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Effects of *Vernonia amygdalina* and *Azadirachta indica* Extracts on Postharvest Weight Loss and Shelf Life of Tomato (*Solanum lycopersicum* L.) Cultivars

Folasade Eunice Ade-Ogunnowo[1] and Oluseyi Damilola Adejoye[1]
[1]Department of Biological Sciences, Tai Solarin Federal University of Education, Ijagun, Ogun State, Nigeria

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ABSTRACT

Postharvest weight loss is a major constraint on tomato (*Solanum lycopersicum* L.) shelf life in tropical environments. This study evaluated ethanol and aqueous leaf extracts of *Vernonia amygdalina* (bitter leaf) and *Azadirachta indica* (neem) for their effects on weight retention and storage kinetics of San Marzano and Royal tomato cultivars over 20 days at ambient conditions (28 ± 2°C). Treatments comprised ethanol extracts (50–200 g/500 mL), aqueous hot and cold extracts (50 g/500 mL), and a distilled water control in a completely randomised design. Physiological loss in weight (PLW) differed significantly among treatments ($p < 0.05$). The 100 g/500 mL ethanol extract of bitter leaf gave the lowest PLW and highest weight retention, in Royal (37.3%) followed by San Marzano (41.9%). Hot aqueous extracts showed moderate efficacy (46.2–50.3% PLW), cold aqueous extracts were least effective (70.7–77.3%), and excess ethanol (150–200 g/500 mL) accelerated deterioration (81.6–86.9% PLW), indicating phytotoxicity. Weight loss followed an exponential decay pattern ($R^2 = 0.91–0.98$), with lower decay constants in optimised treatments ($k \approx 0.063–0.069$ day^{-1}). Royal consistently showed greater postharvest stability than San Marzano. These findings indicate that a 100 g/500 mL *V. amygdalina* ethanol formulation offers an accessible, low-cost postharvest coating that can extend tomato shelf life and reduce reliance on synthetic fungicides for smallholder farmers in tropical regions.

Corresponding Author(s):

Folasade E. Ade-Ogunnowo
Department of Biological Sciences, Tai Solarin Federal University of Education
Ijagun. P.M.B. 2118, Ijebu Ode, Ogun State, Nigeria
Email: adeogunnowo@tasued.edu.ng

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and consumed horticultural crops globally and constitutes an important source of vitamins, minerals, lycopene and dietary fibre in human diets (Kumar *et al*., 2022; Kumar *et al*., 2020). In Nigeria, tomato production plays a vital role in food security and rural livelihoods, with annual output estimated at approximately 3.5–4.0 million tonnes (Ajenifujah-Solebo *et al*., 2025). Despite this high level of production, the country continues to rely heavily on imports of processed tomato products, reflecting substantial inefficiencies within the postharvest value chain (Abdulrahman et al., 2025). In the past, Nigeria recorded the highest postharvest losses of fresh tomatoes in sub-Saharan Africa with an estimated loss of 13.4 % compared to 10.1 % in Kenya and 10.2 % in South Africa (Sibomana *et al*., 2016). More recently, postharvest losses of fresh tomatoes in Nigeria have been reported to range from 30% to 50%, largely due to poor handling practices, inadequate storage infrastructure and limited access to preservation technologies (Odeyemi *et al*., 2022; Kitinoja *et al*., 2019).

The high perishability of tomato fruits is primarily attributed to their elevated moisture content, delicate epidermal structure and continued metabolic activity after harvest (Umeohia & Olapade, 2024). One of the earliest

and most critical indicators of postharvest deterioration is weight loss, which occurs through transpiration and respiration (Firdous *et al.*, 2025; Jung *et al.*, 2019). This process results in moisture depletion, leading to shrivelling, loss of firmness and reduced visual appeal. Even relatively small losses in fresh weight can significantly diminish market value and consumer acceptance. In addition, desiccation compromises the fruit's natural defence barriers, thereby increasing susceptibility to microbial infection and accelerating spoilage (Firdous *et al.,* 2025; Jung *et al.*, 2019). Therefore, strategies aimed at reducing moisture loss are central to improving postharvest quality and extending shelf life.

Conventional approaches for prolonging tomato shelf life include refrigeration, modified or controlled atmosphere storage and the use of synthetic fungicides or wax coatings (Godana & Gurmu, 2020). While effective, these methods are often inaccessible to smallholder farmers in developing countries due to high costs, unreliable electricity supply and increasing concerns regarding chemical residues and environmental safety (Anusha *et al.*, 2024). Consequently, there has been growing interest in the use of plant-based preservatives as low-cost, safe and sustainable alternatives (El Alami El Hassani *et al.*, 2025; Shahbaz *et al.*, 2022; Nxumalo *et al.*, 2021). Plant extracts are rich in bioactive secondary metabolites such as phenolics, flavonoids, alkaloids and terpenoids, which exhibit antimicrobial, antioxidant and film-forming properties that can delay ripening, suppress spoilage organisms and reduce water loss from fruit surfaces (Howlader *et al.*, 2026).

Among the plant species commonly available in West Africa, neem (*Azadirachta indica* A. Juss.) and bitter leaf (*Vernonia amygdalina* Delile) have attracted attention for their potential application in postharvest preservation. Neem is well known for its broad-spectrum antimicrobial activity, largely attributed to compounds such as azadirachtin, nimbin and related limonoids (Wylie & Merrell, 2022). Extracts from neem leaves and seeds have been shown to inhibit the growth of several postharvest pathogens affecting fruits and vegetables (Ali *et al.*, 2025). Bitter leaf, on the other hand, is rich in phenolic compounds and flavonoids with strong antioxidant and antimicrobial activities (Edo *et al.*, 2023). Emerging evidence suggests that extracts from *V. amygdalina* may also enhance oxidative stability and contribute to delayed senescence in horticultural produce (Chen *et al.*, 2025).

Despite increasing interest in botanical extracts, critical factors influencing their efficacy remain insufficiently understood. In particular, the role of extraction solvent and concentration requires further investigation. Ethanol extraction typically yields a broader range of phytochemicals, including both polar and moderately non-polar compounds, whereas aqueous extraction is largely restricted to polar constituents (Darwin *et al.*, 2025). Moreover, the relationship between extract concentration and preservation effect is often non-linear (Tušek *et al.*, 2018). While low concentrations may be ineffective, our study hypothesised that excessively high concentrations may exert phytotoxic effects, disrupting the fruit cuticle and accelerating moisture loss of tomato fruits. In addition, differences among tomato cultivars in cuticle composition, permeability and water loss kinetics may influence their response to such treatments (Lara *et al.*, 2014), yet this variability has received limited experimental attention.

The present study evaluated the effects of ethanol and aqueous leaf extracts of *A. indica* and *V. amygdalina* on postharvest weight retention and shelf life of two tomato cultivars, Royal and San Marzano. Specifically, the study assessed the influence of extract concentration on physiological loss in weight, compared the efficacy of ethanol and aqueous extraction methods and modelled the kinetics of weight loss using linear and exponential functions. It was hypothesised that intermediate concentrations of ethanol extracts would provide optimal preservation, that *V. amygdalina* would exhibit greater efficacy than *A. indica*, and that cultivar-specific differences would significantly influence treatment response. The findings are intended to support the development of practical, low-cost and environmentally sustainable postharvest technologies for smallholder farming systems in tropical regions.

2. MATERIALS AND METHODS

2.1 Study Area and Environmental Conditions

The research was conducted at the Biological Sciences Laboratory, Department of Biological Sciences, Tai Solarin Federal University of Education (TASFUED), Ijagun, Ogun State, Nigeria. The laboratory environment was maintained under ambient conditions throughout the duration of the study, with a mean temperature of 28 ± 2°C and a relative humidity range of 65–75%.

2.2 Plant Material Collection and Preparation

Two distinct cultivars of tomato (*Solanum lycopersicum* L.), namely *San Marzano* and *Royal*, were utilised for the experiment. The fruits were procured at the pink-to-light-red ripeness stage from Oke-Aje commercial market in Ijebu-Ode, Ogun State, Nigeria. Strict selection criteria were applied to ensure uniformity, including a weight range of 80 to 100 g per fruit and the total absence of physical injuries, cracks, or visible microbial decay. The botanical materials, comprising leaves of Bitter leaf (*Vernonia amygdalina*) and Neem (*Azadirachta indica*), were harvested from the university's botanical garden. The leaves were meticulously washed with tap water followed by a distilled water rinse to eliminate surface debris. They were subsequently air-dried under ambient conditions for 72 hours and pulverised into a fine powder using an electric laboratory blender to maximize the surface area for subsequent solvent extraction.

2.3 Extraction Procedures

Ethanol extracts were prepared using cold maceration, a widely used technique for extracting bioactive plant metabolites (Azwanida, 2015). Four concentrations (50, 100, 150, and 200 g/500 mL) of leaf powder were soaked in 70% ethanol, a solvent effective for extracting both polar and moderately non-polar phytochemicals (Do *et al.*, 2014), in airtight conical flasks and allowed to macerate for 48 hours with intermittent agitation to enhance the release of secondary metabolites. Aqueous extracts were prepared at 50 g/500 mL using two approaches: hot infusion at 80°C, which promotes extraction of heat-stable polar compounds (Azwanida, 2015), and cold maceration at room temperature for 24 hours. All extracts were filtered through double-layer muslin cloth and stored in sterile amber bottles at 4°C for up to 72 hours prior to use. Aqueous extraction was limited to *A. indica* (Table 1) because water extraction of *V. amygdalina* produced low saponin and flavonoid yields with poor coating stability, whereas *A. indica* aqueous extracts showed greater stability and proven postharvest efficacy (Alara *et al*., 2020; Ghamba *et al*., 2014; Dheeba *et al*., 2015; Tripathi *et al*., 2009).

2.4 Experimental Design

The study was organised using a Completely Randomized Design (CRD) with 21 treatments (Table 1) comprising combinations of two tomato cultivars, two botanical species, and solvent–concentration profiles. Each treatment was replicated three times, with three uniform fruits per replicate, giving nine fruits per treatment and a total of 189 tomato fruits. A 1:1 mixed-cultivar composite was utilized for the control group (T9) because preliminary screening and baseline control trials indicated no statistically significant difference ($p > 0.05$) in ambient kinetics between the two untreated San Marzano and Royal fruits under the local storage parameters.

Table 1. Experimental Design and Treatment Allocation

Treatment Code	Tomato Cultivar	Botanical Extract	Solvent Type	Concentration (g/500 mL)
T1a	San Marzano	Bitter leaf (*V. amygdalina*)	Ethanol	50
T1b	San Marzano	Bitter leaf (*V. amygdalina*)	Ethanol	100
T1c	San Marzano	Bitter leaf (*V. amygdalina*)	Ethanol	150
T1d	San Marzano	Bitter leaf (*V. amygdalina*)	Ethanol	200
T2a	Royal	Bitter leaf (*V. amygdalina*)	Ethanol	50
T2b	Royal	Bitter leaf (*V. amygdalina*)	Ethanol	100
T2c	Royal	Bitter leaf (*V. amygdalina*)	Ethanol	150
T2d	Royal	Bitter leaf (*V. amygdalina*)	Ethanol	200
T3a	San Marzano	Neem (*Azadirachta indica*)	Ethanol	50
T3b	San Marzano	Neem (*Azadirachta indica*)	Ethanol	100
T3c	San Marzano	Neem (*Azadirachta indica*)	Ethanol	150
T3d	San Marzano	Neem (*Azadirachta indica*)	Ethanol	200
T4a	Royal	Neem (*Azadirachta indica*)	Ethanol	50
T4b	Royal	Neem (*Azadirachta indica*)	Ethanol	100
T4c	Royal	Neem (*Azadirachta indica*)	Ethanol	150
T4d	Royal	Neem (*Azadirachta indica*)	Ethanol	200
T5	San Marzano	Neem (*Azadirachta indica*)	Aqueous (Hot)	50
T6	San Marzano	Neem (*Azadirachta indica*)	Aqueous (Cold)	50
T7	Royal	Neem (*Azadirachta indica*)	Aqueous (Hot)	50
T8	Royal	Neem (*Azadirachta indica*)	Aqueous (Cold)	50
T9	Mixed (1:1)	Control (No extract)	Distilled Water	—

Key:
V. amygdalina = Vernonia amygdalina (bitter leaf)
A. indica = Azadirachta indica (neem leaf)
T1–T9 = treatment groups
a–d suffix = ethanol concentration levels within cultivar/extract combinations
Hot aqueous = 80°C extraction method
Cold aqueous = room temperature extraction method
Control = distilled water-treated fruits without plant extract

2.5 Treatment Application and Storage

Prior to extract application, all tomato fruits were surface-sterilised by immersion in a 1% sodium hypochlorite solution for two minutes and air-drying, followed by three successive rinses with distilled water under aseptic conditions. This step was included to minimise the influence of pre-existing epiphytic microorganisms on treatment efficacy (Salgado-Cruz *et al.*, 2021). This procedure was essential to eliminate existing epiphytic pathogens and isolate the effects of the plant extracts. The treatment process involved fully immersing the fruits

into their respective botanical extracts for 10 minutes. Following immersion, the fruits were transferred to sterile wire mesh racks and allowed to air-dry for 30 minutes, a process that enabled the formation of a phytochemical coating on the fruit cuticle. The treated tomatoes were then placed in open-top plastic crates in a single layer to ensure uniform gas exchange and prevent mechanical stress. A distilled water control group was maintained under identical conditions.

2.6 Experimental Storage and Data Collection

The weight of the tomato fruits was recorded at 5-day intervals (Day 1, 5, 10, 15, and 20) using a digital precision balance with an accuracy of ±0.01 g. Weight values were recorded as mean ± standard error (SE).

2.7 Physiological Loss in Weight (PLW)

Weight measurements were used to calculate the physiological loss in weight (PLW %) relative to the initial mass using the following formula:

$$\text{PLW (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where W_i is the initial weight and W_f is the weight at the specific measurement interval.

2.8 Statistical Analysis

Fruit weight and physiological loss in weight (PLW %) data were first processed in Microsoft Excel to compute means and standard errors, with descriptive summaries generated at 5-day intervals. Graphical outputs (line graphs and heatmaps) and inferential analyses, including one-way ANOVA, were performed using SAS version 9.4.

2.8.1 Analysis of Variance (ANOVA) and Post-hoc Mean Separation

To determine if the observed variations in weight retention were statistically significant, the data were subjected to a One-Way Analysis of Variance (ANOVA). This was performed independently for each storage interval (Day 5, 10, 15, and 20) to identify the point at which different extract concentrations began to deviate significantly from the control. Where the F-test indicated a significant difference ($p < 0.05$), mean separation was conducted using Duncan's Multiple Range Test (DMRT). This test was utilised to rank the treatments and identify specific groupings of efficacy, allowing for the determination of the most effective concentration relative to others. Significance was established at a 95% confidence level. Numerical results throughout the study are reported as the mean followed by the standard error (±SE).

2.8.2 Modelling of Weight Loss Kinetics

To characterise the rate of moisture loss over time, the weight data were fitted to both linear and non-linear (exponential) regression models. Linear regression (equation 2) was used to calculate the constant rate of loss (r) in gramme per day while exponential regression (equation 3) was used to calculate the decay constant (k), providing a more biologically accurate representation of the transpiration process where the rate of loss is proportional to the remaining moisture content. The goodness-of-fit for these models was assessed using the coefficient of determination (R^2). A higher R^2 value (typically > 0.90) was used as the criterion to select the most appropriate model for describing the storage kinetics of each cultivar.

$$W_t = W_0 - rt \quad (2)$$

where *r* is the linear rate of weight loss (g/day)

$$W_t = W_0 \, . \, e^{-kt} \quad (3)$$

where *k* is the decay constant (day^{-1}).

2.8.3 Cultivar–Concentration Comparison

To explore whether the effectiveness of the plant extracts depended on the specific tomato variety, mean fruit weight at Day 20 was compared graphically between cultivar and extract concentration. This descriptive comparison was used to indicate whether certain cultivars (e.g., Royal) showed patterns of greater responsiveness to specific treatments (e.g., Bitter leaf ethanol extract); a formal two-way ANOVA testing the statistical significance of the cultivar × concentration interaction was not performed.

3. RESULTS AND DISCUSSION

3.1 Postharvest Changes in Fruit Weight During Storage

Tomato fruits from all treatment groups exhibited a progressive decline in weight over the 20-day storage period, as summarised in **Table 2**. Despite this general trend, the magnitude and rate of weight loss differed significantly

among treatments ($p < 0.05$), reflecting the combined effects of extract type, concentration, and cultivar. Initial fruit weights (236.3–259.3 g) were statistically comparable across treatments, confirming that the experimental material was uniform and that subsequent differences were attributable to treatment effects rather than baseline variation. From Day 5 onwards, clear divergence in weight trajectories became evident (**Table 2**). Fruits treated with high ethanol concentrations (150–200 g/500 mL) and the control exhibited accelerated declines, whereas those treated with optimised extract concentrations maintained significantly higher weights. The temporal trends indicate that weight loss was not constant but treatment-dependent, with protective effects becoming more pronounced as storage progressed. These observations highlight the critical role of botanical extracts in modulating postharvest water loss. The initial stability phase (Day 1–5) likely reflects residual physiological integrity following harvest, while the subsequent divergence suggests that treatment efficacy becomes increasingly important as fruits enter the transition and senescence phases. This behaviour is consistent with the physiological understanding that postharvest deterioration is largely driven by moisture loss and metabolic activity.

Table 2. Mean Fruit Weight (g) of Tomato Fruits Treated with Ethanol and Aqueous Leaf Extracts During 20 Days of Storage

Treatment	Day 1	Day 5	Day 10	Day 15	Day 20
T1a (SM + BL, EtOH 50 g)	249.3 ± 1.1^{cd}	232.3 ± 1.6^{bc}	167.3 ± 2.8^{d}	108.3 ± 3.2^{d}	71.3 ± 4.1^{c}
T2a (Royal + BL, EtOH 50 g)	254.3 ± 1.1^{b}	232.3 ± 1.6^{bc}	139.3 ± 2.6^{f}	78.3 ± 3.1^{fg}	45.3 ± 3.9^{e}
T3a (SM + Neem, EtOH 50 g)	248.3 ± 1.2^{d}	230.3 ± 1.7^{c}	100.3 ± 2.9^{h}	73.3 ± 3.4^{gh}	60.3 ± 4.2^{cd}
T4a (Royal + Neem, EtOH 50 g)	248.2 ± 1.2^{d}	230.3 ± 1.8^{c}	157.2 ± 2.7^{e}	91.3 ± 3.3^{e}	72.3 ± 4.0^{bc}
T1b (EtOH 100 g)	248.3 ± 1.1^{d}	230.3 ± 1.6^{c}	193.6 ± 2.2^{b}	166.4 ± 2.9^{b}	144.3 ± 3.6^{b}
T2b (EtOH 100 g)	252.3 ± 1.0^{bc}	238.7 ± 1.5^{ab}	202.1 ± 2.1^{a}	181.5 ± 2.5^{a}	158.3 ± 3.1^{a}
T3b (EtOH 100 g)	245.4 ± 1.1^{de}	229.3 ± 1.7^{cd}	191.2 ± 2.4^{b}	162.8 ± 3.0^{b}	141.3 ± 3.8^{b}
T4b (EtOH 100 g)	259.3 ± 1.1^{a}	244.3 ± 1.8^{a}	186.2 ± 2.5^{bc}	151.4 ± 3.2^{c}	123.2 ± 4.0^{bc}
T1c (EtOH 150 g)	247.3 ± 1.1^{def}	237.3 ± 1.9^{b}	140.2 ± 3.1^{f}	75.3 ± 4.5^{gh}	42.3 ± 5.2^{ef}
T2c (EtOH 150 g)	245.3 ± 1.2^{de}	229.3 ± 1.8^{cd}	111.3 ± 3.4^{g}	61.3 ± 4.2^{hi}	39.3 ± 5.1^{ef}
T3c (EtOH 150 g)	247.3 ± 1.1^{def}	224.3 ± 1.7^{d}	97.3 ± 3.6^{h}	53.2 ± 4.6^{ij}	45.4 ± 5.3^{e}
T4c (EtOH 150 g)	245.3 ± 1.1^{de}	229.3 ± 1.8^{cd}	143.4 ± 3.2^{f}	81.3 ± 4.7^{f}	51.3 ± 5.4^{de}
T1d (EtOH 200 g)	248.3 ± 1.2^{d}	229.3 ± 2.0^{cd}	132.3 ± 3.8^{fg}	85.3 ± 5.2^{ef}	42.7 ± 6.0^{ef}
T2d (EtOH 200 g)	250.3 ± 1.1^{cd}	227.3 ± 1.9^{cd}	132.3 ± 3.5^{fg}	88.3 ± 4.8^{ef}	39.3 ± 5.5^{ef}
T3d (EtOH 200 g)	250.2 ± 1.2^{cd}	229.3 ± 2.1^{cd}	122.3 ± 3.6^{g}	52.3 ± 5.5^{ij}	29.3 ± 6.2^{f}
T4d (EtOH 200 g)	244.3 ± 1.3^{e}	225.4 ± 2.2^{d}	122.3 ± 3.4^{g}	75.3 ± 4.9^{gh}	32.0 ± 5.8^{f}
T5 (Aq hot 50 g)	251.3 ± 1.1^{cd}	228.3 ± 1.8^{cd}	196.3 ± 2.9^{ab}	152.3 ± 4.2^{c}	135.3 ± 4.9^{b}
T6 (Aq cold 50 g)	236.3 ± 1.3^{f}	200.3 ± 2.1^{e}	128.3 ± 3.2^{g}	93.3 ± 4.8^{e}	69.3 ± 5.1^{cd}
T7 (Aq hot 50 g)	248.3 ± 1.1^{d}	233.3 ± 1.9^{bc}	162.3 ± 3.0^{de}	139.3 ± 4.3^{d}	123.3 ± 4.9^{bc}
T8 (Aq cold 50 g)	245.3 ± 1.2^{de}	206.3 ± 2.0^{e}	104.3 ± 3.4^{h}	81.7 ± 4.6^{f}	55.3 ± 5.2^{de}
T9 (Control)	252.0 ± 1.0^{bc}	231.5 ± 2.8^{c}	160.5 ± 6.1^{de}	135.5 ± 6.6^{d}	115.4 ± 7.2^{bc}

Key: SM = San Marzano tomato cultivar, BL = Bitter leaf (*Vernonia amygdalina*), Neem = *Azadirachta indica* (Neem leaf extract), EtOH = Ethanol extract, Aq hot = Hot aqueous extract, Aq cold = Cold aqueous extract, T1–T9 = Treatment codes in experimental design Day 1–Day 20 = Storage duration at ambient conditions, ± = Standard error of the mean (SEM). *Values are means (n = 3). Different superscripts within the same column indicate significant differences at $p < 0.05$ (DMRT)*

3.2 Effect of Extract Type and Concentration

A clear concentration-dependent pattern emerged (**Table 2**). Ethanol extracts at 100 g/500 mL consistently achieved the highest retention, with final weights ranging from approximately 141.3 ± 3.8 g to 158.3 ± 3.1 g across treatments. These values were markedly higher than the control and all other concentration levels.

At 50 g/500 mL, final weights generally fell below 100 g, indicating limited preservation. In addition, the low concentration (50 g) failed to create a cohesive lipid/metabolite barrier film, leaving the fruit vulnerable to accelerated moisture loss and room-temperature desiccation under tropical conditions. In contrast, increasing the concentration to 150–200 g/500 mL resulted in severe deterioration, with final weights dropping to as low as 29.3–51.3 g. This confirms that the response is not linear but follows an optimum curve. The superior performance at 100 g/500 mL likely reflects an optimal balance between phytochemical extraction and preservation of fruit surface integrity (El-Saadony *et al*., 2025). Lower concentrations appear insufficient to inhibit microbial activity, while higher concentrations may damage the cuticle, increasing permeability and accelerating water loss (Lara *et al*., 2014; Chen *et al*., 2025; Howlader *et al*., 2026).

Aqueous extracts showed intermediate efficacy (**Table 2**). Hot aqueous neem treatments retained between 123.3 ± 4.9 g and 135.3 ± 4.9 g by Day 20, outperforming cold aqueous treatments, which declined to 55.3 ± 5.2 g and 69.3 ± 5.1 g. These results suggest that thermal extraction enhances the availability of active compounds (Žagar *et al*., 2024; Benito-Román *et al*., 2020).

3.3 Physiological Loss in Weight (PLW)

The PLW values (**Table 3**) closely mirrored the weight retention data. The lowest PLW was recorded in the optimised ethanol treatments, ranging from 37.3% to 42.4%. In comparison, the control recorded 54.2%, while hot aqueous treatments ranged from 46.2% to 50.3%. Cold aqueous treatments exhibited substantially higher PLW values (70.7–77.3%), indicating poor preservation, while the highest ethanol concentrations resulted in extreme losses, reaching up to 86.9%. These results confirm that moderate extract concentration is critical for reducing moisture loss and maintaining fruit integrity. The consistency between PLW patterns and the weight loss curves in **Figure 1** reinforces the reliability of these measures in evaluating postharvest performance and highlights the importance of balanced treatment conditions.

Table 3. Physiological Loss in Weight (PLW%) at Day 20

Treatment	PLW (%)
T2b (100 g ethanol, Royal + Bitter Leaf)	37.26
T1b (100 g ethanol, San Marzano + Bitter Leaf)	41.89
T3b (100 g ethanol, San Marzano + Neem)	42.37
T5 (Aqueous hot)	46.20
T7 (Aqueous hot Royal)	50.34
T9 (Control)	54.22
T6 (Aqueous cold San Marzano)	70.67
T8 (Aqueous cold Royal)	77.30
T3c (150 g ethanol)	80.90
T4d (200 g ethanol)	86.90

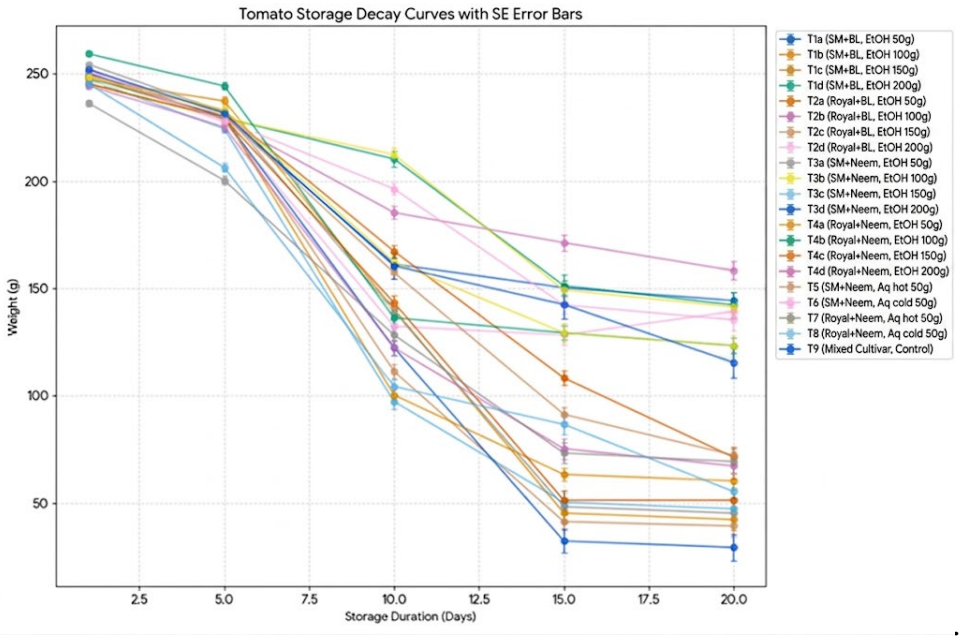

Figure 1. Weight loss kinetics of San Marzano and Royal tomatoes under ethanol, aqueous, and control treatments over 20 days (mean ± SE, n = 3). Clear divergence occurs after Day 5, with 100 g/500 mL ethanol treatments (T1b, T2b) showing highest weight retention, while high ethanol (200 g/500 mL) and some aqueous treatments show rapid decline.

3.4 Weight Loss Kinetics

The exponential decay model provided a better fit than the linear model for all treatments (**Table 4**), with R^2 values ranging from 0.91 to 0.98. This indicates that weight loss is proportional to remaining moisture content, consistent with the curvature observed in **Figure 1**. Decay constants (k) ranged from 0.043 day^{-1} to 0.081 day^{-1}. The lowest k value (0.043 day^{-1}) was observed in a cold aqueous treatment, but this did not correspond to superior retention, as final weight remained low. Optimised ethanol treatments showed moderate k values (0.063–0.069 day^{-1}) but achieved higher final weights, indicating better overall moisture regulation. This highlights that cumulative retention and PLW are more reliable indicators of preservation efficacy than decay rate alone (Peleg, 2019; Taoukis *et al*., 1997; Xie *et al*., 2025).

Table 4. Kinetic Parameters of Weight Loss (Exponential and Linear Models)

Treatment	Linear rate (g/day)	R^2 (Linear)	k (day^{-1})	R^2 (Exponential)
T1b (100 g ethanol San Marzano + Bitter Leaf)	9.6	0.96	0.069	0.97
T2b (100 g ethanol Royal + Bitter Leaf)	10.2	0.94	0.063	0.98
T5 (Aqueous hot San Marzano)	7.8	0.93	0.055	0.95
T6 (Aqueous cold San Marzano)	6.1	0.90	0.043	0.91
T9 (Control)	8.0	0.95	0.058	0.96
T2d (200 g ethanol, Royal + Bitter Leaf)	12.1	0.89	0.081	0.93

R^2, coefficient of determination k, decay rate

3.5 Cultivar-Dependent Response

Cultivar differences were evident in both weight retention and physiological loss in weight (PLW) (**Tables 2 and 3; Figure 1**). Under optimised ethanol treatment, **Royal** retained up to 158.3 g compared with 144.3 g in **San Marzano**. Similarly, PLW values were lower in Royal, indicating greater postharvest tolerance. At higher ethanol concentrations, San Marzano exhibited more rapid deterioration, with fruit weight declining to below 50 g. These differences likely reflect cultivar-specific variations in cuticle structure and permeability (Barraj Barraj *et al*., 2021; Lara *et al*., 2014), as well as physiological differences in water transport and respiration rates (Xie *et al*., 2025).

3.6 Cultivar–Concentration Pattern

The pattern observed between cultivar and concentration (**Figure 2**) indicates that 100 g/500 mL represents the optimal level for both cultivars. However, at 200 g/500 mL, divergence became pronounced, with one cultivar maintaining relatively higher weights while the other declined sharply. This pattern suggests that treatment efficacy may not be uniform across genotypes and points to the need for cultivar-specific optimisation to avoid adverse effects; confirming this would require formal statistical testing of the cultivar × concentration interaction.

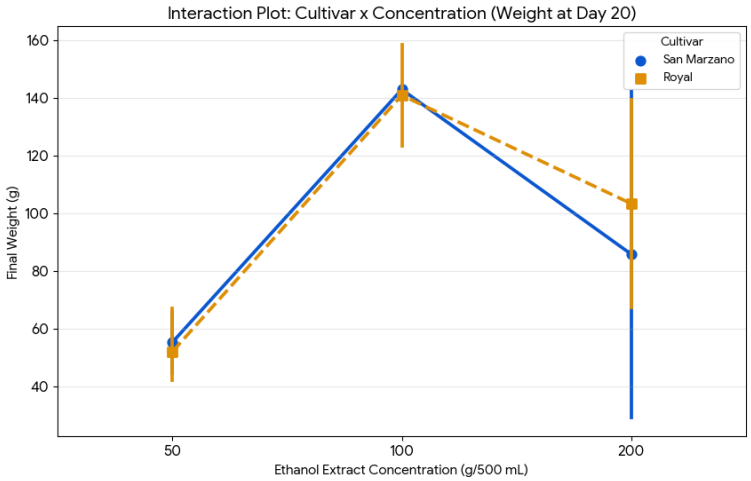

Figure 2. Observed pattern of tomato cultivar and ethanol concentration on final fruit weight after 20 days (mean ± SE). Both cultivars show highest retention at 100 g/500 mL, while 200 g/500 mL causes a sharper decline in San Marzano, indicating cultivar-dependent sensitivity.

3.7 Temporal Dynamics of Weight Loss

The overall weight loss pattern (**Figure 3**) can be divided into three phases. From Day 1 to Day 5, weight loss was minimal across all treatments. Between Day 5 and Day 10, divergence became evident, with optimised treatments maintaining weights above 180 g while others declined more rapidly. From Day 10 to Day 20, rapid deterioration occurred in the control and high ethanol treatments, while optimised treatments stabilised at higher final weights. This pattern demonstrates that effective treatments primarily influence the later stages of storage, where senescence-related losses are most pronounced.

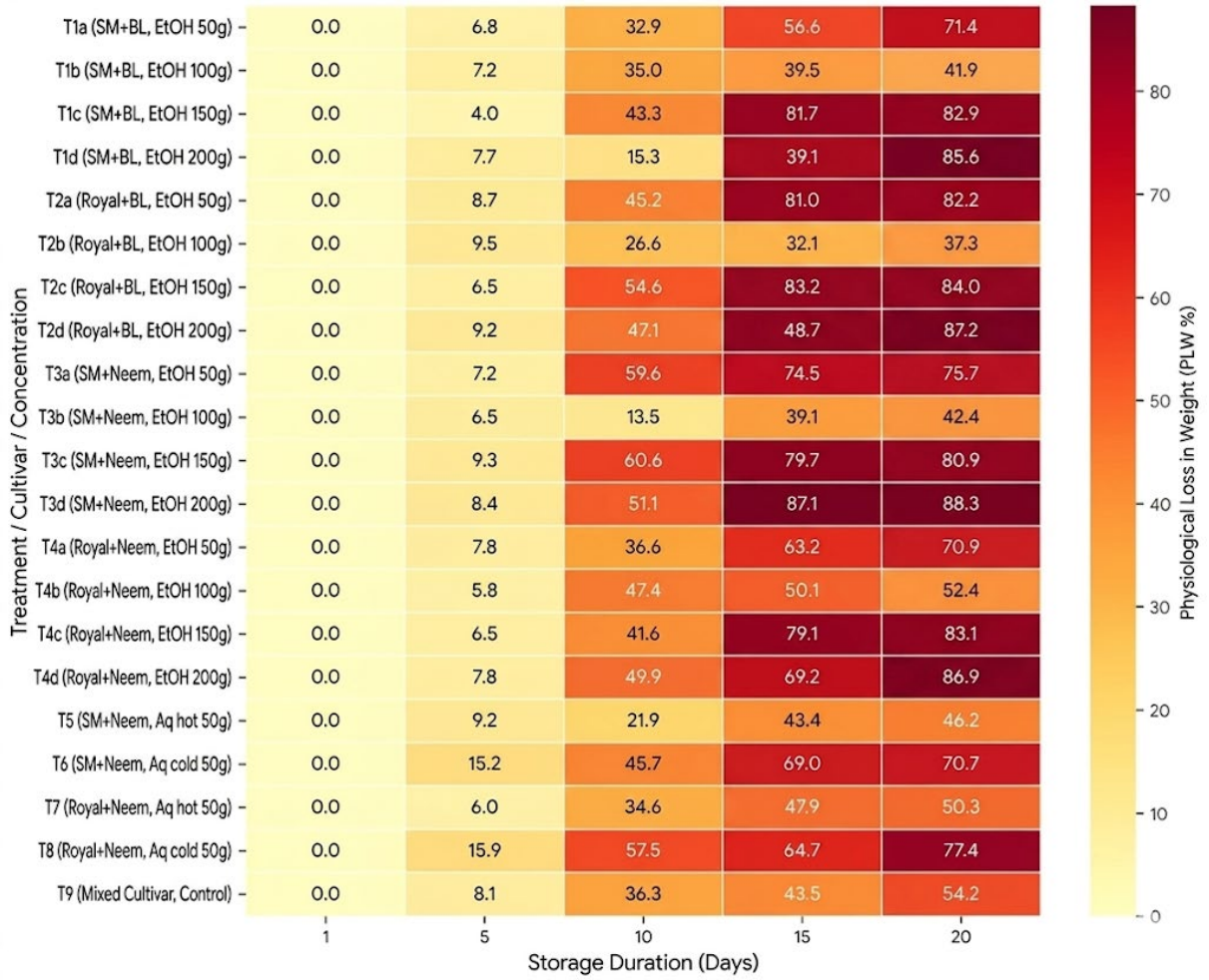

Figure 3. Spatiotemporal heat map of physiological loss in weight (PLW %) in tomato cultivars during 20 days of ambient storage. The heat map displays the mean percentage of weight loss relative to the initial weight (Day 1) for various postharvest treatments. The Y-axis represents the treatment groups, including ethanol extracts (EtOH) of bitter leaf and neem at varying concentrations (50–200 g/500 mL), aqueous extracts (Aq hot and Aq cold), and the distilled water control (T9). The X-axis denotes the storage duration in 5-day intervals. The color gradient corresponds to the magnitude of desiccation, ranging from light yellow (0% PLW, representing total weight retention) to dark maroon (>80% PLW, representing severe moisture loss). Values within the cells indicate the specific mean PLW (%) for each treatment-day combination. The data reveal a clear concentration-dependent response for ethanol extracts, with T2b (EtOH 100g) exhibiting the highest preservation efficiency (37.3% PLW at Day 20), whereas higher concentrations (150–200 g) and cold aqueous extracts (T6, T8) showed accelerated decay constants, indicating a loss of cuticular integrity.

3.8 Mechanisms Underlying Preservation Effects

The observed preservation effects are likely driven by multiple complementary mechanisms. Plant extracts may form semi-permeable coatings on the fruit surface, reducing transpiration and gas exchange (Kocira *et al*., 2021). Their antimicrobial properties inhibit spoilage organisms such as *Botrytis cinerea* and *Aspergillus niger* (Okolo *et al*., 2022; Ekhuemelo & Eigege, 2017), while phytochemicals may modulate physiological processes such as respiration and ethylene production, delaying ripening (Chen *et al*., 2025). Additionally, plant-derived compounds may enhance antioxidant defence systems, including enzymes such as peroxidase and superoxide dismutase (Fujita & Hasanuzzaman, 2022), thereby reducing oxidative stress. The combined effects of these mechanisms are reflected in the sustained weight retention (**Figure 1**) and reduced PLW (**Table 3**) observed in optimised treatments.

3.9 Comparative Performance of Plant Species

Differences between plant species were evident (**Table 2**). Treatments based on *Vernonia amygdalina* achieved higher final weights (up to 158.3 g) and lower PLW (as low as 37.3%) compared with *Azadirachta indica*. This may reflect higher concentrations of phenolics and flavonoids, which enhance antioxidant capacity and membrane stability (Patathananone *et al*., 2023; Nursuhaili *et al.*, 2019). However, *A. indica* performed relatively better in

aqueous form, particularly under hot extraction, indicating that solvent type influences phytochemical efficacy (Wylie & Merrell, 2022; Chime & Aiwansoba, 2023; Hosea *et al*., 2017).

3.10 Comparison with Previous Studies

The present findings contrast with those of Okolo *et al.* (2022), who reported that higher concentrations (up to 10.0 g/mL) of neem and bitter leaf extracts progressively improved tomato shelf life without evidence of phytotoxicity. This discrepancy may be attributed to differences in tomato cultivars (undefined in their study vs. Royal and San Marzano here), extraction protocols (absolute ethanol vs. 70% ethanol), concentration ranges (2.5–10.0 g/mL vs. 0.1–0.4 g/mL), or the lack of intermediate concentrations in their design that would reveal a downturn. Our study demonstrates, for the first time, a clear optimum concentration for ethanol extracts of both plant species, above which accelerated weight loss occurs, likely due to cuticle damage. Furthermore, our inclusion of two cultivars and comparison of hot versus cold aqueous extracts provides novel practical insights absent from previous reports. Nevertheless, these studies underscore the potential of plant-derived bio-preservatives as sustainable alternatives to synthetic chemicals.

3.11 Practical Implications for Postharvest Management

The findings of this study offer important practical implications for postharvest tomato management, particularly in developing regions where losses are high and access to refrigeration is limited. The optimised treatment, namely ethanol extract of *Vernonia amygdalina* at 100 g per 500 mL applied to the Royal cultivar, markedly improved weight retention and effectively extended marketable shelf life relative to the control, with clear benefits for reducing losses, enhancing food availability, and increasing farmer income. In contexts where ethanol is unavailable or prohibitively expensive, hot aqueous extracts of neem represent a feasible and low-cost alternative, providing measurable improvements using locally accessible materials and simple preparation methods. The concentration-dependent response observed in this study further emphasises the need for optimisation, as excessive concentrations may compromise fruit integrity rather than enhance preservation. In addition, the differential responses between cultivars indicate that postharvest interventions should be tailored to specific genotypes, with Royal showing greater compatibility with ethanol-based treatments, while San Marzano may require modified concentrations or alternative approaches for optimal results.

3.12 Limitations and Future Research

This study was limited to weight loss as the primary quality parameter and did not assess other attributes such as firmness, colour, or nutritional composition. The 20-day storage period and controlled conditions also limit extrapolation to real-world supply chains. Future studies should incorporate broader quality metrics, longer storage durations, field validation, and phytochemical characterisation, alongside advanced formulation strategies to enhance efficacy and scalability.

4. CONCLUSION

This study shows that ethanol and aqueous extracts of *Vernonia amygdalina* and *Azadirachta indica* can improve tomato postharvest weight retention, with efficacy strongly dependent on concentration and cultivar. The 100 g/500 mL ethanol treatment consistently gave the best results, while lower concentrations were less effective and higher concentrations caused rapid deterioration, indicating an optimal rather than linear response. Hot aqueous extracts provided moderate preservation and may serve as a practical alternative where ethanol is unavailable. Overall, effective postharvest use of these botanicals requires careful optimisation of concentration and consideration of cultivar differences. These findings highlight the potential of these plant-based treatments as low-cost, accessible postharvest preservation options for smallholder farmers in tropical regions.

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REFERENCES

Abdulrahman, I. M., Umar, U. A., & Oyedeji, A. N. (2025). Postharvest losses of a developing nation's tomatoes value chain-evidence from actors' perspectives in Nigeria. *J. Appl. Res. Ind. Eng.*, 12(1), 119–132. https://doi.org/10.22105/jarie.2024.422732.1570

Ajenifujah-Solebo, S. O., Akin-Idowu, P. E., Aduloju, A. O., Adedeji, V. O., Akinyode, E. T., Ibitoye, D. O., ... & Bello, F. (2025). Tomato crop improvement efforts in Nigeria: Past, current and future perspectives. *Solanum lycopersicum L.-Res. Methods, Approaches, Perspect.*, 29. https://doi.org/10.5772/intechopen.1009299

Alara, O. R., Abdurahman, N. H., & Olalere, O. A. (2020). Ethanolic extraction of flavonoids, phenolics and

antioxidants from Vernonia amygdalina leaf using two-level factorial design. *Journal of King Saud University-Science*, *32*(1), 7-16. https://doi.org/10.1016/j.jksus.2017.08.001

Ali, J., Hussain, A., & Abbas, J. (2025). In vitro control of post-harvest fruits rot pathogenic fungi using Azadirachta indica (Neem) seeds and leaves extracts. *Bull. Biol. Allied Sci. Res.*, 2025(1), 102–102. https://doi.org/10.64013/bbasr.v2025i1.102

Anusha, M., Sri, K. R., Lokesh, M., Deepthi, N. M., & Malleswari, M. D. (2024). Postharvest management techniques for improved shelf life of horticultural crops: A review. *J. Exp. Agric. Int.*, 46(11), 362–380. https://doi.org/10.9734/jeai/2024/v46i113059

Azwanida, N. N. (2015). A review on the extraction methods use in medicinal plants, principle, strength and limitation. *Med. Aromat. Plants*, 4, 2167-0412. https://doi.org/10.4172/2167-0412.1000196

Barraj Barraj, R., Segado, P., Moreno-González, R., Heredia, A., Fernández-Muñoz, R., & Domínguez, E. (2021). Genome-wide QTL analysis of tomato fruit cuticle deposition and composition. *Hortic. Res.*, 8. https://doi.org/10.1038/s41438-021-00548-5

Benito-Román, Ó., Blanco, B., Sanz, M. T., & Beltrán, S. (2020). Subcritical water extraction of phenolic compounds from onion skin wastes (Allium cepa cv. Horcal). *Antioxidants*, 9(12), 1233. https://doi.org/10.3390/antiox9121233

Chen, D., Liu, L., Gao, Z., Zhao, J., Yang, Y., & Shen, Z. (2025). Preservation of fruit quality at postharvest through plant-based extracts and elicitors. *Horticulturae*, 11(10), 1186. https://doi.org/10.3390/horticulturae11101186

Chime, A. O., & Aiwansoba, R. O. (2023). Antifungal activity of neem (Azadirachta indica) leaf extract against pathogens associated with tomato fruit spoilage. *Afr. Sci.*, 24, 297–303

Darwin, R., Valmon, R., Chithanna, S., Galla, S. H., Syed, S. H., Mohathasim Billah, A. A., ... & Arjun, U. V. N. V. (2025). Sustainable extraction and purification of phytochemicals: A review of green solvents and techniques. *Chem. Methodol.*, 9(5), 356–385. https://doi.org/10.48309/chemm.2025.504050.1892

Dheeba, B., Niranjana, R., Sampathkumar, P., Kannan, K., & Kannan, M. (2015). Efficacy of neem (Azadirachta indica) and tulsi (Ocimum sanctum) leaf extracts against early blight of tomato. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *85*(1), 327-336. https://doi.org/10.1007/s40011-014-0340-9

Do, Q. D., Angkawijaya, A. E., Tran-Nguyen, P. L., Huynh, L. H., Soetaredjo, F. E., Ismadji, S., & Ju, Y. H. (2014). Effect of extraction solvent on total phenol content and antioxidant activity. *J. Food Drug Anal.*, 22(3), 296–302. https://doi.org/10.1016/j.jfda.2013.11.001

Edo, G. I., Samuel, P. O., Jikah, A. N., Onoharigho, F. O., Idu, L. I., Obasohan, P., ... & Owigho, J. E. (2023). Biological and bioactive components of bitter leaf. *Food Chem. Adv.*, 3, 100488. https://doi.org/10.1016/j.focha.2023.100488

Ekhuemelo, C., & Eigege, O. (2017). Evaluation of stem bark extracts of Azadiratcha indica and Vernonia amygdalina. *Asian Res. J. Agric.*, 5(3), 1–7. https://doi.org/10.9734/ARJA/2017/34640

El Alami El Hassani, N., Baraket, A., & Alem, C. (2025). Recent advances in natural food preservatives. *J. Food Meas. Charact.*, 19(1), 293–315. https://doi.org/10.1007/s11694-024-02969-x

El-Saadony, M. T., Saad, A. M., Mohammed, D. M., Alkafaas, S. S., Abd El-Mageed, T. A., Fahmy, M. A., ... & El-Tarabily, K. A. (2025). Plant bioactive compounds: A comprehensive review. *Front. Nutr.*, 12, 1659743. https://doi.org/10.3389/fnut.2025.1659743

Firdous, N., Farooq, U., Batool, A., Aslam, A., Erum, A., Ahmad, S., ... & Khalil, S. (2025). Postharvest metabolomics of tomato. In *Omics Approaches for Tomato Yield and Quality Trait Improvement*, 147–176. Springer. https://doi.org/10.1007/978-981-96-3890-1_7

Fujita, M., & Hasanuzzaman, M. (2022). Approaches to enhancing antioxidant defense in plants. *Antioxidants*, 11(5), 925. https://doi.org/10.3390/antiox11050925

Ghamba, P. E., Balla, H., Goje, L. J., Halidu, A., & Dauda, M. D. (2014). In vitro antimicrobial activities of Vernonia amygdalina on selected clinical isolates. *International Journal of Current Microbiology and Applied Sciences*, *3*(4), 1103-1113.

Godana, E. A., & Gurmu, A. H. (2020). Postharvest disease control approaches. *Ann. Food Sci. Technol.*, 21(3)

Hosea, Z. Y., Liamngee, K., Owoicho, A. L., & David, T. (2017). Neem leaf powder and tomato shelf life. *Int. J. Dev. Sustain.*, 6(10), 1334–1349

Howlader, N. C., Hossain, M. M., Roy, T. K., Ahsan, S. M., Injamum-Ul-Hoque, M., & Miah, M. H. (2026). Botanical extracts for postharvest preservation. *J. Crop Health*, 78(1), 17. https://doi.org/10.1007/s10343-025-01277-8

Jung, J. M., Shim, J. Y., Chung, S. O., Hwang, Y. S., Lee, W. H., & Lee, H. (2019). Changes in quality parameters of tomatoes during storage: A review. *Korean J. Agric. Sci.*, 46(2), 239–256. https://doi.org/10.7744/kjoas.20190011

Kitinoja, L., Odeyemi, O., Dubey, N., Musanase, S., & Gill, G. S. (2019). Commodity system assessment studies on the postharvest handling and marketing of tomatoes in Nigeria, Rwanda and Maharashtra, India. *J. Hortic.*

Postharvest Res., 2(Special Issue), 1–14. https://doi.org/10.22077/jhpr.2019.2060.1040

Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E., & Hortyńska, P. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review. *Agronomy*, 11(5), 813. https://doi.org/10.3390/agronomy11050813

Kumar, A., Kumar, V., Gull, A., & Nayik, G. A. (2020). Tomato antioxidants. In *Antioxidants in Vegetables and Nuts*, 191–207. Springer. https://doi.org/10.1007/978-981-15-7470-2_10

Kumar, M., Chandran, D., Tomar, M., Bhuyan, D. J., Grasso, S., Sá, A. G. A., ... & Mekhemar, M. (2022). Tomato seed nutraceutical properties. *Horticulturae*, 8(3), 265. https://doi.org/10.3390/horticulturae8030265

Lara, I., Belge, B., & Goulao, L. F. (2014). The fruit cuticle as a modulator of postharvest quality. *Postharvest Biol. Technol.*, 87, 103–112. https://doi.org/10.1016/j.postharvbio.2013.08.012

Nursuhaili, A. B., Nur Afiqah Syahirah, P., Martini, M. Y., Azizah, M., & Mahmud, T. M. M. (2019). A review: medicinal values, agronomic practices and postharvest handlings of Vernonia amygdalina. *Food Res.*, 3(5), 380–390. https://doi.org/10.26656/fr.2017.3(5).306

Nxumalo, K. A., Aremu, A. O., & Fawole, O. A. (2021). Potentials of medicinal plant extracts as an alternative to synthetic chemicals in postharvest protection and preservation of horticultural crops: A review. *Sustainability*, 13(11), 5897. https://doi.org/10.3390/su13115897

Odeyemi, O. M., Kitinoja, L., Dubey, N., Musanase, S., & Gill, G. S. (2022). Preliminary study on improved postharvest practices for tomato loss reduction in Nigeria, Rwanda and India. *Afr. J. Sci. Technol. Innov. Dev.*, 14(6), 1500–1505. https://doi.org/10.1080/20421338.2021.1961986

Okolo, J. C., Igborgbor, J. C., Eze, E. M., Ogu, G. I., & Jonah, G. U. (2022). The shelf life of tomato fruits (Solanum lycopersicum L.) treated with extracts of two medicinal plants: Azadirachta indica and Vernonia amygdalina. *Int. J. Environ.*, 11(2), 124–140. https://doi.org/10.3126/ije.v11i2.48653

Patathananone, S., Pothiwan, M., Uapipatanakul, B., & Kunu, W. (2023). Inhibitory effects of Vernonia amygdalina leaf extracts on free radical scavenging, tyrosinase, and amylase activities. *Prev. Nutr. Food Sci.*, 28(3), 302–311. https://doi.org/10.3746/pnf.2023.28.3.302

Peleg, M. (2019). Food degradation kinetics. *Food Eng. Rev.*, 11(1), 1–13. https://doi.org/10.1007/s12393-018-9185-y

Salgado-Cruz, M. D. L. P., Salgado-Cruz, J., García-Hernández, A. B., Calderón-Domínguez, G., Gómez-Viquez, H., Oliver-Espinoza, R., Fernández-Martínez, M. C., & Yáñez-Fernández, J. (2021). Chitosan as a coating for biocontrol in postharvest products: A bibliometric review. *Membranes*, 11(6), 421. https://doi.org/10.3390/membranes11060421

Shahbaz, M. U., Arshad, M., Mukhtar, K., Nabi, B. G., Goksen, G., Starowicz, M., Nawaz, A., Ahmad, I., Walayat, N., Manzoor, M. F., & Aadil, R. M. (2022). Natural plant extracts: An update about novel spraying as an alternative of chemical pesticides to extend the postharvest shelf life of fruits and vegetables. *Molecules*, 27(16), 5152. https://doi.org/10.3390/molecules27165152

Sibomana, M. S., Workneh, T. S., & Audain, K. J. F. S. (2016). Tomato supply chain losses. *Food Security*, 8(2), 389–404. https://doi.org/10.1007/s12571-016-0562-1

Taoukis, P., Labuza, T., & Saguy, I. (1997). Food deterioration kinetics. In *Handbook of Food Engineering Practice*, 361–404

Tripathi, A., Chandrasekaran, N., Raichur, A. M., & Mukherjee, A. (2009). Antibacterial applications of silver nanoparticles synthesized by aqueous extract of *Azadirachta indica* (Neem) leaves. *Journal of Biomedical Nanotechnology*, *5*(1), 93-98. https://doi.org/10.1166/jbn.2009.038

Tušek, A. J., Benković, M., Valinger, D., Jurina, T., Belščak-Cvitanović, A., & Kljusurić, J. G. (2018). Bioactive extraction modelling. *Ind. Crops Prod.*, 126, 449–458. https://doi.org/10.1016/j.indcrop.2018.10.040

Umeohia, U. E., & Olapade, A. A. (2024). Tomato postharvest technologies. *Am. J. Food Sci. Technol.*, 12(2), 42–64. https://doi.org/10.12691/ajfst-12-2-1

Wylie, M. R., & Merrell, D. S. (2022). The antimicrobial potential of the neem tree Azadirachta indica. *Front. Pharmacol.*, 13, 891535. https://doi.org/10.3389/fphar.2022.891535

Xie, L., Guerra, M., Tijskens, L. M. M., Schoevaars, A. M., Verdonk, J. C., Woltering, E. J., & Schouten, R. E. (2025). Tomato weight loss modelling. *Postharvest Biol. Technol.*, 230, 113747. https://doi.org/10.1016/j.postharvbio.2025.113747

Žagar, T., Frlan, R., & Kočevar Glavač, N. (2024). Using subcritical water to obtain polyphenol-rich extracts with antimicrobial properties. *Antibiotics*, 13(4), 334. https://doi.org/10.3390/antibiotics13040334