



**EFFECT OF MATURITY STAGE AND PLANT EXTRACT COATINGS ON
POSTHARVEST QUALITY AND NUTRITIONAL CONTENTS OF TOMATO FRUITS
(*Solanum lycopersicum* L.) UNDER ROOM TEMPERATURE CONDITION**

¹Kapsiya, J., ²Pwaluwari, M. M., ¹Abba, A. and ³Daniel, J. E.

¹Department of Horticultural Technology, Federal College of Horticulture
P.M.B. 108, Dadinkowa, Gombe State, Nigeria.

²Crop Unit, Agriculture and Rural Development Secretariat,
Federal Capital Territory Administration P.M.B. 24 FCT, Abuja, Nigeria.

³Department of Social Development, Federal College of Horticulture
P.M.B. 108, Dadinkowa Gombe State, Nigeria.

Corresponding Author's Email: jkapsiya.hort@fchdk.edu.ng, **GSM:** 08107445114

ABSTRACT

This study evaluated how harvest maturity and low-cost aqueous plant extracts interact to influence tomato shelf life and quality under ambient storage temperature. The treatments consisted of three (3) harvest ripening stage (mature green, breaker, red), three (3) postharvest treatment (neem aqueous extract, moringa aqueous extract, ginger aqueous extract) and a control. These were factorially combined and laid out in a randomized complete block design with four replications. Standardized aqueous extracts were applied as two-minute dips prior to storage at 25 ± 3 °C and $60 \pm 10\%$ relative humidity. Fruits were monitored over nine days at three-day intervals for weight loss, marketability, decay incidence and severity, soluble solids content, titratable acidity, pH, and vitamin C. Data collected were subjected to analysis of variance (ANOVA) and least significant difference (LSD) was adopted in separating the means. Results indicated that, harvest maturity exerted a dominant influence on cumulative deterioration: red fruits experienced the most rapid transpiration and metabolic water loss, exhibiting the highest weight loss and fastest decline in marketability, while breaker fruits showed lower cumulative losses but greater early susceptibility to infection. Aqueous plant extracts provided transient protection, significantly reducing weight loss and infection at three and six days; ginger and moringa were most effective at limiting early weight loss, and moringa sustained lower infection incidence by day nine. Neem and moringa enhanced vitamin C retention, whereas ginger increased soluble solids but reduced vitamin C. By day 9, botanical dips could not fully prevent long-term losses under ambient conditions. Integrating optimal harvest timing with targeted botanical treatments can delay early deterioration and offer practical, low-cost strategies to reduce tomato postharvest losses in resource-constrained supply chains. Future work should optimize extract formulations and application timing for scalable adoption by smallholder producers globally.

Keywords: Fruit, Maturity, Aqueous, Extracts, Tomato, Fruits.

INTRODUCTION

Tomato (*Solanum lycopersicum*) is a globally important horticultural crop, supplying essential vitamins, minerals, and dietary antioxidants while supporting livelihoods across smallholder and commercial value chains (FAO, 2021). Postharvest losses of tomato are particularly severe in regions that rely on ambient-temperature handling and lack cold-chain infrastructure; estimates indicate that up to 30–50% of tomato production can be lost between harvest and consumption in low- and middle-income countries, driven by rapid ripening, mechanical injury, and microbial decay. Fruit physiological status at harvest strongly determines postharvest behavior. Tomatoes harvested at mature green, breaker, or red stages differ in respiration rate, ethylene production and sensitivity, cell-wall integrity, and pathogen susceptibility; fruits harvested at earlier maturity generally have longer potential shelf life but require careful handling to avoid chilling or physiological disorders, while later-harvested fruit reach marketable color sooner but deteriorate faster under ambient conditions (Silva *et al.*, 2020).

Concurrently, there is growing interest in plant-derived aqueous extracts as low-cost, environmentally friendly postharvest treatments. Aqueous extracts from leaves, seeds, and peels of



species such as neem (*Azadirachta indica*), moringa (*Moringa oleifera*), clove and ginger (*Zingiber officinale*) contain phenolics, flavonoids, terpenoids, and other bioactive compounds with antimicrobial and antioxidant properties that can reduce decay and delay senescence when applied as dips, washes, or coatings (Singh *et al.*, 2020; Rahman *et al.*, 2022). Recent experimental studies report that aqueous extracts can lower decay incidence, reduce weight loss, and preserve firmness and color in tomato and other fruits, though efficacy varies with extract source, concentration, application method, and storage environment.

Mechanistically, plant extracts may act through multiple pathways: direct antimicrobial activity against common postharvest pathogens (e.g., *Alternaria*, *Botrytis*, *Rhizopus*), antioxidant scavenging of reactive oxygen species that drive membrane deterioration, and modulation of ethylene biosynthesis or action, thereby slowing ripening-related softening (González-Aguilar *et al.*, 2019; Patel & Sharma, 2021). Field- and laboratory-scale trials have shown promising reductions in decay and modest extensions of shelf life at ambient temperature, but results are inconsistent across cultivars and maturity stages, and few studies systematically examine interactions between harvest ripeness and extract treatment.

In many tomato-producing regions, especially across sub-Saharan Africa and parts of South and Southeast Asia, ambient-temperature storage and market-level handling predominate; refrigeration and controlled-atmosphere systems are often unavailable or prohibitively expensive (World Bank, 2021). Practical, low-cost interventions that can be prepared from locally available plant materials would therefore be highly valuable for reducing postharvest losses, improving food security, and increasing farmer incomes. While synthetic fungicides and commercial coatings can be effective, concerns about residues, cost, and regulatory restrictions motivate exploration of plant-based alternatives that are perceived as safer and more accessible (Adebayo *et al.*, 2021). However, adoption requires robust, context-specific evidence: which extracts work best, at what concentrations and application methods, and how harvest maturity modifies treatment outcomes under ambient conditions. Addressing these questions will enable extension services and market actors to recommend feasible, evidence-based practices.

Despite accumulating studies on plant extracts for postharvest preservation, there is limited systematic evidence on how fruit ripening stage at harvest influences the effectiveness of aqueous plant-extract treatments for tomato stored at ambient temperature. Existing literature often tests a single maturity stage or a single extract without factorially combining ripeness and treatment variables; consequently, practical guidance for producers who must choose both harvest timing and postharvest treatment is lacking. This gap constrains the uptake of plant-extract interventions and limits their potential to reduce losses in resource-constrained supply chains.

The aim of this study is to evaluate the effects of selected aqueous plant extracts and fruit ripening stage on the postharvest shelf life and quality of tomato under ambient-temperature storage. Specifically, the objectives are: to compare postharvest shelf life and quality changes of tomato fruits harvested at different ripening stages (mature green, breaker, and red) during ambient storage and; to assess the efficacy of selected aqueous plant extracts on fruit decay incidence, weight loss, firmness and nutritional contents.

MATERIALS AND METHODS

Treatments and Experimental Design

The treatments consisted of three (3) harvest ripening stage (mature green, breaker, red), three (3) postharvest treatment (neem aqueous extract, moringa aqueous extract, ginger aqueous extract) and a control. These were factorially combined and laid out in a randomized complete block design with four replications. Each experimental unit consisted of 10 uniform fruits, giving a total sample size of $3 \times 5 \times 4 \times 10 = 600$ fruits. The experiment was conducted under ambient laboratory conditions representative of local market environments. Data were collected at 0, 3, 6, and 9 days intervals.



Plant Materials and Cultivar Selection

A widely grown, commercially representative cultivar ‘Roma VF’ was used for the experiment. Fruits were sourced from one commercial farm to minimize preharvest variability. Fruits selected for the experiment were uniform in size, free from visible defects, and free from prior disease symptoms.

Harvest maturity definitions

Mature green: fully sized fruit with green color, no visible color break.

Breaker: first visible color change (less than 10-30% surface showing pink or yellow).

Red: full red color, marketable ripe stage. Maturity classification will follow established visual and colorimeter thresholds (Silva *et al.*, 2020).

Preparation of Aqueous Plant Extracts

Fresh leaves were collected from healthy neem, moringa and fresh ginger rhizomes. Plant materials were washed under running water to remove debris.

Extraction Procedure (standardized aqueous extraction):

The plant materials were air-dried in shade to constant weight and ground to a coarse powder using a laboratory mill. The extracts were prepared at a standardized ratio (1:10 w/v) by mixing 100 g of powdered plant material with 1 L of distilled water. For fresh ginger, equivalent fresh weight was also used. The mixture was heat at 60–70°C for 30 minutes with occasional stirring to facilitate extraction, then cooled at room temperature. The individual solution was filtered through muslin cloth followed by Whatman No. 1 filter paper. The solutions were prepared at 10% v/v. All extracts were prepared and used on the day of application.

Postharvest Treatment, Application and Storage

Fruits were randomly assigned to treatment groups. For each treatment, fruits were dipped in the respective solution for 2 minutes with gentle agitation, then allowed to drain and air-dried at room temperature for 30 minutes before storage. Control fruits were however dipped in distilled water for the same duration. The fruits were stored in a well-ventilated laboratory room maintained at $25 \pm 3^\circ\text{C}$ and $60 \pm 10\%$ relative humidity to mimic typical market conditions. Measurements were taken at initial day of storage and at regular intervals of 3 days until 9 days after storage.

Measurement of Parameters

Weight loss (%): Individual fruit weight was recorded at each sampling time using an analytical balance. Weight loss was expressed as percentage loss relative to initial weight.

Marketability assessment: At each sampling interval, a trained panel evaluated a subset of fruits for marketability (yes/no) based on appearance, firmness, and absence of decay.

Decay incidence and severity: Decay incidence was recorded as the percentage of fruits showing visible fungal or bacterial spoilage per replicate. Decay severity was scored on a 0–5 scale (0 = no decay; 5 = >75% surface affected) and used to compute a decay index.

Soluble solids content (SSC, °Brix): Juice from a composite sample of three fruits per replicate was extracted and measured using a digital refractometer.

Titrateable acidity (TA): TA was determined by titration of juice against 0.1 N NaOH to pH 8.1 and expressed as percentage citric acid equivalents.

pH: Measured using a calibrated pH meter on extracted juice.

Data Analysis

Data collected were analyzed using analysis of variance (ANOVA) to test main effects of harvest maturity and treatment and their interaction. The significantly different treatment means were separated using least significant difference (LSD). Statistical analysis was performed using SAS (version 9.1).

RESULTS AND DISCUSSION

Effect of Ripening Stage and Aqueous Plant Extracts on Weight Loss of Tomato Fruits

The results of the effect of tomato ripening stage and plant extracts on percentage weight loss of tomato fruits is presented in Table 1. The result obtained showed that, weight loss increased with storage time for all treatments and maturities, with the largest absolute losses recorded at 9 days ranging from 53.4% to 93.5%. On the effect of ripening stage, weight loss differed significantly ($P < 0.05$) among



ripening stages, with red fruit showing the highest loss (47.1%) and breaker/green lower and similar values (30.2–31.3%) at 3 days. At 6 days however, differences among ripening stages were not significant, indicating convergence of weight-loss rates mid-storage. By 9 days, ripening stage again showed a significant effect, with red fruit (93.2%) and green fruit (84.1%) showing much higher losses than breaker fruit (53.4%). As for the effect of extracts, extract treatments produced statistically significant differences in weight loss at 3 days and 6 days, but by 9 days extract effects were not significant. At 9 days the control recorded the highest weight loss (93.5%), while ginger and moringa showed the lowest end-of-period losses among extracts (66.1% and 75.0%), respectively. Neem extract however showed intermediate performance (77.2%).

The pattern suggests that extract effects are most detectable early–mid storage (3–6 days) and that ripening stage exerts a dominant influence on cumulative weight loss by late storage of 9 days. The significant differences at 3 days and 9 days indicate that harvest maturity strongly influences transpiration and metabolic water loss, particularly immediately after harvest and at advanced storage times. Red fruit exhibited the highest early loss (3 days) and the highest cumulative loss by 9 days, consistent with higher respiration and cuticle permeability in ripe fruit (Silva *et al.*, 2020). The temporary non-significance at 6 days likely reflects differing rates of change across stages; breaker fruit accelerated in loss between days 3 and 6 while green fruit remained relatively stable producing convergence mid-storage before divergence again by day 9. This temporal pattern aligns with prior observations that ripening stage alters both the rate and timing of quality decline (Silva *et al.*, 2020). Extract treatments produced significant reductions in weight loss at 3 and 6 days but not at 9 days, indicating that aqueous plant extracts can delay water loss and early deterioration but may not fully prevent cumulative losses over longer ambient storage. This transient protective effect is consistent with studies showing that botanical dips and coatings often form a short-term barrier to transpiration and can reduce metabolic activity via antioxidant or antimicrobial action, thereby slowing early deterioration (González-Aguilar *et al.*, 2019; Singh *et al.*, 2020). The lack of significant differences at 9 days suggests that the protective barrier or biochemical modulation provided by aqueous extracts is eventually overcome by ongoing respiration, senescence, and pathogen activity, especially in fruit already near full ripeness (Patel & Sharma, 2021; Rahman *et al.*, 2022).

At 9 days the control had the highest weight loss (93.5%), indicating untreated fruit suffered the greatest cumulative water loss. Among extracts, ginger and moringa showed comparatively lower final losses (66.1% and 75.0%), while neem was intermediate (77.2%). These relative outcomes mirror literature reporting variable efficacy across botanicals: clove and neem often show strong antimicrobial/antioxidant activity in some studies, while moringa and ginger can be effective depending on extraction method and concentration (Singh *et al.*, 2020; Patel & Sharma, 2021). The present data suggest that moringa and ginger extracts were particularly effective at limiting cumulative weight loss under the specific extraction and application protocols used, though neem also reduced early losses relative to control. Differences among extracts likely reflect variation in phenolic content, volatile compounds, and film-forming constituents that influence both transpiration resistance and metabolic modulation (González-Aguilar *et al.*, 2019; Rahman *et al.*, 2022).



Table 1: Effect of Ripening Stage and Aqueous Plant Extracts on the Weight Loss of Tomato Fruits

Maturity	3 Days	6 Days	9 Days
RIPENING STAGE			
Green	31.3	37.7	84.1
Breaker	30.2	45.1	53.4
Red	47.1	77.0	93.2
LS	**	NS	**
LSD (0.05)	5.20	23.07	14.33
EXTRACTS			
Neem	37.0	65.0	77.2
Moringa	35.5	33.9	75.0
Ginger	40.3	33.0	66.1
Control	41.5	67.7	93.5
LS	**	**	NS
LSD (0.05)	6.01	26.64	16.54

Effect of Ripening Stage and Aqueous Plant Extracts on Infected Tomato Fruits

The results of fruit infection incidence were low at 3 and 6 days for most treatments and maturities but rose sharply by day 9 across all groups Table 2. Ripening stage had a significant effect ($p < 0.05$) on infected fruits at 3 and 6 days, but differences were not significant at 9 days. Early in storage, breaker fruit showed the highest infection at 3 and 6 days (20.1% and 30.48%) respectively, while green and red stages had lower early infection rates. By day 9, infection converged across stages (78.4–81.7%). Extract treatments significantly affected infection at all sampling times. At 3 and 6 days, moringa and neem produced the lowest infection percentages (≈ 9 –15%), while the control had the highest early infection (24.90% and 34.87%) at 3 and 6 days respectively. By day 9, moringa maintained the lowest infection (61.31%), whereas ginger and neem showed high infection (≈ 84 –85%) and the control remained highest (90.62%). The significant differences among ripening stages at 3 and 6 days indicate that harvest maturity influences early susceptibility to infection, a pattern reported in postharvest physiology studies where maturity affects cuticle integrity, wound-healing capacity, and pathogen susceptibility (Silva *et al.*, 2020). The relatively high early infection in breaker fruit (20.1% at 3 days; 30.48% at 6 days) suggests that the transitional physiology of breaker-stage fruit (active cell-wall modification and increasing ethylene sensitivity) may create a window of vulnerability to pathogens (Silva *et al.*, 2020).

Aqueous botanical extracts markedly reduced early infection compared with the control. Neem and moringa produced the lowest infected-fruit percentages at 3 and 6 days. This aligns with recent experimental reports that neem and moringa extracts possess strong antimicrobial compounds (azadirachtin, phenolics, flavonoids) that inhibit common postharvest pathogens when applied as dips or washes (Singh *et al.*, 2020; Rahman *et al.*, 2022). Early suppression of infection by these extracts likely reflects direct antimicrobial activity on surface inocula and transient reduction of pathogen establishment (Patel & Sharma, 2021). By day 9, infection incidence converged across ripening stages (78.4–81.7%), and ripening stage was no longer a significant source of variation. This convergence indicates that cumulative pathogen pressure and progressive tissue senescence overwhelm initial maturity-related differences over extended ambient storage, a phenomenon noted in postharvest studies where long storage times reduce the relative influence of initial maturity on final decay outcomes (Silva *et al.*, 2020). However, extract effects remained significant at day 9 for moringa-treated fruit with substantially lower infection (61.31%) than neem (84.70%), ginger (85.05%), and control (90.62%). This sustained efficacy of moringa suggests that its extract, under the preparation and concentration used, provided long-lasting antimicrobial or antioxidant protection, possibly through higher or more persistent phenolic content or by inducing host resistance mechanisms (Patel & Sharma, 2021; Rahman *et al.*, 2022). Comparable studies have reported variable longevity of protection among botanicals, with moringa) showing more durable effects than others depending on extraction method and dose (Singh *et al.*, 2020; González-Aguilar *et al.*, 2019).

Table 2: Effect of Ripening Stage and Aqueous Plant Extracts on Infected Fruits of Tomato

Maturity	3 Days	6 Days	9 Days
RIPENING STAGE			
Green	11.7	12.50	78.4
Breaker	20.1	30.48	81.1
Red	13.9	14.16	81.7
LS	**	**	NS
LSD (0.05)	5.09	4.077	17.57
EXTRACTS			
Neem	10.00	10.00	84.70
Moringa	9.64	14.83	61.31
Ginger	16.41	16.48	85.05
Control	24.90	34.87	90.62
LS	**	**	**
LSD (0.05)	5.88	4.708	20.29

Effect of Ripening Stage and Aqueous Plant Extracts on Disease Severity of Tomato Fruits

The result for the effect of harvest maturity stage and plant extracts on disease severity of tomato is presented in Table 3. The result indicated that disease severity increased between day 6 and day 9 across most treatments and ripening stages, indicating progressive pathogen development and tissue breakdown under ambient conditions. This temporal escalation of severity is consistent with general postharvest disease dynamics in tomato, where ongoing respiration, softening, and pathogen colonization accelerate symptom expression over time (Silva *et al.*, 2020).

Ripening stage did not significantly affect disease severity at 6 days, but a significant variation was observed by day 9. This pattern suggests that initial susceptibility differences among maturities are small or masked early after harvest, but as storage progresses, physiological differences associated with maturity (cuticle integrity, cell-wall degradation, ethylene-driven softening) lead to divergent disease outcomes (Silva *et al.*, 2020). The relatively high 9-day severity for breaker fruit (2.38) compared with green (1.94) implies that the breaker stage may represent a vulnerability window in which tissue changes favor pathogen progression, an observation reported in other studies that link transitional ripening physiology to increased decay risk (Silva *et al.*, 2020).

Extract treatments produced significant reductions in disease severity at 6 days, with neem showing the lowest mean severity (1.19) and moringa intermediate (1.45). By 9 days, extract differences were not significant, although numerically moringa (1.78) and ginger (1.92) had lower means than neem (2.07) and control (2.28). These results indicate that aqueous botanical dips can suppress early disease development, likely through direct antimicrobial activity and antioxidant-mediated slowing of tissue senescence, but their protective effect may wane as storage time increases—consistent with prior reports that botanical extracts often provide transient protection unless formulated for sustained release or combined with barrier coatings (Singh, Kumar, & Verma, 2020; Patel & Sharma, 2021; González-Aguilar, Wang, & Buta, 2019). The strongest early suppression (lowest severity) at 6 days, observed in neem extract well-documented immediate antimicrobial activity (azadirachtin and related limonoids) reported in recent trials (Rahman *et al.*, 2022; Singh *et al.*, 2020). The rise in neem-treated severity by day 9 suggests limited persistence of active compounds under ambient conditions. The highest severity recorded in the control at both times, underscores the baseline disease pressure in ambient storage and the potential value of botanical interventions (World Bank, 2021).

Table 3: Effect of Ripening Stage and Aqueous Plant Extracts on Disease Severity of Tomato Fruits

Maturity	6 Days	9 Days
RIPENING STAGE	1.35	1.72
Green	1.45	1.94
Breaker	1.60	2.38
Red	NS	**
LS	0.278	0.378
LSD (0.05)		
EXTRACTS		
Neem	1.19	2.07
Moringa	1.45	1.78
Ginger	1.58	1.92
Control	1.64	2.28
LS	*	NS
LSD (0.05)	0.3198	0.4361

Effect of Ripening Stage and Aqueous Plant Extracts on Nutritional Contents of Tomato Fruits

The result of the effect of maturity stage and plant extracts on the nutritional contents of tomato fruits is presented in Table 4. It was observed that all the four nutritional parameters (pH, TA, TSS, Vitamin C) determined showed statistically significant differences among both ripening stages and extract treatments after 9 days, with the provided LSDs indicating the minimum detectable differences at $\alpha = 0.05$. For ripening-stage patterns, breaker fruits had the highest pH (4.14) and vitamin C (21.53 mg/100 g) but the lowest TA (0.33%) and slightly lower TSS (5.97 °Brix) compared with mature green and red. Mature green fruit retained moderate TSS (6.68 °Brix) and TA (0.42%), while red fruit showed the highest TA (0.48%) and intermediate TSS (6.29 °Brix).

In terms of extract-treatment, ginger-treated fruits had the highest TSS (6.71 °Brix) and the lowest vitamin C (15.36 mg/100 g). Neem and moringa treatments produced identical mean pH and TSS values (pH 4.07; TSS 5.87 °Brix) and elevated vitamin C (19.27 mg/100 g) relative to ginger and control. The control fruit had intermediate values for most parameters. The significant effects of harvest maturity on pH, TA, TSS and vitamin C after 9 days reflect well-known ripening physiology: as tomato ripens, organic acid metabolism, sugar accumulation, and ascorbate biosynthesis follow distinct trajectories so that different maturity classes retain different nutritional profiles during storage (Silva *et al.*, 2020). The higher vitamin C in breaker fruit observed here is consistent with reports that ascorbic acid often peaks around the breaker to turning stages before declining in overripe fruit, because biosynthesis and degradation rates change during late ripening and senescence (Silva *et al.*, 2020; González-Aguilar *et al.*, 2019). The higher TA in red fruit likely reflects concentration effects from water loss and organic acid redistribution during full ripening (Kader, 2002).

Total soluble solids (TSS) are a composite of sugars and soluble solids that influence perceived sweetness and processing quality. The modest differences in TSS among maturities (6.68 green; 5.97 breaker; 6.29 red) indicate that, after 9 days of ambient storage, sugar concentration changes were small but detectable. The higher TSS in ginger-treated fruit may reflect either a slight concentration effect (reduced water content) or a treatment-mediated modulation of respiration and carbohydrate metabolism; similar treatment-dependent shifts in TSS have been reported where botanical treatments alter metabolic rates or reduce transpiration losses (González-Aguilar *et al.*, 2019; Patel & Sharma, 2021).

Extract treatments significantly affected vitamin C after 9 days, with neem and moringa showing higher mean vitamin C (19.27 mg/100 g) than ginger (15.36 mg/100 g) and control (18.21 mg/100 g). Botanical extracts rich in phenolics and antioxidant compounds can reduce oxidative degradation of ascorbate by scavenging reactive oxygen species and slowing senescence, thereby improving vitamin C retention during storage (González-Aguilar *et al.*, 2019; Patel & Sharma, 2021). The superior vitamin C retention with neem and moringa is consistent with studies that report these botanicals' high phenolic loads and antioxidant activity, which can protect labile nutrients during ambient storage (Rahman *et al.*, 2022). The observed pH and TA patterns-breaker fruit with higher pH



and lower TA, red fruit with higher TA is consistent with organic acid metabolism during ripening and with concentration effects from water loss. Extracts also influenced pH and TA significantly; neem and moringa treatments produced slightly higher pH and lower TA than control and ginger, suggesting that these treatments may have moderated acid accumulation or slowed acid-related metabolic changes during storage (Patel & Sharma, 2021).

Table 4: Effect of Ripening Stage and Aqueous Plant Extracts on Nutritional Contents of Tomato Fruits after 9 Days of Storage

Maturity	pH	TA	TSS	VIT.C
RIPENING STAGE				
Green	3.82	0.42	6.68	16.49
Breaker	4.14	0.33	5.97	21.53
Red	3.75	0.48	6.29	15.87
LS	**	**	**	**
LSD (0.05)	0.1132	0.03028	0.0523	0.4649
EXTRACTS				
Neem	4.07	0.34	5.87	19.27
Moringa	4.14	0.34	5.87	19.27
Ginger	3.62	0.47	6.71	15.36
Control	3.73	0.45	6.52	18.21
LS	**	**	**	**
LSD (0.05)	0.1462	0.03909	0.0675	0.6002

CONCLUSION AND RECOMMENDATIONS

Harvest maturity and botanical aqueous extracts jointly determine tomato postharvest quality under ambient storage. Early harvesting extends shelf life but requires careful handling; later harvesting accelerates marketability yet increases deterioration. Aqueous extracts from moringa, ginger, and neem provide low-cost, eco-friendly, transient protection by reducing early weight loss, infection, and preserving vitamin C and soluble solids variably but did not fully prevent long-term losses at ambient conditions. Integrating optimal harvest timing with targeted botanical dips delays deterioration and lowers decay risk, offering practical interventions for resource-constrained supply chains. Further studies on extract formulation, concentration, and application timing is recommended for scalable adoption by smallholders globally.

REFERENCES

- Adebayo, O., Nwankwo, E., & Okonkwo, P. (2021). Postharvest handling constraints and opportunities for tomatoes in West Africa. *Journal of Postharvest Technology*, **9**(2): 45–58.
- FAO. (2021). *Tomato production and postharvest management: Global overview*. Food and Agriculture Organization.
- González-Aguilar, G. A., Wang, C. Y., & Buta, J. G. (2019). Antioxidant treatments to extend shelf life of fresh produce. *Postharvest Biology and Technology*, **150**: 1–12.
- Patel, R., & Sharma, S. (2021). Plant extracts as natural preservatives for fruits: Mechanisms and applications. *International Journal of Food Science*, 2021, Article ID 667890.
- Rahman, M., Islam, M., & Hossain, M. (2022). Efficacy of aqueous plant extracts in reducing postharvest decay of tomato under ambient conditions. *Journal of Horticultural Science and Biotechnology*, **97**(4): 512–520.
- Silva, J. P., Oliveira, L. M., & Costa, R. (2020). Influence of harvest maturity on tomato quality and shelf life. *Scientia Horticulturae*, **265**: 109–117.
- Singh, A., Kumar, P., & Verma, S. (2020). Use of botanical extracts to control postharvest diseases of fruits: A review. *Crop Protection*, **134**: 104–112.
- World Bank. (2021). *Reducing food loss and waste in developing countries: The role of postharvest technologies*. World Bank Reports.