc}	25.34^{b}	36.30^{b}	40.52^{b}	48.34^{b}
T_3-MLE + Plastic Film–Ambient	1.64	1.59^{a}	2.14^{a}	4.29^{a}	4.80^{a}	6.39^{a}
T_4-MLE + Plastic Film–Refrigerated	3	5.51^{ab}	8.53^{a}	9.58^{a}	12.10^{a}	13.14^{a}
T_5-MLE + PE Bag–Ambient	1.13	2.31^{a}	4.03^{a}	5.17^{a}	6.85^{a}	10.94^{a}
T_6-MLE + PE Bag–Refrigerated	2.64	3.91^{ab}	5.88^{a}	7.82^{a}	10.41^{a}	11.69^{a}
Pr (> F)	0.3283	0.001	0	0	0	0
CV (%)	137.98	57.21	30.97	19.03	15.2	16.49

*Means having the same letter superscripts are not significantly different at 5% level of significance using Least Significance Difference (LSD) Test; Values are means of three replications; * - significant; **- highly significant at 5% level and ns – not significant.*

The reduced fruit weight loss observed in MLE-treated and packaged fruits can be attributed to the combined effects of *Moringa oleifera* leaf extract and packaging materials in minimizing moisture loss during storage. Packaging materials act as barriers to water vapor diffusion, thereby reducing transpiration and respiration rates, maintaining high relative humidity around the fruits, preserving tissue moisture, and delaying postharvest deterioration (Kader, 2002; Thompson, 2015; Wills et al., 2016). In addition, *Moringa oleifera* leaf extract contains natural antioxidants and antimicrobial compounds that help maintain cell membrane integrity and reduce physiological deterioration, thereby contributing to improved postharvest quality (Anwar et al., 2007). The present findings demonstrate that the combined application of *Moringa oleifera* leaf extract and packaging materials effectively reduced fruit weight loss and prolonged the postharvest shelf life of lady's finger (*Abelmoschus esculentus* L. Moench) fruits.

Shriveling Index (%)

This study demonstrated no shriveling was observed at the initial evaluation and on Day 1. However, highly significant differences among treatments were detected from Day 2 to Day 6 ($P < 0.05$), indicating that the treatments effectively delayed the development of shriveling during storage (Table 3). The untreated control stored under ambient conditions (T_1) exhibited the highest shriveling index throughout the storage period, reaching 100.00% on Day 6, followed by the refrigerated control (T_2) with 75.00%. In contrast, fruits treated with MLE and packaged in plastic film or polyethylene bags showed significantly lower shriveling indices. The lowest shriveling was recorded in T_3 (MLE + Plastic Film–Ambient) with 33.33%, followed by T_5 (MLE + PE Bag–Ambient) with 50.00% on Day 6.

Table 3. Mean shriveling index (%) of lady's finger (*Abelmoschus esculentus* L. Moench) fruits as affected by *Moringa oleifera* leaf extract (MLE), packaging material, and storage temperature over a six-day storage period.

TREATMENTS	DAYS OF OBSERVATION						
	Initial^{ns}	Day 1^{ns}	Day 2**	Day 3**	Day 4**	Day 5**	Day 6**
T_1-Control–Ambient	0	0	25.00^{b}	33.33^{b}	58.33^{c}	75.00^{b}	100.00^{b}
T_2-Control–Refrigerated	0	0	16.67^{b}	25.00^{b}	50.00^{bc}	50.00^{ab}	75.00^{ab}
T_3-MLE + Plastic Film–Ambient	0	0	0.00^{a}	0.00^{a}	8.33^{a}	25.00^{a}	33.33^{a}
T_4-MLE + Plastic Film–	0	0	0.00^{a}	16.67^{ab}	25.00^{ab}	50.00^{ab}	75.00^{ab}

Refrigerated							
T_5-MLE + PE Bag–Ambient	0	0	0.00 [a]	0.00 [a]	16.67 [a]	25.00 [a]	50.00 [a]
T_6-MLE + PE Bag–Refrigerated	0	0	0.00[a]	25.00 [b]	33.33 [abc]	41.67 [ab]	66.67 [ab]
Pr (> F)	-	-	0.0004	0.0013	0.0015	0.0173	0.0064
CV (%)	-	-	84.85	49	36.89	35.08	24

*Means having the same letter superscripts are not significantly different at 5% level of significance using Least Significance Difference (LSD) Test; Values are means of three replications; * - significant; **- highly significant at 5% level and ns – not significant.*

The lower shriveling index observed in MLE-treated and packaged fruits may be attributed to reduced moisture loss and transpiration, as packaging maintains a humid microenvironment around the fruits while limiting water vapor diffusion (Kader, 2002; Wills et al., 2016). Moreover, the antioxidant and antimicrobial properties of *Moringa oleifera* leaf extract may have helped maintain cellular integrity and delayed physiological deterioration during storage (Anwar et al., 2007). These findings suggest that the combined application of MLE and suitable packaging materials effectively reduced shriveling and maintained the postharvest quality of lady's finger fruits.

Visual Quality Rating (VQR)

The study resulted that all fruits had an initial VQR of 9.00, indicating excellent quality at the beginning of storage. Significant differences among treatments were observed from Day 1 to Day 5 ($P < 0.05$), indicating that the treatments effectively maintained fruit quality during storage (Figure 4). The untreated control stored under ambient conditions (T_1) showed the fastest decline in visual quality, reaching a VQR of 1.00 on Day 6, followed by the refrigerated control (T_2), which also declined to 1.00. In contrast, fruits treated with MLE and packaged in plastic film under ambient conditions (T_3) maintained the highest visual quality, recording a VQR of 7.00, followed by MLE with polyethylene bags under ambient conditions (T_5) with a VQR of 5.00 (Table 4).

Table 4. Mean visual quality rating (VQR) score of lady's fingers (*Abelmoschus esculentus* L. Moench) fruits as affected by *Moringa oleifera* leaf extract (MLE), packaging material, and storage temperature over a six-day storage period.

TREATMENTS	**DAYS OF OBSERVATION**						
	Initial[ns]	Day 1[**]	Day 2[**]	Day 3[**]	Day 4[**]	Day 5[**]	Day 6
T_1-Control–Ambient	9	7.00 [b]	7.00[b]	5.00 [c]	4.33 [b]	3.00 [c]	1
T_2-Control–Refrigerated	9	9.00 [a]	7.00 [b]	5.67 [bc]	4.33 [b]	3.00 [c]	1
T_3-MLE + Plastic Film–Ambient	9	9.00 [a]	9.00 [a]	9.00 [a]	9.00 [a]	7.67 [a]	7
T_4-MLE + Plastic Film–Refrigerated	9	7.67 [b]	7.67 [ab]	6.33 [abc]	5.00 [b]	3.67[bc]	3
T_5-MLE + PE Bag–Ambient	9	9.00 [a]	9.00 [a]	8.33 [ab]	7.67 [ab]	5.67 [ab]	5
T_6-MLE + PE Bag–Refrigerated	9	9.00 [a]	7.67 [ab]	7.00 [abc]	5.67 [ab]	3.00 [c]	3
Pr (> F)	-	0.0004	0.0069	0.0081	0.0026	0	NaN
CV (%)	-	5.58	8.45	16.76	20.79	18.84	NaN

*Means having the same letter superscripts are not significantly different at 5% level of significance using Least Significance Difference (LSD) Test; Values are means of three replications; * - significant; **- highly significant at 5% level, and ns – not significant.*

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The improved visual quality of MLE-treated and packaged fruits may be attributed to reduced moisture loss and delayed physiological deterioration. Packaging materials help maintain a favorable storage microenvironment by limiting transpiration and respiration, thereby preserving freshness and marketability (Kader, 2002; Wills et al., 2016). Similarly, Gonzales and Benitez (2023) reported that coated okra fruits exhibited significantly lower weight loss and shriveling while maintaining firmness and overall visual quality compared with untreated fruits. Furthermore, Tayobong et al. (2025) demonstrated that appropriate storage conditions are essential for maintaining the quality and marketability of Philippine-grown okra during storage and transport. The antioxidant and antimicrobial properties of *Moringa oleifera* leaf extract may have further contributed to delaying tissue deterioration and preserving the visual appearance of the fruits (Anwar et al., 2007). These findings suggest that the combined application of MLE and suitable packaging materials is an effective postharvest strategy for maintaining the visual quality and extending the marketability of lady's finger fruits.



T_1 – Control (no packaging, without *Moringa oleifera* leaf extract, and stored under ambient conditions



T_2 – Control (no packaging, without *Moringa oleifera* leaf extract, and stored under refrigerated conditions at 5°C)



T_3 – Plastic film packaging with *Moringa oleifera* leaf extract under ambient conditions



T_4 – Plastic film packaging with *Moringa oleifera* leaf extract under refrigerated conditions at 5°C



T_5 – Polyethylene bag packaging with *Moringa oleifera* leaf extract under ambient conditions

T_6 – Polyethylene bag packaging with *Moringa oleifera* leaf extract under refrigerated conditions at 5°C.

Post-harvest Shelf-life

In this study, highly significant differences among treatments were observed ($P < 0.01$), indicating that the treatments significantly influenced the postharvest shelf life of the fruits (Table 5). Among the treatments, T_3 (MLE + Plastic Film–Ambient) recorded the longest postharvest shelf life of 8.00 days, followed by T_5 (MLE + PE Bag–Ambient) with 5.33 days and T_6 (MLE + PE Bag–Refrigerated) with 4.67 days. Conversely, the untreated control under ambient conditions (T_1) had the shortest shelf life (3.00 days), while the refrigerated control (T_2) and T_4 (MLE + Plastic Film–Refrigerated) both exhibited a shelf life of 3.33 days.

Table 5. Mean post-harvest shelf life (days) of lady's finger (*Abelmoschus esculentus* L. Moench) fruits as affected by *Moringa oleifera* leaf extract (MLE), packaging material, and storage temperature over an 8-day storage period.

TREATMENTS	Post-Harvest Shelf Life
T_1-Control–Ambient	3.00^{c}
T_2-Control–Refrigerated	3.33 ^{c}
T_3-MLE + Plastic Film–Ambient	8.00 ^{a}
T_4-MLE + Plastic Film–Refrigerated	3.33 ^{c}
T_5-MLE + PE Bag–Ambient	5.33 ^{b}
T_6-MLE + PE Bag–Refrigerated	4.67 ^{b}
Pr (> F)	0
CV (%)	9.53

*Means having the same letter superscripts are not significantly different at 5% level of significance using Least Significance Difference (LSD) Test; Values are means of three replications; * - significant; **- highly significant at 5% level and ns – not significant.*

The extended shelf life observed in MLE-treated fruits, particularly those packaged in plastic film, may be attributed to reduced moisture loss, delayed senescence, and suppression of microbial deterioration. *Moringa oleifera* leaf extract is rich in phenolic compounds, flavonoids, and ascorbic acid, which possess antioxidant and antimicrobial properties that help preserve cellular integrity during storage (Leone et al., 2015; Saini et al., 2016). Likewise, suitable packaging materials reduce water vapor loss and create a favourable storage atmosphere that delays physiological deterioration and maintains fruit marketability (Thompson, 2015). Similar observations were reported by Gonzales and Benitez (2023), who found that edible-coated okra fruits maintained better postharvest quality and exhibited lower shriveling and weight loss than untreated fruits. Furthermore, Shi et al. (2024) demonstrated that reducing oxidative stress and delaying fruit softening

effectively prolonged the storage life of okra. These findings indicate that the combined application of MLE and plastic film packaging is an effective and environmentally friendly approach for extending the postharvest shelf life of lady's finger fruits.

CONCLUSION

This study demonstrates that combining *Moringa oleifera* leaf extract (MLE) with protective packaging is an effective, eco-friendly postharvest strategy to mitigate physiological decay in lady's finger (*Abelmoschus esculentus* L. Moench). Untreated ambient (T1) and refrigerated (T2) controls deteriorated rapidly, exhibiting extreme weight loss (73.22% and 48.34%), high shriveling (100% and 75%), and complete loss of marketability (VQR = 1.00) by Day 6. In contrast, MLE-treated fruits with packaging maintained superior quality metrics. Treatment 3 (MLE + Plastic Film – Ambient) performed best, restricting weight loss to 6.39% and shriveling to 33.33%, while maintaining a high visual quality rating (7.00) and extending shelf life to 8.00 days (compared to 3.00 days for T1). Refrigeration paired with packaging (T4, T6) failed to offer additive benefits due to chilling injury, which accelerated tissue collapse. Ultimately, the synergistic effect of MLE's antioxidant properties and the moisture-barrier function of plastic film effectively retards the fruit respiration and maintains cell wall integrity under ambient conditions.

RECOMMENDATION

MLE combined with plastic film under ambient conditions is recommended for further evaluation as a potential postharvest treatment. Future studies should include a cost-benefit analysis, trials under real market conditions, and testing across multiple okra varieties. Biodegradable packaging alternatives should also be evaluated to reduce plastic use while maintaining product quality. Further research should determine suitable storage temperatures and investigate the treatment's mechanisms of action before recommending large-scale commercial application.

Ethical Considerations

Authors of this paper were permitted to conduct the study as one of the institutional research outputs noting that all experimental procedures were performed in accordance with the institutional and scientific guidelines.

Conflict of Interest

The authors declare that there are no conflicts of interest, financial or otherwise that could have influenced the design, execution, interpretation, or reporting of this research.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, as the dataset is not publicly archived.

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