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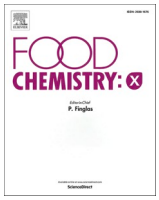

# Influence of tomato peel fiber and moringa leaf extract bioactive coatings on the quality, shelf life, and sensory properties of fresh tomatoes☆

Uchenna Emmanuel Umeohia *, Abiodun Adekunle Olapade

*Department of Food Technology, University of Ibadan, Ibadan, Nigeria*

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ABSTRACT

This study assessed the impact of bioactive coatings made from tomato peel fiber and moringa leaf extract on the physiological, physicochemical, shelf life, and sensory properties of fresh tomatoes during storage, with an emphasis on sustainable packaging and postharvest technology. Fresh tomatoes were coated with a bioactive solution containing tomato peel fiber and moringa leaf extract, followed by storage under ambient conditions. Quality parameters, including weight loss rate, firmness, colour change (ΔE), pH, total titratable acidity (TTA), total soluble solids (TSS), total phenolic content (TPC), ascorbic acid content (AAC), antioxidant activity, lycopene content, and respiration rate, were evaluated at four time points over a month. A control group of uncoated tomatoes was also analyzed. The data were analyzed using descriptive statistics and ANOVA ($\alpha = 0.05$). Results showed that the bioactive coating significantly reduced weight loss (0.61 vs. 0.93 %/day), firmness loss (0.4 vs. 0.7 N/day), colour change (ΔE 17.20 vs. 18.90), and respiration rate (4 vs. 10.7 mL $CO_2$/kg·h) compared to uncoated tomatoes. Moreover, it preserved key quality attributes such as TTA, TSS, TPC, AAC, antioxidant activity, and lycopene content. Sensory evaluation revealed that the overall acceptability of coated tomatoes (76.01 %) was higher than that of uncoated tomatoes (68.04 %). In conclusion, tomato peel fiber and moringa leaf extract bioactive coatings, as natural preservatives, are effective in extending the shelf life and maintaining the quality of fresh tomatoes by reducing degradation, preserving physicochemical properties, and enhancing sensory appeal. These sustainable bioactive coatings offer a promising postharvest technology solution for improving storage, reducing food waste, and advancing sustainable packaging in the tomato industry.

## 1. Introduction

Tomatoes (*Solanum lycopersicum*) are one of the most widely consumed and nutritionally important vegetables, prized for their high content of vitamins, minerals, and antioxidants (Siddiqui et al., 2018). However, tomatoes are highly perishable due to their high-water content, making them susceptible to rapid deterioration during storage and transportation (Zhang et al., 2023). The deterioration leads to reduced shelf life, loss of nutritional value, and altered sensory characteristics, such as texture, flavor, and appearance (Ungureanu et al., 2023). As a result, effective preservation methods are critical to extending the shelf life of fresh tomatoes while maintaining their nutritional and sensory attributes.

In recent years, there has been increasing interest in the use of natural, plant-based materials as bioactive coatings to improve the shelf life of fresh produce (Sharma et al., 2018). These coatings serve as a barrier to moisture loss, oxygen, and microbial contamination, while also providing a source of bioactive compounds that may contribute to the preservation of quality (Pham et al., 2023). Edible coatings have emerged as a promising strategy to enhance the shelf-life and quality of food products (Mahmed et al., 2021). These coatings, typically composed of lipids, polysaccharides, and/or proteins, act as a protective barrier on the surface of foods, effectively mitigating various mechanisms of deterioration (Asfaq et al., 2023). One of the primary functions of edible coatings is to reduce moisture loss from the food product. By forming a semi-permeable layer on the surface, the coatings restrict the outward diffusion of water, thereby maintaining the product's firmness, texture, and overall quality (Saikumar et al., 2023). Additionally, edible coatings can impede the inward diffusion of oxygen, hindering oxidative processes that lead to the deterioration of flavor, colour, and nutritional content of the food (Galus et al., 2021). Furthermore, the incorporation of antimicrobial agents, such as bacteriocins, into the coating matrix can

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* Corresponding author at: Department of Food Technology, University of Ibadan, Ibadan, Nigeria.
*E-mail address:* uchenna.umeohia@gmail.com (U.E. Umeohia).

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inhibit the growth of pathogenic and spoilage microorganisms, extending the product's shelf-life and ensuring food safety (Ungureanu et al., 2023). The versatility of edible coatings allows for the incorporation of a wide range of functional compounds, including antioxidants, vitamins, and flavors, further enhancing the nutritional and sensory properties of the coated food. (Khalid et al., 2024).

Among the promising natural ingredients, tomato peel fiber and Moringa leaf extract have garnered attention due to their rich composition of bioactive compounds (Laranjeira et al., 2022; Saucedo-Pompa et al., 2018). About 40 % of the total tomato waste is composed of tomato peels (Li et al., 2017). Tomato peel fiber is a byproduct of tomato processing that contains high levels of dietary fiber, antioxidants, and phenolic compounds, while Moringa leaf extract is known for its antimicrobial and antioxidant properties (Salem et al., 2021). These bioactive properties make both ingredients suitable for use in bioactive coatings. Tomato peels are rich in dietary fiber, which can account for up to 48.5 % of the total composition as insoluble dietary fiber and 8.9 % as soluble dietary fiber (Li et al., 2017). Also, over 50 % of the antioxidants in tomatoes are found in the seeds and peels. Hence most of the research has focused on how antioxidants from tomato peels can be extracted organically (Righetti et al., 2023). Compared to the full tomato, tomato peels have three times more lycopene (Trombino et al., 2021). One of the predominant antioxidants included in tomatoes is lycopene. The tomato peel or skin is made up of 2–4 layers of thick-walled hypodermal cells with thickening resembling collenchyma and an exterior epidermal layer (Philippe et al., 2020). The cuticular layer, which is made up of waxes and fibrous polysaccharides embedded in a cutaneous matrix, is covered by the top layer of the cuticle. The plant cuticle develops within the cuticular stratum of cell walls and is composed of both layers. (Philippe et al., 2020). On the other hand, the leaves of moringa are a rich source of various phytochemicals, including flavonoids, which have been shown to possess antioxidant, anti-inflammatory, and antimicrobial properties (dos Braga et al., 2020). Recent studies have investigated the potential of moringa leaf extracts as bioactive coatings for the postharvest preservation of fresh foods. Moring leaf extract has been reported to inhibit the growth of various pathogenic and spoilage microorganisms that commonly affect the shelf-life of fresh produce (Nuryanti & Purwaningsih, 2020). For example, a study conducted by researchers examined the antibacterial activity of moringa leaf extracts against a range of foodborne pathogens, including *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes*, and found that the extracts exhibited potent inhibitory effects, suggesting their potential for use in the development of natural food preservatives (Martono et al., 2019). Another study found that the ethanol extract of Moringa leaves exhibited antibacterial activity against *Staphylococcus epidermidis*, with the largest inhibition zone measured at 14 mm for an 8 % concentration of the extract (Ervianingsih Mursyid et al., 2019). Another study evaluated the antibacterial activity of *Moringa oleifera* leaf extracts and found that the extracts exhibited moderate antibacterial activity, with the highest inhibition zone diameter of 5.75 mm observed at a concentration of 7 % (Tunas et al., 2019). The antimicrobial efficacy of Moringa extracts has been attributed to the presence of various phytochemicals, such as flavonoids, tannins, and saponins, which exhibit potent antibacterial properties (Kalaiyan et al., 2021). The ability of *Moringa oleifera* leaf extracts to inhibit the growth of various microorganisms, including bacteria and fungi, has significant implications for their potential use as natural antimicrobial agents in food preservation. Also, the presence of bioactive compounds such as flavonoids in moringa leaf extracts may contribute to their antioxidant properties, which could help maintain the quality and nutritional value of fresh foods during storage and transportation. (Lin et al., 2018).

This study investigates the effects of novel bioactive coatings made from tomato peel fiber and moringa leaf extract on the physiological, physicochemical, shelf life, and sensory properties of fresh tomatoes. This study is unique in combining tomato peel fiber with moringa leaf extract to create a bioactive coating that offers both mechanical protection and bioactive properties, extending the shelf life of fresh tomatoes. The innovative approach also promotes sustainability by repurposing tomato peel waste while preserving the sensory qualities of the fruit. Additionally, the use of eco-friendly, sustainable materials in food preservation aligns with the growing demand for green technologies in the food industry. The findings from this research could offer valuable insights into novel, cost-effective, and environmentally friendly methods to enhance the shelf life and quality of fresh tomatoes.

## 2. Materials and methods

### 2.1. Materials

Green mature Roma tomatoes for storage studies were grown in Abeokuta, Ogun State. Variety identification took place at NIHORT, Ibadan. Moringa leaves were harvested from a tree at Bells University, Ota, Ogun State. Analytical grade chemicals were provided by the Food Technology labs of the University of Ibadan and Bells University of Technology. Tomato peel fiber was produced from pomace supplied by Tomato Jos Farming and Processing Limited, Kaduna.

### 2.2. Preparation of tomato peel fiber

Tomato peel fiber was prepared using methods described by Donegà et al. (2015), with slight modifications. Tomato pomace, consisting of peels and seeds, was sourced from the pomace produced by Tomato Jos Farming and Processing Limited, Kaduna. A total of 5 kg of pomace was collected and stored at 4 °C until preparation. The peels and seeds were separated using a decanter, and the peels were then centrifuged at 5000 rpm for 2 min. After decanting, the peels were dehydrated in an oven (Memmert, UN30) at 65 °C for 8 h. The dehydrated peels were ground into a fine fiber powder (< 2.5 μm) using a laboratory milling machine. The resulting powder was sifted through a mechanical sieve with a mesh size of <2.5 μm. The milled tomato peel fiber was stored in a glass jar at 4 °C until use.

### 2.3. Preparation of tomato puree base

Red ripe tomatoes were selected based on their external colour, following the USDA guidelines for tomato colour classification (USDA, 1991). A modified version of the method outlined by Zina et al. (2021) was used to prepare the tomato puree. The tomatoes (500 g) were washed with running water to reduce field heat, then blanched in boiling water (100 °C) for three minutes, and their skins were manually peeled off. The tomatoes were halved, and the seeds within the pulp were carefully removed. The pulp was blended using a SONIK SB-520 at 5000 rpm for 10 min. Excess water was drained using a muslin cloth for 10 min, and the resulting puree was sterilized by boiling for 20 min. The puree was then placed in sterile glass jars, inverted for 15 min, and stored in a refrigerator at 4–6 °C. The total soluble solids of the prepared puree were determined to be 18 %.

### 2.4. Preparation of moringa leaf extract

The maceration method described by Laksmiani et al. (2021) was used to prepare the Moringa Leaf Extract (MLE). The leaves were separated from the stems and air-dried under a laboratory shed at a temperature of 30 ± 2 °C. The dried leaves were then ground and combined with 70 % ethanol in a 1:4 ratio. The mixture was left at room temperature (30 ± 2 °C) for 72 h, with occasional shaking. After the extraction period, the mixture was filtered through filter paper. The same solvent was used to reprocess the residue, repeating the extraction five times. The resulting Moringa leaf extract was concentrated using a rotary evaporator (BUCHI F-305) under vacuum at 40 °C. The concentrated MLE was transferred to an airtight jar and stored in a refrigerator at 4–6 °C until further use.

### 2.5. Preparation of coating solution

The coating solution was prepared by mixing 2.68 g of tomato peel fiber and 0.53 g of moringa leaf extract in 100 g tomato puree base, containing 3 % pectin. The components were mixed for 15 min for even dispersion with a magnetic mixer to form the coating solutions. The solution was stored in refrigerated condition (5 °C) until further use (Umeohia & Olapade, 2024).

### 2.6. Coating of tomatoes with bioactive solution

Evaluation of physiochemical changes was conducted on the mature green tomatoes (showing the first change to orange near the blossom scar referred to as just the turning stage of maturity) coated with the film-forming solutions. Mature green tomato fruits were picked and moved to NIHORT, Jericho, Ibadan. To eliminate the field heat, the fruits were cleaned under running tap water, weighed, and kept in a refrigerator at 5 °C and 80–85 % R.H. for 1 h.

Four replicate samples of 50 fruits each coated and uncoated were chosen for uniformity of colour and without any defects. The tomato fruits were submerged in the TP/TPF/MLE solution for 2 min, and then they were transferred to a netted container to drain off the excess coating. Uncoated samples dipped in distilled water were adopted as a control. The coated and uncoated fruits were kept at ambient conditions for 3 h to air-dry. They were kept at ambient conditions (28 ± 2 °C, 56 ± 2.00 %, RH), and changes in the quality parameters of the fruits were measured along with an uncoated control at 7-day intervals for a total of 28 days.

### 2.7. Determination of physiological weight loss

Using a Mettler balance type Toledo PB 602, the weight of tomatoes was measured with a precision of 0.0001 g. Weight loss was calculated and reported as a change from the beginning weight over time (Abebe et al., 2017).

$$\text{Weight loss (W\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \text{ X } 100 \quad (1)$$

### 2.8. Analysis of the firmness of the tomatoes

By using a Magness and Taylor firmness tester with an 8 mm diameter plunger tip from the D. Ballanf Meg. Co., tomato flesh firmness was evaluated. Flesh Firmness was expressed in kg/cm$^2$ (Newton). For each fruit, the average was calculated after two readings were collected from opposing sides (Safari et al., 2020). The probe's contact with the tomato surface signalled the start of the penetration test, which ended after it had advanced at a pace of 1.5 mm/s into the tissues to a depth of 8 mm. Fruit hardness was assessed and quantified in Newtons at the location where the greatest force was registered at the time of penetration.

### 2.9. Determination of total colour change

Utilizing a portable colorimeter (Minolta CR-300), the surface colour of each tomato was assessed once a week after storage. The $L^*$, $a^*$, $b^*$ colour space, in which L denotes brightness, $a^*$ denotes green (−) to red (+) axis, and $b^*$ denotes blue (−) to yellow (+) axis, was used to record colour.

Total colour change was quantified in terms of "$a^*$" (redness) value, "$b^*$" (yellowness), and "$L^*$" (lightness), which ranged from 100 (white) to zero (black). Colour measurements were obtained on day 0 and then every 7 days. Fruit colours on day zero were taken into consideration as a baseline sample colour, and colour variations were assessed in comparison to day zero colour. To get representative colour measurements, five readings per tomato were taken from each set by turning the fruits (Saikumar et al., 2023). The total colour change was computed using eq. 2.

$$\Delta E = \sqrt{(L^* - L)^2 + (a^* - a)^2 + (b^* - b)^2} \quad (2)$$

where $L^*$ and $L$ were the initial and final values for lightness; $a^*$ and $a$ were the initial and final values for redness; $b^*$ and $b$ were the initial and final values for yellowness.

### 2.10. Analysis of changes in pH

The method of Sinha et al. (2019) was adopted for the determination of the pH of the tomatoes. Buffers 7 and 4 were used to calibrate the pH meter (Hannan). Determination of the pH of the tomato fruits was done using 4 g of fresh pulp. The pulp was mixed with 10 mL of distilled water in a conical flask. The pulp-distilled water homogenised was transferred to a laboratory mortar and crushed thoroughly with a pestle. The extract was filtered with filter papers. The pH of the extract was analyzed using a Hannan pH meter, after buffer calibration and temperature correction. Three fruits per group were measured as replicates and the average result was taken.

### 2.11. Determination of total titratable acidity (TTA)

The AOAC (2010) titrimetric technique was adopted to assess the titratable acidity of 50 g samples, and the findings were represented in percent citric acid. Briefly, distilled water was used to dilute a specified amount of filtered juice. An aliquot (10 mL) of this sample will be obtained, and phenolphthalein indicators will be used to titrate it with 0.1 N NaOH. The finish point will be designated as the appearance of light pink colour. Calculated acidity will be given as % citric acid.

$$\text{Acid content (\%)} = \frac{\text{Titre value X Normality X m.eq.wt of acid}}{\text{Volume of sample}} \text{ X } 100 \quad (3)$$

The milli-equivalent weight of citric acid is equal to 0.06404.

### 2.12. Analysis of total soluble solids (TSS)

The method of AOAC (2010) was adopted for the determination of TSS of the tomatoes. A handheld refractometer with a 0–32 (°Brix) range was used to measure the TSS. To measure the TSS of the tomatoes, a drop of juice squeezed from the tomatoes was utilised, and the results were given as °brix.

### 2.13. Analysis of total phenolic content (TPC)

The Folin-Ciocalteu reagent technique reported by Katırcı et al. (2020) was employed for the analysis of the TPC of the tomatoes. The extracted supernatant from the tomatoes was measured (0.5 mL) in test tubes. Folin-Ciotalteu reagent (2.5 mL) was added in the test tubes containing the tomato extracts and left to react for 3 min. Up to 2.5 mL of 20 % sodium carbonate was added to the test tubes, and the test tubes were stored in the dark for 2 h for them react to completely. The absorbance of the mixture was determined using a spectrophotometer (HACH DR 6000). Gallic acid was used to obtain the graph of linearity from which the TPC of the extract was determined and reported as mg gallic acid equivalent per 100 g of the tomato.

### 2.14. Determination of ascorbic acid content

The ascorbic acid content of the tomatoes was analyzed using dye-titration methods of AOAC (2010). Briefly, tomato samples (5 g) were ground and homogenised thoroughly with a 100 mL solution of meta-phosphoric acid-acetic acid at the ratio of 1.0:0.5. The mixture was filtered and was titrated against phenol-2,6-dichloroindophenol dye.

The end of titration was determined with the change of colour to pink that lasted for at minimum 5 s. The standardisation of the dye was done with ascorbic acid.

$$\text{Respiration rate} = \frac{\text{Carbondioxide produced}}{\text{Mass of sample in Kg X h incubated X volume glass container}} \quad (6)$$

### 2.15. Antioxidant analysis of tomatoes

#### 2.15.1. Sample extraction for antioxidant determination

The extraction of tomatoes for antioxidant assay was done by employing the procedure of Mazumder et al. (2021) with minimal modification. Briefly, 3 g of tomatoes were pulverised in a laboratory mortar and pestle. Up to 8 mL of methanol (80 % *v*/v) was poured into an amber bottle, and the ground tomato was added, homogenised using an orbital shaker for 1 h at 180 rpm. The filter paper was used to filter the tomato extract, and the filtrate was stored in a refrigerated condition before analysis.

#### 2.15.2. Analysis of DPPH radical scavenging power of the tomatoes

The method of Mazumder et al. (2021) was used for the assay for the radical scavenging power of the tomatoes. Specifically, 40 mg of 2,2-diphenyl-1-picrylhydrazyl was dissolved in 80 % methanol to give 1 mM stock solution of 2,2-diphenyl-1-picrylhydrazyl. This was kept in refrigerate till when needed. 1 mL tomato extract was reacted with 1 mL of 1 mM DPPH solution and was kept in the dark cupboard to incubate for 30 min. After incubation, the absorbance of the DPPH-extract mixture is measured with a spectrophotometer (HACH DR 6000) at a wavelength of 517 nm. The antioxidant activity of the extracts is computed using the equation below.

$$\text{DPPH antioxidant activity (\%)} = \frac{Ablank - Asample}{Ablank} X\,100 \quad (4)$$

where A stands for absorbance.

### 2.16. Analysis of lycopene content

The lycopene content of the tomatoes was evaluated using a procedure reported by Ishiwu et al. (2014). The tomatoes were selected, and 1 g was collected into a laboratory mortar. Metaphosphoric acid solution (10 mL) was added into the mortar containing the tomato sample and was macerated. The residue was additionally washed with 10 mL of metaphosphoric acid solution. The metaphosphoric washed residue was further macerated with 20 mL acetone and filtered. The absorbance of the filtrate was measured at 440 nm, while pure acetone served as the blank. The lycopene contents of the tomatoes were calculated using the following equation.

$$\text{Lycopene content}\left(\frac{\text{mg}}{100}\text{ mL}\right) = \frac{\text{Absorbance X dilution factor}}{\text{Slope}} \quad (5)$$

The slope was determined from a standard curve of absorbance generated using pure lycopene solution.

### 2.17. Determination of respiration rate of the tomatoes

Five fruits per set of coated and uncoated tomatoes in four replicates were placed into a sealed 500 mL gas jar for 1 h. After 1 h, 1 mL headspace samples were collected with a hypodermic needle and injected into a hand-held carbon dioxide ($CO_2$) meter (Anagas CD 98 model, Air and Acoustics, Chesfire. UK) and were used to determine the amount of $CO_2$ produced in each sample. The $CO_2$ meter recorded the $CO_2$ produced in percentages and was converted to respiration rates in mL $CO_2$/kg/h (Castro-Cegrí et al., 2023). The respiration rate is computed with eq. 3.15.

### 2.18. Descriptive sensory evaluation

The method of Akhtar et al. (2023) was adopted for the sensory evaluation of coated and uncoated tomatoes. Briefly, coated, and uncoated tomatoes were evaluated by 25 panellists (comprising males and females). The sensory evaluation was conducted under fluorescent light at ambient temperature conditions. Five fruits in each category were presented to the panellists in two coded plates for coated and uncoated samples. In addition to rating firmness to touch, panellists were asked to score colour, gloss, and overall appearance. A 9-point descriptive scale was developed for the purpose of the evaluation and scaled as; 1 = extreme poor (unsalable); 3 = poor; 5 = acceptable (limit of marketability); 7 = good, and 9 represented excellent (Ruelas-Chacon et al., 2017).

### 2.19. Statistical analysis

Descriptive analysis, a test of homogeneity, ANOVA, multiple comparisons, and homogeneous subsets (Duncan test) were done using IBM SPSS statistics, version 23 at significant levels set of $p \leq 0.05$.

## 3. Results and discussion

### 3.1. Effects of edible coatings on the physiological weight loss of tomatoes

Coatings with a composite solution of tomato puree, tomato peel fiber, and moringa leaf extract as it affected the physiological weight loss of tomatoes is presented in Fig. 1. From the graph, the edible coatings made from TP/TPF/MLE film-forming solutions significantly ($p \leq 0.05$) reduced the physiological weight loss of the treated tomatoes. The maximum weight loss recorded for samples coated with TP/TPF/MLE coatings was 17.1 ± 2.6 %, while the uncoated samples had a total mass loss of 26.5 ± 0.8 %. The average daily loss of weight per day for coated samples was 0.61 %/day, while samples that were uncoated with the fabricated edible films had a loss of 0.93 %/day. The lower weight loss in tomatoes that were coated may be because of the ability of the TP/TPF/MLE coatings on the rate of biochemical reactions (e.g., ripening) that accelerate transpiration.

Postharvest physiological processes such as transpiration and respiration result in loss of water in fresh produce. The loss of water results in a gradual loss of quality attributes in fresh fruits and vegetables and, therefore, serves as one of the indicators to evaluate senescence and deterioration. To ameliorate this mass loss with its resultant quality loss in fresh produce, edible coatings were applied. The results of the weight loss obtained for tomatoes, both coated and uncoated, stored in natural environments compare closely with the results published by Sree et al. (2020). Sree et al. (2020) reported a similar weight loss for tomatoes coated with 2.5 % chitosan at storage conditions of 30 ± 3 °C after 20 days. In another study, tomatoes coated with a combination of chitosan (4 mg/mL) and *O. vulgare* essential oil (1.25 μL/mL) and kept at 25 °C for 12 days showed weight loss within the range reported for this research (Barreto et al., 2016). Also, Ruelas-Chacon et al. (2017) reported similar observations for Roma tomatoes coated with guar gum with lower weight loss compared to uncoated counterparts over storage at 22 ±

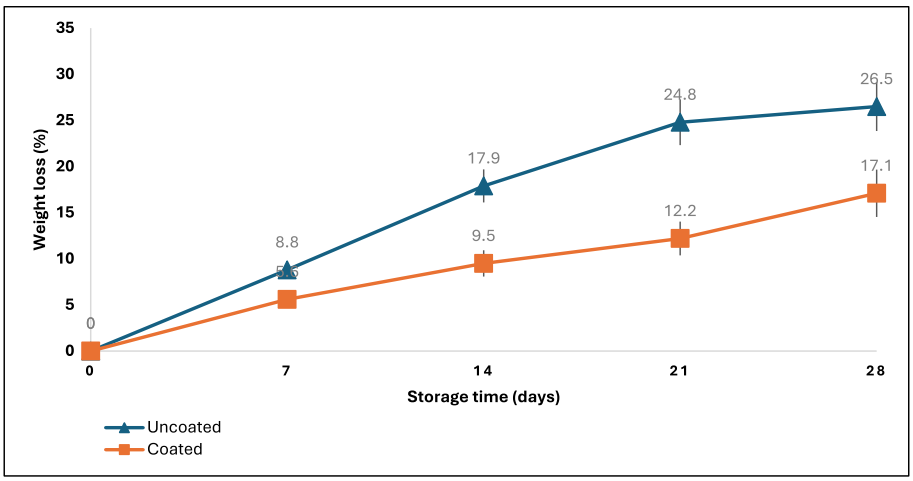


**Fig. 1.** Weight loss of coated and uncoated tomatoes during storage.

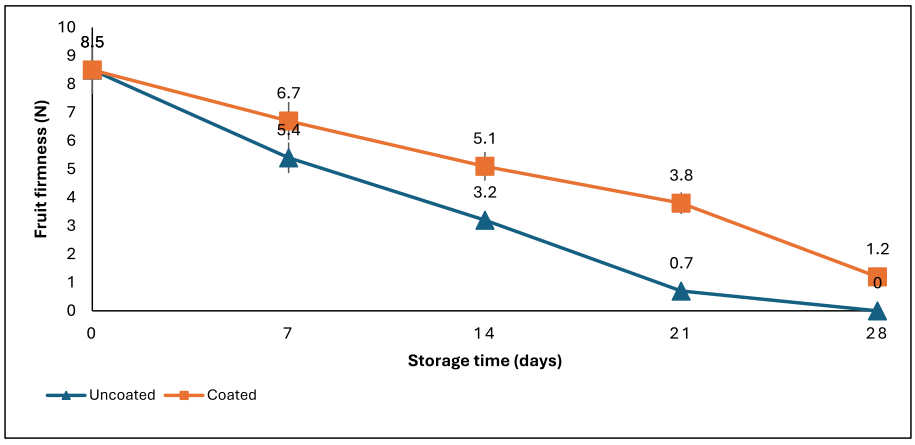


**Fig. 2.** Firmness of coated and uncoated tomatoes during storage.

2 °C for 20 days, which compared closely with the result reported in this study for the effects of TP/TPF/MLE edibles films on coated tomatoes.

### 3.2. *Effects of coatings on the firmness of tomatoes*

Changes in the firmness of the TP/TPF/MLE coated tomatoes and uncoated controls are shown in the trend depicted in Fig. 2. Degradation in the firmness was significantly ($P \leq 0.05$) reduced for tomatoes coated with TP/TPF/MLE, while uncoated tomatoes lost firmness at a faster rate comparably. The lowest loss in firmness recorded for samples coated with TP/TPF/MLE film-forming solution after 28-day storage period was 1.2 N. Conversely, uncoated controlled samples had a 0.7 N firmness value after 21 days under ambient conditions of storage. The daily average loss of firmness per day for uncoated samples was 0.7 N/day, while samples that were coated with the fabricated edible films had firmness loss of 0.4 N/day. Summarily, the overall loss in firmness for the coated samples was 85.9 %, while that of the uncoated control samples was approximately 100 % after 28 days of storage at ambient conditions. The firmness of the uncoated sample could not be detected as the samples were too soft to hold the throbbing head of the firmness tester.

Postharvest biochemical processes result in the breakdown of the cell walls of fresh produce, converting them to simple compounds such as sugars, fatty acids, and amino acids, with a resultant loss in textural characteristics. In addition, postharvest acid degradation of pectin promotes loss of texture in tomatoes. The effects of coatings on the retardation of these degradative processes were evaluated, to prolong the shelf life of tomatoes. Research has shown that chitosan-pullulan composite coatings enriched with pomegranate peel extract can improve tomato shelf life and quality (Kumar et al., 2021). Another study examined cinnamon oil nanoemulsion as an edible coating to enhance tomato storage life (Aisyah et al., 2022). On the other hand, Abhirami et al. (2020) reported higher firmness loss for uncoated tomatoes stored at 32 °C for 18 days as compared to tomatoes coated with wax extracted from rice bran, which had lower total firmness loss. Also, coating with starch extracted from mango kernel laced with glycerol and sorbitol effectively reduced the firmness loss of tomatoes stored at 20 °C for 20 days (Nawab et al., 2017). Ruiz-Martınez et al. (2020) recorded those tomatoes coated with candidelilla wax coating, laced with *flourensia cernua*, and stored at 25 °C had lower firmness loss compared to uncoated samples. Candidelilla wax effectively reduces transpiration rate with the protection of cell wall integrity and maintenance of firmness (Ruiz-Martınez et al., 2020).

### 3.3. *Effects of coatings on the total colour change (ΔE) of tomatoes*

The effects of TP/TPF/MLE edible coatings on the ΔE of tomatoes from green mature to red mature are shown in Fig. 3. There was a significant difference ($p \leq 0.05$) in the total colour changes of treated tomatoes stored at ambient conditions compared to uncoated samples. The TP/TPF/MLE coating on tomatoes at ambient storage caused a slow rise in total colour change. This is in contrast with uncoated tomatoes stored

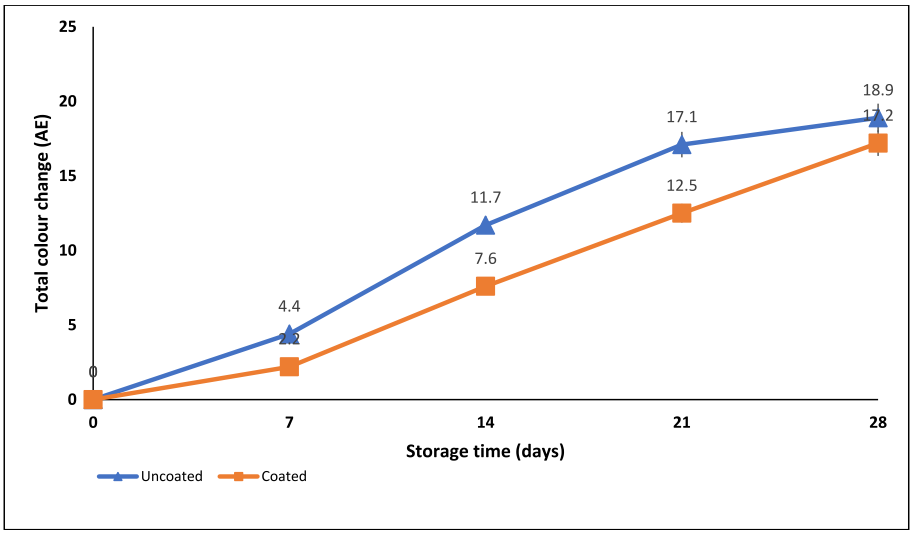


**Fig. 3.** Total colour change of coated and uncoated tomatoes during storage.

in the same ambient condition. The maximum total colour change for TP/TPF/MLE coated samples was 17.2 ± 2.1, while that of uncoated samples was 18.9 ± 1.7 after a storage period of 28 days. Coating of tomatoes with TP/TPF/MLE film solution retarded the ripening and senescence process and hence the total colour change after 28 days. This could be as a result of the impact of the coating materials on ethylene production. Retardation of ethylene production results in a decrease in ripening and colour change, as this gas acts as a catalyst for the biochemical process of depigmentation of climacteric fruits.

Physical indicators of biochemical changes in tomatoes during ripening include progressive colour change from green to reddish. The change in pigmentation is correlated to the lycopene content of tomatoes. Significant increases in the concentration of lycopene have been observed from the full-grown greenish phase to the reddish phase in tomatoes (Kumar et al., 2023). Constant exposure to temperatures between 12 and 21 degrees Celsius promotes the production of lycopene in tomatoes, whereas temperatures over 30 degrees Celsius suppress this activity (Tigist et al., 2015). The results obtained for tomatoes treated with TP/TPF/MLE film-forming solution is comparable with results reported for tomatoes treated with edible coatings composed of whey protein isolate, xanthan gum, and clove oil, which effectively delayed colour change after 15 days of storage at 20 °C and 85 % R.H. Uncoated tomatoes recorded higher total colour change compared to coated samples (Kumar & Saini, 2021). The values reported by Kumar and Saini (2021) are within the range reported for tomatoes coated with optimum TP/TPF/MLE edible coatings. The tomato-based edible films significantly reduced the total colour change of the coated tomatoes, which could be because of its effects on the biochemical processes that catalyse ripening and senescence in fresh tomatoes.

### 3.4. Effects of coatings on the pH of tomatoes

The graphical representation of changes in pH during the period of the experiment is depicted in Fig. 4. From the results obtained, uncoated control tomato samples had a more rapid and significant ($p \leq 0.05$) rise in pH when compared with the coated samples. Application of TP/TPF/MLE coatings effectively reduced biochemical processes such as rate of respiration and ethylene generation, with an attendant decrease in organic acid production. The pH varied from 3.8 to 4.6 and 3.8 to 4.3 for the uncoated and coated samples, respectively. The lowest increase in pH after 28 days of ambient storage was recorded for tomatoes coated with TP/TPF/MLE, while the highest pH was observed for uncoated counterparts.

The balance in taste in tomatoes is created by the right acid-to-sugar levels in the fruit pulp. Postharvest biochemical processes leading to quality loss are associated with changes in pH. This is credited to the breakdown of pectin during maturation and senescence. The rate of change in pH of the tomato fruit pulp is correlated to the degree of

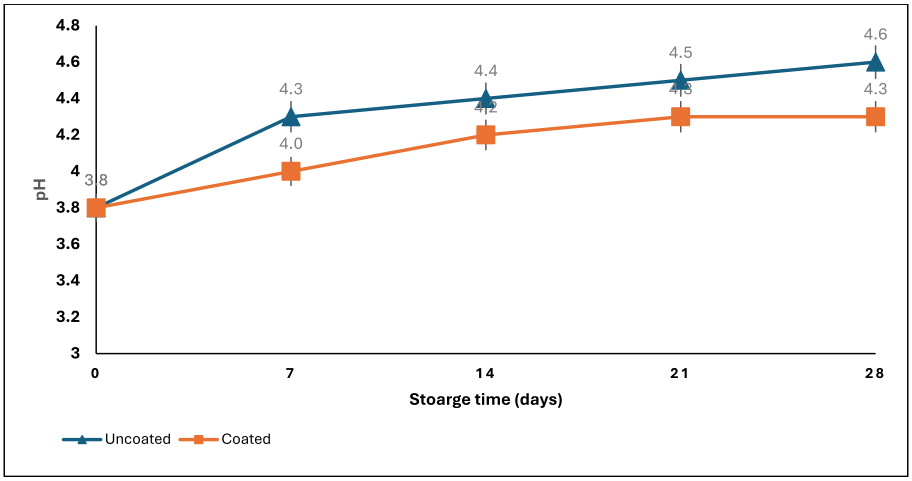


**Fig. 4.** pH of coated and uncoated tomatoes during storage.

maturation levels (Yahia & Brecht, 2012). The reduction in degradation of pectin and other associated biochemical processes contributed, to the rise in pH of the fruit pulps. Storage conditions and packaging systems that reduce pectin degradation cause a commensurate increase in the pH of the fruits and vice versa. The results obtained for the effects of TP/TPF/MLE edible coatings are comparable to findings reported for coatings made from biocomposites by other researchers. For instance, Zewdie et al. (2022), Shanty PM fresh tomatoes treated with neem leaf extract dipping and beeswax coating had significantly lower pH. In comparison to the control (uncoated fruits), the pH of the tomato fruits rise progressively during storage for 36 days at ambient conditions. According to the study, in contrast to solitary neem leaf dipping or the control sample (beeswax or neen leaf untreated tomato fruits), beeswax coating alone or in conjunction with neen leaf, dipping produced a considerably lower pH value (Zewdie et al., 2022).

### 3.5. Effects of coatings on the total titrable acidity (TTA) of tomatoes

The trend in total titrable acidity of the tomatoes during storage as a function of coating with TP/TPF/MLE film-forming solution is graphically represented in Fig. 5. The coating of the green mature tomatoes with TP/TPF/MLE significantly ($p \leq 0.05$) impacted the variation in total titrable acidity of coated and uncoated fruits over the period of 28 days of ambient conditions storage. Tomatoes without coating showed a sharp drop in total titrable acidity, while the coated samples showed a gradual reduction. Overall, coating with TP/TPF/MLE resulted in a slow drop in total titrable acidity of the treated tomatoes, and this could be a result of a slower rate of pectin degradation and depletion of organic acids in the fruit pulps.

Physiological alterations in TTA during the ripening of tomato fruits are correlated to the pulp pH. The decline in TTA of the fruit pulp results in a decrease in positive ion concentration leading to a rise in pH. Also, reduction in respiration after climacteric leads to a decrease in organic acids generation, with an attendant rise in the pH of the fruit pulps. The results obtained compared favourably with the research reported by Khatri et al. (2020) on the impacts of *aloe vera* and chitosan coatings on the total titrable acidity of the fruits over a period of storage. Khatri et al. (2020) showed that tomatoes that were coated with the film-forming solutions from *aloe vera* and chitosan showed remarkably higher total titrable acidity in comparison with tomatoes that were uncoated. Ruelas-Chacon et al. (2017), in their research of guar gum coating of Roma tomato, reported a similar reduction pattern in titrable acidity of coated tomatoes stored for 25 days at 22 ± 2 °C. On the other hand, there was sharp drop of titrable acidity of the uncoated fruits at the same storage conditions. According to the study published by Nur et al. (2021), matured green tomatoes coated with *aloe vera* gel, ascorbic acid, and lactic acid had a reduction of titrable acidity comparable with the results reported for tomato puree, peel, and moringa leaf extract-coated tomatoes in this study, while uncoated samples accordingly had comparable decline during a time of 30 days at temperature and relative humidity of 25–29 °C and 82–84 %, respectively.

### 3.6. Effects of coatings on the total soluble solids ($^{o}$brix) of tomatoes

The effects of TP/TPF/MLE edible coatings on the mature green tomatoes are shown in Fig. 6. The changes in $^{o}$brix of both coated and uncoated tomatoes were not significantly different till day 21. Both setups had a slight rise in levels of the total soluble solids. On the one hand, there was a significant ($p \leq 0.05$) difference in the final brix at the end of 28 days. The brix content of the coated tomatoes was lower (5.0 %) as opposed to the uncoated samples that showed total soluble solids of 5.5 %. The edible coating based on tomato peel fiber and moringa leaf extract effectively reduces the breakdown of the structural integrity of the tomatoes coated with the film-forming solution.

Among the critical indicators for measuring the overall quality of fresh tomatoes is total soluble solids. This is because total soluble solids levels in tomatoes affect the taste and ultimate consumer appeal. An increase in total soluble solids led to a rise in the sugar/acid ratio and pH of tomatoes. At maturity, accumulation of the sugar occurs as the tomato fruits mature and ripen because of the conversion of complex carbohydrates to simple sugars through enzyme-mediated biochemical actions. The range of TSS obtained for this experiment is comparable with results obtained from another research. Zewdie et al. (2022) reported that beeswax coating and dipping with neem leaf extract resulted in a gradual change in total soluble solids from 2.8 to 6.9 % over a storage period of 36 days. A similar finding was reported for tomatoes treated with tragacanth, stearic acid, and paraffin wax at the different concentrations and combinations, in which brix of the coated samples were lower in comparison with uncoated samples (Kondle et al., 2019). Sucrose phosphate synthase, a crucial enzyme in sucrose production, is responsible for the rise in soluble sugar during fruit ripening.

### 3.7. Effects of coatings on the total phenolic contents (TPC) of tomatoes

The changes in the total phenolic contents of the coated and uncoated tomatoes stored at ambient conditions over a period of 28 days are presented in Fig. 7. The total phenolic contents for both coated and uncoated tomatoes were higher after the 28th day storage period,

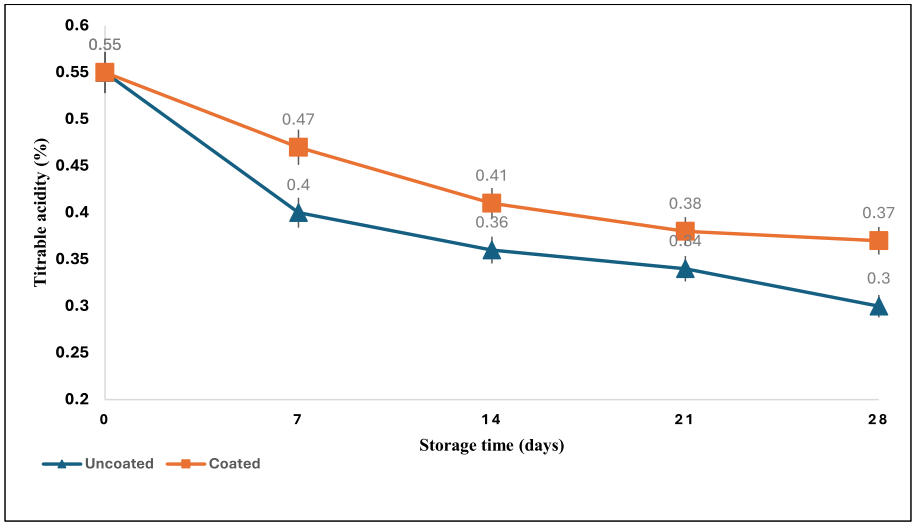


**Fig. 5.** Total titrable acidity of coated and uncoated tomatoes during storage.

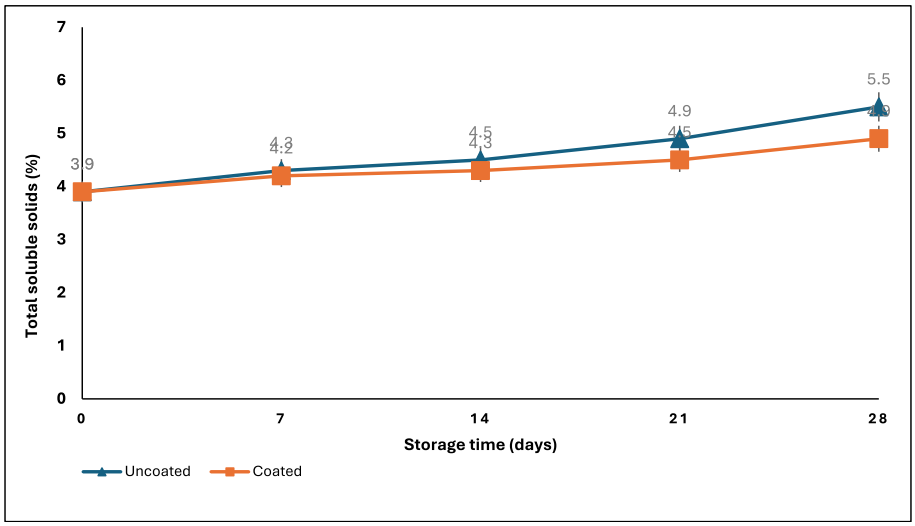


**Fig. 6.** Total soluble solids (°Brix) of coated and uncoated tomatoes during storage.

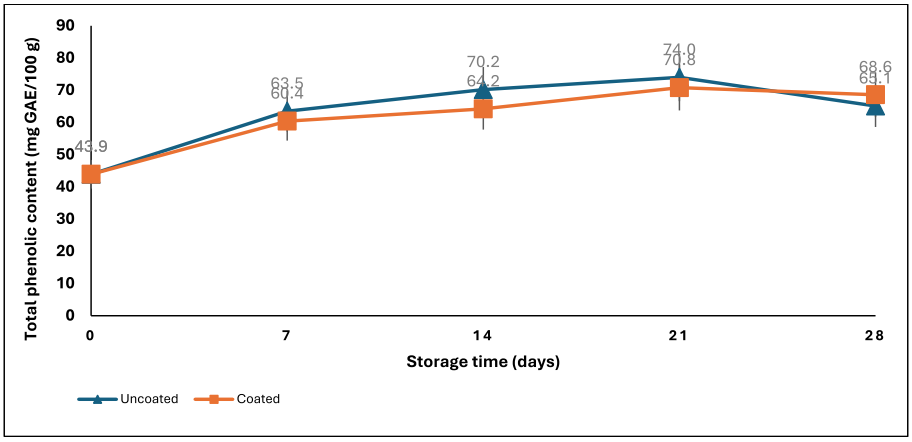


**Fig. 7.** Total phenolic content of coated and uncoated tomatoes during storage.

comparable to the values obtained at 0 day of the experiment. The coated tomatoes presented a higher total phenolic content of 68.6 mg GAE/100 g fresh weight after storage when compared to the uncoated tomatoes with 65.1 mg GAE/100 g fresh weight. There was a significant ($P \leq 0.05$) difference in the rate of accumulation of total phenolic content of the uncoated and coated tomatoes during storage at the ambient conditions for 28 days. The TPC varied from 43.7 to 74.0 mg GAE/100 g and from 43.7 to 70.8 mg GAE/100 g for the uncoated and coated tomatoes, respectively. The coating of the green mature tomatoes with TP/TPF/MLE ameliorated abiotic stress and ultimately supported biochemical activities responsible for the retention of phenolic compounds during senescence.

The phenolic compounds are the major bioactive components of the tomato pulp. The total phenolic compound represents part of the hydrophilic portion of antioxidants found in tomatoes. It is a secondary metabolite in tomatoes vested with the responsibility to protect the tissues from oxidative stress. Postharvest biotic stress occasioned by handling, distribution, and storage of fresh tomatoes could lead to increased biotic stress with attendant increased biochemical reactions. This increase in reactions leads to the accumulation of phenolic compounds, in bits to protect the tissues from radicals. A buildup of phenolic compounds and ascorbic acid has been linked to the use of edible coatings on fresh fruit, increasing the fruit's antioxidant capability (Frusciante et al., 2007). Phenylalanine ammonia-lyase (PAL) activity, which is triggered during stressful circumstances, may facilitate the buildup of phenolic chemicals.

### 3.8. Effects of edible coatings on the ascorbic acid contents of tomatoes

The changes in ascorbic content of the tomatoes treated with TP/TPF/MLE edible coatings vis-à-vis the uncoated samples are presented in Fig. 8. The ascorbic contents of the coated and uncoated tomatoes ranged from 5.2 mg/100 g to 16.6 mg/100 g. Both TP/TPF/MLE coated and uncoated tomatoes showed a progressive increase in ascorbic acid contents of the samples until the 14th day for uncoated and the 21st day for coated storage and declined as senescence progressed. The climax of the ascorbic acid content of the tomatoes coincided with the peak of ripening. Notably, at the peak of ripening, respiration in climacteric fruits occurs with a resultant increase in biochemical reactions and generation of organic acids such as ascorbic acids (Toor & Savage, 2006). The comparison of the results obtained for coated and uncoated samples showed a significant difference ($P \leq 0.05$). Specifically, the coated samples showed the highest values for ascorbic acid at the end of the storage period. The coated samples had 14.6 mg/100 g, while uncoated tomatoes had 11.4 mg/100 g after 21 days of storage.

From the point of view of nutrition, ascorbic acid is one of the most important nutrients in tomatoes. Notably, ascorbic acid is extremely sensitive to physiological stress and can easily be lost during processing. The nutraceutical properties of tomato and tomato products are majorly attributable to the presence of bioactive components such as ascorbic

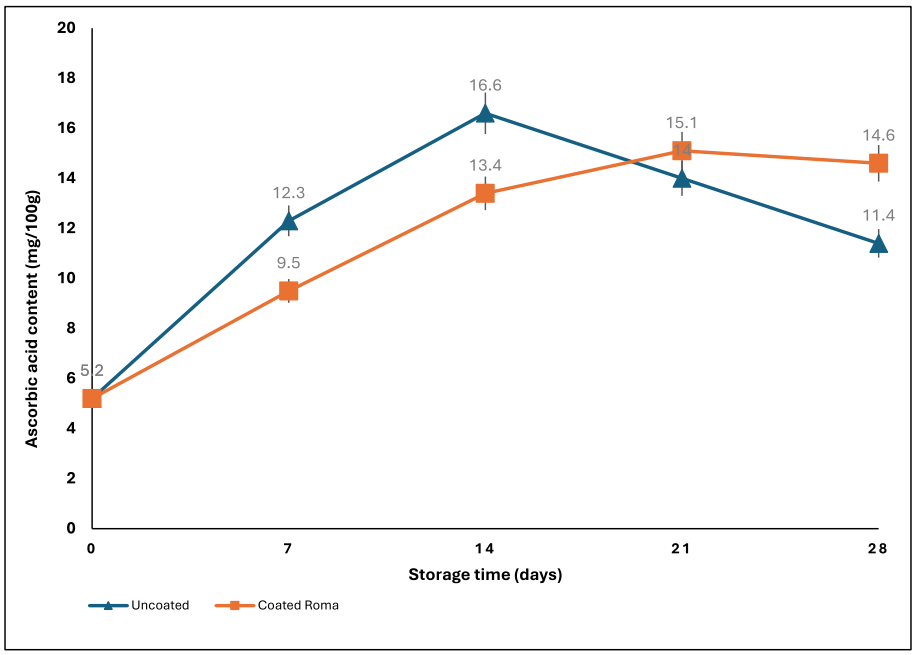


**Fig. 8.** Ascorbic acid content of coated and uncoated tomatoes during storage.

acid. The ascorbic acid content of tomatoes increases as ripening progresses and drops with incipient senescence. This is because the fruit undergoes physiological changes and metabolic processes that contribute to the accumulation of vitamin C (Yadav et al., 2022). The peak concentration of ascorbic acid is observed at optimal ripeness. Beyond this point the concentration declines as a result of enzymatic and biochemical changes that lead to the breakdown and degradation of vitamin C (Hou et al., 2020). The trend observed from the study is comparable to values reported by Zewdie et al. (2022), in which combinations of neem leaf dipping and bee wax coating significantly improved the retention of ascorbic acid. Coated samples had higher ascorbic acid content over a period of 28 days of storage at ambient conditions, comparable to uncoated samples.

### *3.9. Effects of edible coatings on the DPPH antioxidant activity of tomatoes*

The effects of TP/TPF/MLE edible coatings on the DPPH radical scavenging activities of the treated tomatoes compared to the uncoated counterparts are shown graphically in Fig. 9. The changes in the DPPH radical scavenging activities of the coated and uncoated tomatoes were significantly ($p \leq 0.05$) different. The DPPH of coated tomato samples increased from 47.6 % to 87.2 % on the 21st day and dropped to 82.2 % on the 28th day of ambient storage. On the other hand, the DPPH antioxidant activity of the uncoated sample increased from 47.6 % to 84.3 % in 14 days and dropped to 73.1 % on the 28th day.

Tomatoes are rich in antioxidant activity and contribute immensely to their nutrient values. The phytochemicals responsible for the antioxidant activities of tomatoes include but are not limited to lycopene, flavonoids, ß-carotenoids, phenolic compounds, and ascorbic acid. Therefore, the changes in the concentration of the bioactive substances

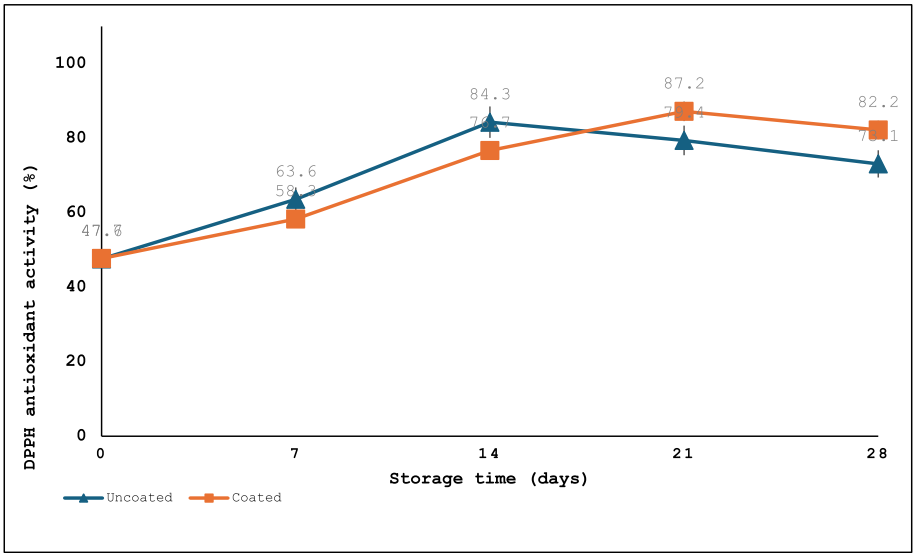


**Fig. 9.** DPPH radical scavenging power of coated and uncoated tomatoes during storage.

result commensurate to the changes in the antioxidant activity of the tomato. Many studies reported an upward trend for antioxidant activity from mature to red ripe stages of maturity. However, a downward trend is noticed at the late stages of ripeness, leading to senescence (Nour et al., 2014). These have been attributed to degradative activities that accompany aging and senescence. The finding from this study underscores this pattern and is in line with a report published by Iqba et al. (2022), who reported an increase in radical scavenging activities from 37.5 to 43.6 % of tomatoes from green to red maturity levels. In another research, tomatoes coated with 50 % corn flour and 50 % pectin maintained a higher concentration of antioxidant activity of 35 μMTE 100 g-$^{1}$, compared with uncoated samples at 20 MTE 100 g$^{-1}$ (Sucheta et al., 2019). Dávila-Aviña et al. (2014) observed significantly different trends for breaker and light tomatoes coated with mineral oil wax and camauba wax over a storage of 28 days at 10 °C. The average DPPH (%RSA) for breaker tomatoes were 48.5, 36.8, and 46.0 %, respectively for control (uncoated), mineral oil wax, and camauba wax coated tomatoes. The light tomato samples had DPPH of 48.9, 49.4, and 38.8 % in the same pattern.

### 3.10. Effects of edible coatings on the lycopene contents of tomatoes

Fig. 10 shows the effects of the TP/TPF/MLE edible coatings on the changes in the lycopene content of green mature tomatoes evaluated over a storage period of 28 days at ambient conditions. From the figure, there was a significant difference ($p \leq 0.05$) in the changes in the concentration of lycopene in the TP/TPF/MLE coated and uncoated tomatoes. The lycopene contents of the uncoated and coated tomatoes spanned between 0.4 mg/100 g and 3.5 mg/100 g fresh weight. The accumulation of lycopene in uncoated commenced from 0.4 mg/100 g and peaked at 3.5 mg/100 g during storage. On the other hand, tomatoes coated with TP/TPF/MLE film-forming solution show a similar trend but slower than the controlled samples. The lycopene content of the coated tomatoes increased from 0.35 mg/100 g to 3.0 mg/100 g FW at 28 days, which is lower than the values obtained for the controlled counterpart. So, the edible coatings effectively slowed the chlorophyll degradation and accumulation of lycopene content of the treated tomatoes.

The change in colour is correlated to the lycopene content of tomatoes. Significant increases in the concentration of lycopene have been observed from the full-grown greenish phase to the reddish phase in tomatoes (Kumar et al., 2023). The activities that promote ripening in tomatoes impact positively on lycopene accumulation. In addition to the role of lycopene in colour development, it contributes to the overall radical scavenging power of tomatoes. The range of values obtained is within the results reported by Raza et al. (2022). According to their study, the range obtained for lycopene content of ninety-three geographically diverse tomatoes was between 1.74 and 7.96 mg/100 g FW. On the effects of edible coatings on the lycopene content of tomatoes, Bernardino-Nicanor et al. (2018) reported that the lycopene concentration of the tomatoes that had not been coated was 20 % and 6 % greater than that of the tomatoes that had been coated with mucilage made from the parenchyma and the chlorenchyma after 21 days of storage at 20 °C. The same pattern was reported by Safari et al. (2021), in which uncoated tomatoes exhibited significantly higher content of lycopene than samples coated with chitosan and vanillin after a storage period of 25 days at 28 ± 2 °C and 60 ± 5 % relative humidity.

### 3.11. Effects of edible coatings on the respiration rate of tomatoes

The effects of TP/TPF/MLE edible coatings on the respiration rate of the green mature tomatoes vis-à-vis the uncoated samples stored at ambient conditions for 28 days are presented in Fig. 11. The respiration rate of the coated and uncoated tomatoes ranged from 3.2 mL $CO_2$ kg$^{-1}$ h$^{-1}$ to 7.3 mL $CO_2$ kg$^{-1}$ h$^{-1}$. Notably, the rates of respiration of coated and uncoated samples are significantly ($p \leq 0.05$) different, as a slower rate of respiration and climacteric peak were observed for the coated samples. For the uncoated samples, the respiration peak was 10.7 mL $CO_2$ kg$^{-1}$ h$^{-1}$, while the TP/TPF/MLE coated samples had a peak at 4 mL $CO_2$ kg$^{-1}$ h$^{-1}$. The respiration rate of the tomatoes coated with TP/TPF/MLE film-forming solution was retarded comparable to the uncoated controlled samples. In addition to a slower rate of respiration, the climacteric peak of the coated tomatoes was significantly lower, with an evident slow pace of ripening.

Like every living thing, freshly harvested tomatoes respire. Respiration in fresh commodities is crucial to ensure the provision of energy needed to maintain and promote the metabolic process of the cells of the tomatoes, which occurs in the cytoplasm and mitochondrion of cells. Respiration involves oxidative catabolism of carbohydrates into the water and carbon dioxide, with the liberation of adenosine triphosphate, an energy source, and heat. Adenosine triphosphate is the energy currency of living cells including fresh commodities, which is responsible for the activation of many biochemical reactions within the cells. The findings from this study compared well with the range of values obtained by Ruelas-Chacon et al. (2017). According to their study, in comparison to the uncoated Roma variety, the coated tomatoes generated the lowest $CO_2$ (2.8 mL/kg/h vs. 10.7 mL/kg/h), suggesting that coating may have changed the interior environment and slowed the rate of respiration of roma tomato variety. In another research by Paul et al.

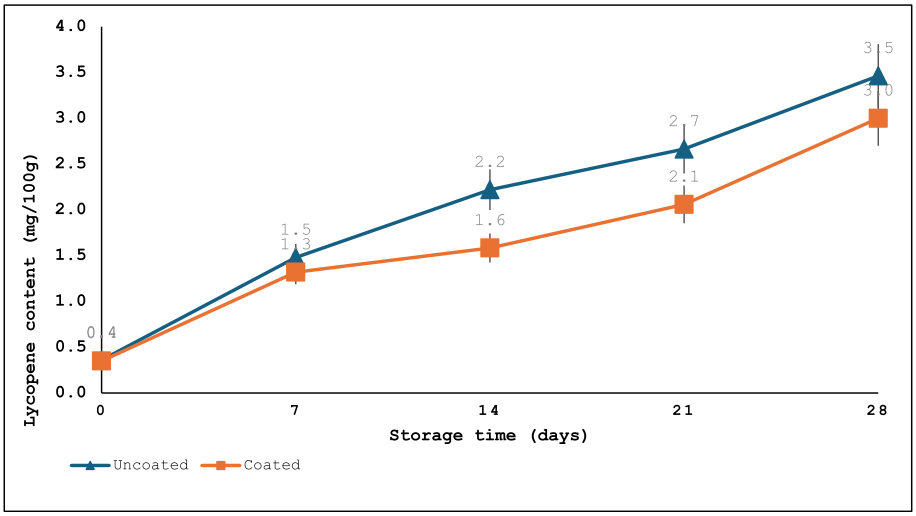


**Fig. 10.** Lycopene content of coated and uncoated tomatoes during storage.

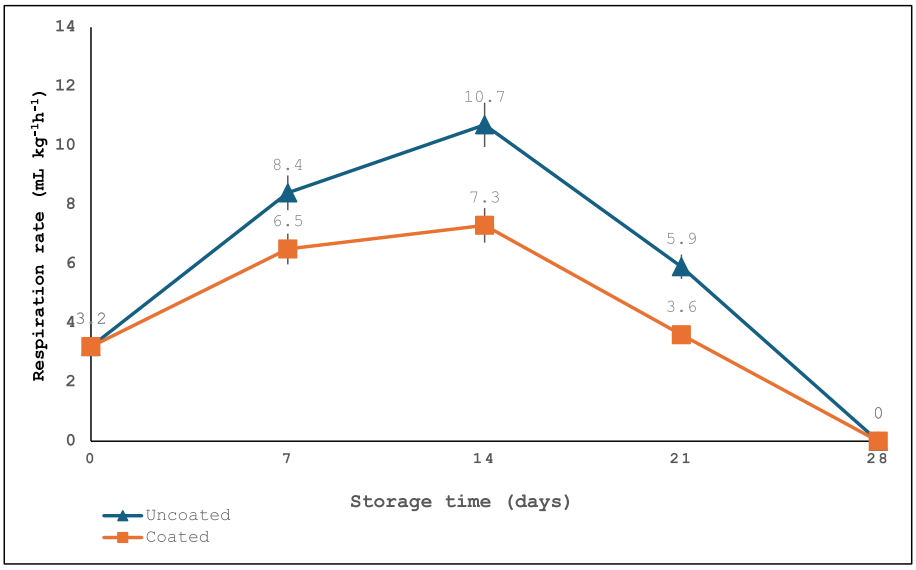


**Fig. 11.** Respiration rate of coated and uncoated tomatoes during storage.

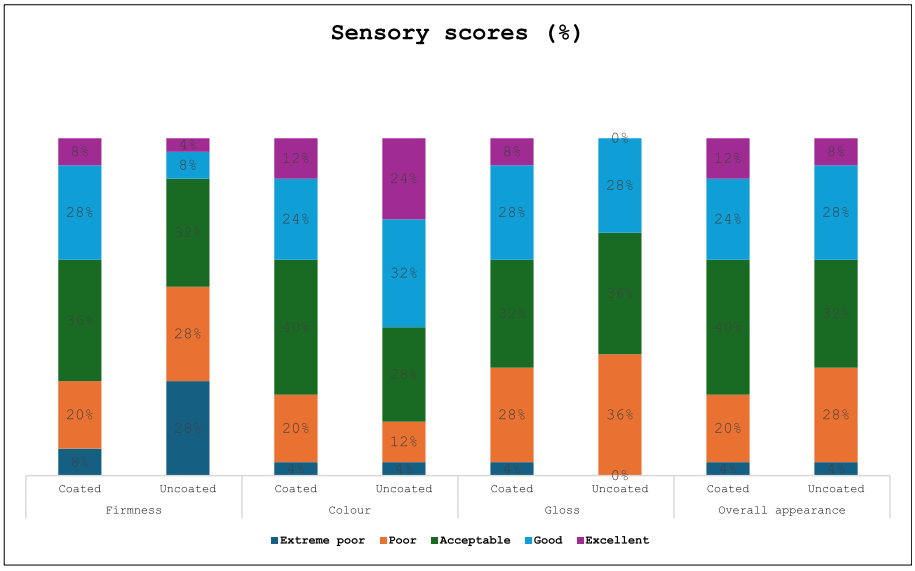


**Fig. 12.** Sensory scores for firmness, colour, gloss, and overall appearance of coated and uncoated tomatoes.

(2018), tomatoes coated with a high concentration of chitosan and a low concentration of glycerol significantly caused a decrease in respiration rate. In a similar study, Won et al. (2018) reported a slower respiration rate for tomatoes coated with grape seed extract laced with chitosan and stored at 25 °C for 15 days.

### 3.12. Sensory scores for coated and uncoated tomatoes

The sensory score for firmness, colour, gloss, and overall appearance is presented in Fig. 12. It shows the descriptive scale adopted for the sensory evaluation. The coated samples had a significantly higher score for the "excellent" category for firmness at 8 %, compared to uncoated samples at 4 %. Overall, the firmness cumulative scores for points 5 (acceptable), 7 (good), and 9 (excellent) for coated and uncoated samples were 72 % and 44 %, respectively. Edible coatings from tomato puree, peel, and moringa leaf extract significantly maintained the firmness of the coated samples, unlike uncoated samples. For colour, uncoated tomato samples had a higher score (24 %) for "excellent" compared to coated samples which had 12 % in that category. Also, cumulative colour scores for points (acceptable) and above were 76 % and 84 % for coated and uncoated tomatoes, respectively. Observably, uncoated tomatoes had a more pronounced reddish colour development than their coated counterparts. This could be because of the faster biochemical reactions (respiration and ethylene production) witnessed for uncoated samples, as ethylene production enhances colour development during ripening. For gloss, there was a significant difference between coated and uncoated tomatoes. The coated tomatoes had a 4 % score for the "excellent" point, while uncoated tomatoes had 0 %. The cumulative sum of scores for "acceptable" and above was 68 % and 64 % for coated and uncoated tomatoes, respectively. The higher score on the "acceptable" and above category could be a result of the impact of moringa leaf extract, which conferred an oily appearance to coated tomatoes and thereby enhanced shininess. The overall appearance of coated and uncoated tomatoes was significantly different. While coated tomatoes had a score of 12 % for the "excellent" category, the uncoated sample was judged by the panellists to be 8 %. Also, the scores for "acceptable" and above category for coated and uncoated tomatoes were 76 % and 68 %, respectively. The higher overall appearance of coated

tomatoes could be a result of better scores on firmness, and gloss. The findings are comparable with the assertion from other studies which posited that edible coating enhances gloss, firmness, and overall appearance of tomatoes. The incorporation of essential oils significantly improves gloss and enhances overall appearance (Peralta-Ruiz et al., 2020; Vignesh & Nair, 2019).

## 4. Conclusion

The coating solution significantly decelerated the rate of biochemical-mediated degradation in fresh tomatoes, retarding senescence and the attendant quality loss. The coated tomatoes had lower weight loss, high firmness, total colour change, pH, TSS, and respiration peak. Also, titrable acidity production was lower for the coated samples, total phenolic content, total flavonoid content, ascorbic acid content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, lycopene, and ß-carotene were better preserved. Mature ripe tomatoes coated with the developed edible films had acceptable sensory properties after a storage period of 28 days. The bioactive coating significantly preserved the qualities of fresh tomatoes for 28 days at ambient storage. The coated tomatoes had a significantly higher overall appearance than an uncoated sample.

While these findings are promising, challenges remain in the field of edible coatings. Developing coatings that are both effective and cost-efficient for large-scale applications is crucial. Furthermore, consumer acceptance of coated produce can be influenced by factors such as appearance, texture, and perceived "naturalness." Future research should focus on optimizing coating formulations to address these challenges. Exploring novel biopolymers, incorporating natural antimicrobial agents, and refining application techniques are key areas for investigation. Additionally, studies assessing the long-term stability and efficacy of coatings under various storage conditions are needed. By addressing these challenges, edible coatings can play a significant role in reducing postharvest losses, extending the shelf life of tomatoes, and ensuring the availability of high-quality produce for consumers. Further studies should also evaluate the long-term stability of coated tomatoes under different storage conditions, including cold storage and modified atmosphere packaging.

## Consent to publish declaration

Not applicable.

## CRediT authorship contribution statement

**Uchenna Emmanuel Umeohia:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Abiodun Adekunle Olapade:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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