Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Cassava Starch and Tea Extract Edible Coating Delays Postharvest Quality Loss of Tomato Fruit Under Ambient Storage in Rwanda

Jerome Hagenimana
INES-Ruhengeri
Gisubizo Fabien
gisubizofabien@gmail.com

Catholic university of Rwanda
Jean Claude Dusabumuremyi
INES-Ruhengeri
Marc Antoine Ndisanze
INES-Ruhengeri
Elias Kubwimana
IPRC musanze
Christine Mukantwali
Food and Agriculture Organization of the United Nations (FAO)–Rwanda,
Bahizi Marcel
Kigali Independent University

Research Article

Keywords: Edible coating, Postharvest loss, Cassava starch, Tea extract, Smallholder farmers, Food security

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11349775/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Tomato (*Solanum lycopersicum* L.) is highly perishable, and postharvest losses threaten food security and smallholder income in Rwanda, where refrigeration and plastic packaging are largely inaccessible. This study evaluated a low-cost cassava starch–glycerol coating containing aqueous tea extract for preserving tomato under ambient storage.

Methods

Coatings contained 3–5% (w/v) gelatinised cassava starch, 1–2% (v/v) glycerol and 0.5% (T1) or 1.0% (T2) (w/v) dried tea extract. Uncoated (T0) and dip-coated tomatoes (three replicate lots per treatment) were stored at 25 ± 2°C and 65–85% relative humidity for 21 days. Weight loss, moisture content, vitamin C, titratable acidity, crude fibre, total soluble solids, visual deterioration and sensory attributes were assessed on days 1, 7, 14 and 21 and analysed by two-way ANOVA or non-parametric tests.

Results

Both coatings reduced weight loss at every sampling day ($p < 0.001$); on day 21, weight loss was 15.94% in T0, 10.72% in T1 and 7.26% in T2. T2 fruit also retained more vitamin C (12.0 vs 6.47 mg/100 g), titratable acidity (0.43 vs 0.36%) and crude fibre (1.23 vs 1.00%) than T0, and less visual deterioration (2.5 vs 4.0). Uncoated fruit became sensorially unacceptable after about 15 days, whereas both coated treatments remained acceptable at day 21.

Conclusions

The coating delayed tomato quality loss without refrigeration, with the 1.0% tea-extract formulation performing best. Because no starch-only coating was tested, the specific role of the tea extract remains to be confirmed. Made from locally available, biodegradable materials, the coating is a promising postharvest option for smallholder farmers and traders.

1 Introduction

Postharvest food loss is one of the most persistent and least visible threats to global food security[1]. Unlike production shortfalls, which attract policy attention because they are measured at the farm gate, postharvest losses occur silently across handling, transport, storage and marketing, and disproportionately affect smallholder farmers and traders in low- and middle-income countries who lack access to cold-chain infrastructure. Fruits and vegetables are especially exposed because, unlike cereals and pulses, they cannot be stored dry and remain physiologically active – respiring, transpiring and

ripening – long after harvest. Tomato (Solanum lycopersicum L.) exemplifies this vulnerability: it is among the most widely produced and consumed vegetables worldwide, contributing substantially to household nutrition and rural income, yet it is also among the most perishable, with postharvest losses across Sub-Saharan African value chains driven by a combination of transport, storage, handling and market factors [2, 3]. In Rwanda specifically, poor handling practices, inadequate packaging and the near-total absence of affordable storage technologies remain principal drivers of loss between the farm and the final consumer, a pattern echoed across the wider East African region. Field assessments in Rwanda estimated cumulative tomato losses between harvest and the retail market at 50–60% [3].

The physiological basis of this vulnerability lies in tomato's biology. As a climacteric fruit, tomato continues to ripen after harvest through a coordinated burst of respiration and autocatalytic ethylene production that activates cell-wall-degrading enzymes such as polygalacturonase, pectin methylesterase and cellulase, driving the softening, colour change and eventual senescence that make the fruit unmarketable [4]. Concurrently, its high water content (often exceeding 90%) and thin, delicate skin make it highly susceptible to transpirational water loss, while wounds and cracks created during harvesting and handling provide easy entry points for spoilage fungi and yeasts. Ascorbic acid (vitamin C) and other nutritionally important compounds degrade progressively during this process through oxidation and enzymatic activity, meaning that postharvest losses are not only volumetric but also nutritional, reducing the value of the food that does reach the consumer even when it is not discarded outright [5, 6].

Conventional strategies for slowing this deterioration – mechanical refrigeration, controlled-atmosphere storage, synthetic plastic wraps and chemical fungicides or preservatives – are all effective under the right conditions, but each carries costs or risks that limit its usefulness in the settings where postharvest losses are highest. Refrigerated storage and transport require capital investment and a reliable electricity supply that many rural value chains in Sub-Saharan Africa simply do not have; synthetic plastics raise growing environmental and, increasingly, regulatory concerns because of their non-biodegradability; and chemical preservatives raise food-safety questions and consumer resistance. Studies of fruit and vegetable value chains in Eastern Africa, and field trials in Rwanda, nevertheless show that simple, low-cost practices – correct harvest maturity, reusable crates and non-electric evaporative cooling – can substantially reduce tomato losses, underlining the need for affordable technologies that smallholders can apply themselves [7, 8].

Edible coatings have emerged as one of the most promising responses to this call. An edible coating is a thin, continuous layer of biopolymer applied directly to the surface of a fresh commodity to form a semi-permeable barrier that restricts the exchange of oxygen, carbon dioxide, water vapour and volatile compounds between the fruit and its environment, thereby slowing respiration, delaying ripening and reducing moisture loss, while remaining safe to consume together with the food itself [9, 10]. Because the coating is applied as a liquid and dries in place, it requires no specialised machinery, cold storage or packaging infrastructure, making it inherently well suited to smallholder and informal-market contexts. Reviews of protein- and polysaccharide-based coatings further show that their protective performance is substantially enhanced when natural antimicrobial or antioxidant compounds – essential oils, plant

extracts or purified polyphenols – are incorporated directly into the film-forming matrix, turning a purely physical barrier into an “active” packaging system that also intervenes biochemically in the fruit’s own senescence pathways [11, 12].

Among the biopolymers available for such coatings, starch is particularly attractive for African food systems because it is abundant, inexpensive, non-toxic, and renewable, and forms transparent, largely tasteless films with a naturally high oxygen-barrier capacity once gelatinised and plasticized [13, 14]. Cassava (Manihot esculenta), in particular, is cultivated across most of Sub-Saharan Africa, including Rwanda, and its starch – rich in amylose and amylopectin – has been used successfully as a base polymer for biodegradable packaging films and fruit coatings [15, 16]. However, native starch films are hydrophilic, mechanically brittle and offer little intrinsic antimicrobial or antioxidant activity, which is why plasticisers such as glycerol are routinely added to improve flexibility, and why researchers increasingly combine starch matrices with polyphenol-rich plant extracts to supply the antimicrobial and antioxidant functionality that starch alone cannot provide [11, 12].

Tea (Camellia sinensis) leaves are a particularly attractive source of such polyphenols. Tea is rich in catechins, theaflavins, tannins and other phenolic compounds with well-documented free-radical-scavenging, antioxidant and antimicrobial properties, and tea polyphenols have repeatedly been shown to improve the barrier, antioxidant and antibacterial performance of starch-, chitosan- and biopolyester-based active packaging films across a range of food applications[17, 18]. Because dried tea is inexpensive, widely traded and simple to extract with hot water, it offers a functional additive that is realistically accessible to smallholder producers and small agro-processors, in contrast to purified essential oils or synthetic antioxidants that require industrial processing or importation.

Despite the individual promise of both materials, and despite the wide local availability of cassava and tea in Rwanda, little published research has combined the two into a single edible coating formulation and tested its performance on a major perishable crop such as tomato under realistic ambient, non-refrigerated tropical storage conditions – the conditions under which most Rwandan tomatoes are actually handled and sold. This study addresses that gap. Specifically, the objectives of this work were: (i) to formulate an edible coating from locally available, biodegradable materials – cassava starch, glycerol and aqueous tea extract – at two tea-extract levels; (ii) to evaluate its effect on the physicochemical quality (weight loss, moisture content, vitamin C, titratable acidity, crude fibre, total soluble solids and visual deterioration) of tomato fruit stored at ambient temperature for 21 days; and (iii) to assess its effect on the sensory acceptability of the coated fruit relative to an uncoated control. In doing so, the study provides preliminary evidence on whether a cassava starch–tea extract coating could serve as a low-cost option for reducing tomato postharvest losses in Rwanda and similar cold-chain-limited settings.

2 Materials and Methods

2.1 Study Area and Plant Materials

The study was conducted in the Department of Biotechnology laboratories of INES-Ruhengeri, Musanze District, Northern Province, Rwanda, between March and July 2026. Fresh tomato fruit of a locally grown cultivar, harvested at the red-ripe maturity stage, uniform in size and colour and free of mechanical damage, disease and insect infestation, were purchased from a local market in Musanze District on the day of harvest. Fruit were washed with potable water, sanitised by immersion in 0.1% (v/v) sodium hypochlorite for 3 min, rinsed with distilled water and air-dried at room temperature. Fresh cassava (*Manihot esculenta* Crantz; local variety) roots were obtained from Musanze District, and dried green tea (*Camellia sinensis*) leaves were purchased directly from tea farms in Nyabihu District, Rwanda.

2.2 Extraction of Cassava Starch

Cassava roots were washed, peeled, grated and mixed with clean water to release starch granules from the fibrous pulp. The slurry was filtered through muslin cloth, and the filtrate was allowed to sediment for 4–6 hours; the supernatant was decanted, and the sedimentation was repeated two to three times to purify the starch. The washed starch cake was dried in a hot-air oven at 40–50°C to constant weight, ground and sieved to obtain a fine, food-grade cassava starch powder, which was stored in an airtight container until use. Starch yield was 12 g dry starch per 100 g fresh peeled roots and its moisture content was 12% (Section 2.5). Purity and physicochemical properties of the starch (amylose content, swelling power, pasting behaviour) were not determined; these properties vary with cassava genotype and extraction conditions and can influence film formation [38, 39].

2.3 Preparation of Tea Extract

Dried green tea leaves were ground and sieved to a particle size of 250–425 µm. Ten grams of ground tea were extracted in 100 mL distilled water (1:10, w/v) at 70–80°C for 15 min with gentle stirring. The extract was cooled, filtered through muslin cloth and then Whatman No. 1 filter paper, and the filtrate was dried in a hot-air oven at 40–50°C to constant weight to obtain a dry tea-extract powder. The extraction yield was 8 g of dry extract per 100 g of tea leaves (8%, w/w). The powder was stored in an airtight amber container at room temperature and was dissolved directly in the coating solution at the time of formulation (Section 2.4), so that the tea-extract concentrations are expressed as g dry extract per 100 mL coating solution (% w/v). Total phenolic content and individual catechins of the extract were not quantified; its phenolic composition is therefore inferred from the literature on *Camellia sinensis* [34] and is not used as a measured variable in this study.

2.4 Coating Formulation and Application

Coating solutions were prepared by dispersing cassava starch at 3–5% (w/v) in distilled water and heating at 70–80°C with continuous stirring until gelatinisation (a translucent, viscous dispersion). The dispersion was cooled to about 40°C, food-grade glycerol was added at 1–2% (v/v) as a plasticiser, and the dry tea extract was dissolved at 0.5 or 1.0 g per 100 mL of coating solution (0.5% and 1.0%, w/v). The starch and glycerol levels lie within the ranges commonly used for starch-based fruit coatings [27, 32] and were selected because starch at 3–5% (w/v) gives a gelatinised dispersion that is fluid enough to be applied by dipping yet forms a continuous, transparent film on drying, and glycerol at 1–2% (v/v) is

needed to keep the otherwise rigid starch film from cracking [27]. The two tea-extract levels (0.5% and 1.0%, w/v) were chosen because they fall within the 0.5–2% range considered in the design of this study, allow a first assessment of a dose response, and keep the quantity of extract, and therefore the cost, low. The composition of each treatment is given in Table 1.

The experiment followed a completely randomised design with three treatments (Table 1): T0, uncoated control; T1, starch–glycerol coating containing 0.5% tea extract; and T2, starch–glycerol coating containing 1.0% tea extract. Each treatment comprised three independent replicate lots (biological replicates) of fruit (nine lots in total); fruits were allocated at random to treatments and replicate lots. At each sampling day, fruits from each lot were taken for destructive analyses, while weight loss was recorded on tagged fruits of each lot that were weighed repeatedly (the same fruits were reweighed at each interval). Coated fruits were immersed in the respective coating solution for 2 min, drained and air-dried at room temperature; control fruits were left uncoated and were not dipped. All fruits were stored on open trays at 25 ± 2°C and 65–85% relative humidity for 21 days; temperature and relative humidity were recorded throughout the storage period with a digital thermometer and hygrometer. A starch–glycerol coating without tea extract was not included (see Section 3.9).

Table 1
Composition of the coating treatments

Treatment	Cassava starch (% w/v)	Glycerol (% v/v)	Tea extract, dry (% w/v)	Description
T0	–	–	–	Uncoated control
T1	3–5	1–2	0.5	Starch–glycerol coating + 0.5% tea extract
T2	3–5	1–2	1.0	Starch–glycerol coating + 1.0% tea extract

2.5 Physicochemical Analyses

Weight loss, moisture content, vitamin C, titratable acidity, crude fibre, total soluble solids and visual deterioration were assessed on days 1, 7, 14 and 21 of storage. Each replicate lot was analysed separately, and each analytical determination was performed in replicate; the mean of the analytical replicates was taken as the value for that lot (n = 3 biological replicates per treatment and day).

Weight loss was determined gravimetrically as the percentage difference between the initial and current weight of each sample (the same tagged fruits, weighed on a digital balance with 0.01 g resolution) using Eq. 1:

Weight loss (%) = [(Initial weight − Weight on sampling day) / Initial weight] × 100 (1)

Moisture content was determined by the oven-drying method [40]: approximately 5 g of homogenised tomato pulp (W_1) was dried at 105°C to constant weight, cooled in a desiccator and reweighed (W_2).

Moisture content was expressed on a wet (fresh-weight) basis as the mass lost on drying relative to the initial sample mass, using Eq. 2:

Moisture content (%, wet basis) = $[(W_1 - W_2) / W_1] \times 100$ (2)

Visual deterioration was scored on a 1–4 descriptive scale developed for this study: 1 = sound fruit, no visible defects; 2 = slight shrivelling or loss of gloss; 3 = moderate wrinkling, discolouration or softening; 4 = severe wrinkling or softening and/or visible mould growth. Because the scale combines dehydration-related and decay-related symptoms, it is reported as a composite index of visual deterioration and not as a measure of microbial decay. Each fruit was scored independently by the 10 semi-trained panellists described in Section 2.6, and scores were averaged per replicate lot. Total soluble solids (°Brix) were measured on filtered juice with a digital refractometer calibrated with distilled water [40]. Vitamin C was determined by 2,6-dichlorophenolindophenol (DCPIP) titration [40]: a known weight of homogenised pulp was blended with 3% (w/v) oxalic acid and filtered, and a measured aliquot of the filtrate was titrated with DCPIP solution, standardised daily against an ascorbic acid standard (1 mg/mL), to a faint pink end point persisting for 15 s; results were expressed as mg ascorbic acid per 100 g fresh weight. Titratable acidity was determined by titrating a measured volume of filtered juice (diluted with distilled water) with standardised 0.1 N NaOH to the phenolphthalein end point (persistent faint pink, pH ≈ 8.2) [40], and was expressed as % citric acid using Eq. 3:

TTA (% citric acid) = (V × N × E × 100) / W (3)

where V is the volume of NaOH used (mL), N is the normality of NaOH, E is the milliequivalent weight of citric acid (0.064 g/meq), and W is the volume (mL) or weight (g) of the tomato sample titrated. Crude fibre was determined by the acid–alkali digestion method (AOAC 962.09) [40]: a weighed sample was boiled successively in 1.25% H_2SO_4 and 1.25% NaOH for 30 min each, filtered, washed, dried at 105°C, weighed, ashed at 550°C and reweighed; crude fibre was calculated from the loss in mass on ignition and expressed as % of fresh weight.

2.6 Sensory Evaluation

Sensory quality (colour, appearance, texture and overall acceptability) was evaluated on days 1, 7, 14 and 21 by a panel of 10 semi-trained panellists (4 women and 6 men, aged 20–30 years) recruited from staff and students of INES-Ruhengeri. Panellists were regular tomato consumers with no reported food allergies and received an orientation session on the attributes and on the 5-point hedonic scale (1 = dislike very much; 5 = like very much) before the study [31]. Evaluations were carried out in the laboratory at room temperature. At each session, panellists assessed whole intact fruit (texture was judged by gently pressing the fruit with the fingers) from the three treatments, coded with random three-digit numbers and presented in randomised order; water was provided for rinsing between samples. Written informed consent was obtained from all panellists before participation.

2.7 Statistical Analysis

The experimental unit was the replicate lot of fruit (n = 3 biological replicates per treatment); analytical replicates were averaged within each lot and were not treated as independent observations. Physicochemical data are expressed as mean ± standard deviation and were analysed by two-way ANOVA with treatment, storage day and their interaction as fixed factors, after checking normality of residuals (Shapiro–Wilk test) and homogeneity of variances (Levene's test). Where the interaction was significant, treatments were compared within each storage day, and storage days within each treatment, by Tukey's HSD test. Weight loss on day 1 (zero by definition) was excluded from the analysis. Sensory scores, which are ordinal and were given by the same panellists to all treatments, were analysed within each storage day by the Friedman test followed by Wilcoxon signed-rank tests with Bonferroni correction. Differences were considered significant at $p < 0.05$. Analyses were performed with IBM SPSS Statistics (IBM Corp., Armonk, NY, USA).

3 Results and Discussion

3.1 Effect of Coating on Weight Loss

Weight loss of the three treatments over 21 days of storage is shown in Table 2 and Fig. 1a.

Table 2
Percentage weight loss of uncoated and cassava starch–tea extract coated tomato fruit during storage at 25 ± 2°C (mean ± SD, n = 3 replicate lots)

Storage day	T0 (uncoated)	T1 (0.5% TE)	T2 (1.0% TE)
Day 1	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Day 7	4.82 ± 0.35^{aC}	3.10 ± 0.28^{bC}	2.15 ± 0.21^{cC}
Day 14	9.67 ± 0.52^{aB}	6.45 ± 0.41^{bB}	4.38 ± 0.33^{cB}
Day 21	15.94 ± 0.68^{aA}	10.72 ± 0.55^{bA}	7.26 ± 0.44^{cA}

T0, uncoated control; T1 and T2, cassava starch–glycerol coating containing 0.5% and 1.0% (w/v) tea extract (TE), respectively (Table 1). Values are mean ± SD of three replicate lots. Within a storage day, means with different lowercase letters differ significantly between treatments; within a treatment, means with different uppercase letters differ significantly between storage days (Tukey's HSD, $p < 0.05$). Day 1 is the reference weighing and was excluded from the ANOVA. Two-way ANOVA: treatment, $F(2, 18) = 361.6$, $p < 0.001$; storage day, $F(2, 18) = 734.8$, $p < 0.001$; treatment × day, $F(4, 18) = 35.3$, $p < 0.001$.

Weight loss increased with storage time in all treatments, but both coatings reduced it significantly at every sampling day, and the significant treatment × day interaction shows that the differences widened during storage (Table 2). By day 21, weight loss was 15.94% in T0, 10.72% in T1 and 7.26% in T2, i.e. 33% and 54% lower than in the uncoated control. Postharvest weight loss of tomato is due mainly to transpiration and, to a lesser extent, to respiratory loss of carbon, and a continuous starch–glycerol film

on the fruit surface is expected to add a resistance to water-vapour diffusion, as reported for starch-based coatings on climacteric fruit [21, 27, 32]. Because T1 and T2 contained the same starch and glycerol concentrations and differed only in tea-extract level, the lower weight loss of T2 indicates that the extract altered the performance of the film. One possible explanation is that phenolic compounds form hydrogen bonds with starch hydroxyl groups and reduce the free volume of the film matrix [12, 19]; however, film thickness, water-vapour permeability and phenolic–starch interactions were not measured, so this remains a hypothesis. The size of the difference between T1 and T2 should be confirmed in a trial that includes a starch–glycerol coating without tea extract.

3.2 Effect of Coating on Vitamin C Retention

All treatments started storage with similar vitamin C contents (22.47–22.53 mg/100 g fresh weight). Vitamin C declined in all treatments, as expected from the oxidative degradation of ascorbic acid in stored tomato [5]. By day 21 it had fallen to 6.47 mg/100 g in T0, 8.50 mg/100 g in T1 and 12.00 mg/100 g in T2 (Table 3; Fig. 1b), so that T2 retained about 53% of its initial vitamin C compared with about 29% in the control. Two factors may have contributed: the coating can reduce oxygen availability at the fruit surface, and tea phenolics act as radical scavengers when incorporated into films [19, 20]. Because neither the oxygen permeability of the coating nor the antioxidant activity of the fruit was measured, these explanations are tentative.

Table 3
Physicochemical attributes of tomato fruit at the start (day 1) and end (day 21) of storage at 25 ± 2°C

Attribute	Day 1 (all treatments)	T0 (uncoated), day 21	T1 (0.5% TE), day 21	T2 (1.0% TE), day 21
Vitamin C (mg/100 g FW)	22.47–22.53	6.47	8.50	12.00
Moisture content (%)	94.0–94.6	80.4	86.3	94.0
Titratable acidity (% citric acid)	0.55–0.58	0.36	0.38	0.43
Crude fibre (%)	1.48–1.50	1.00	1.18	1.23
Total soluble solids (°Brix)	5.2–5.3	4.5	4.6	4.8
Visual deterioration score (1–4)	1.0	4.0	3.5	2.5

T0, uncoated; T1 and T2, starch–glycerol coating with 0.5% and 1.0% (w/v) tea extract (TE). FW, fresh weight. Values are means of three replicate lots.

3.3 Effect of Coating on Moisture Content

Moisture content was similar across treatments on day 1 (94.0–94.6%) and, on day 21, was 80.4% in T0, 86.3% in T1 and 94.0% in T2 (Table 3). Because moisture content was determined on the pulp of

destructively sampled fruit, whereas weight loss was recorded on the whole tagged fruit, the two variables are not directly interchangeable. The ranking of treatments for moisture content was the same as for weight loss, which is consistent with the water-vapour barrier function of glycerol-plasticised starch films [21] and with the reported influence of plasticiser content and active-ingredient loading on the barrier properties of starch-based films [22, 23].

3.4 Effect of Coating on Visual Decay

Visual deterioration scores increased with storage in all treatments but were lower in coated fruit at every interval; on day 21 the control reached the maximum score of 4.0 (severe wrinkling, softening and visible mould), compared with 3.5 in T1 and 2.5 in T2 (Table 3; Fig. 1f). Because the score combines dehydration symptoms (shrivelling, wrinkling) with decay symptoms (mould), part of this difference reflects the lower water loss of coated fruit (Section 3.1). Tea catechins have antifungal activity in vitro and in active films [24, 25], and starch coatings containing antimicrobial agents often reduce decay more than plain starch coatings [26, 27]. However, yeast and mould counts were not determined in this study, so the present data do not demonstrate an antimicrobial effect of the tea extract on the fruit surface. Microbial enumeration and decay incidence (percentage of affected fruit) should be included in future trials. Photographs of T0, T1 and T2 fruit taken on day 21 are shown in Fig. 2.

3.5 Effect of Coating on Titratable Acidity

Titratable acidity decreased in all treatments during storage, consistent with the use of organic acids as respiratory substrates during ripening. On day 21, it was 0.43% citric acid in T2, 0.38% in T1 and 0.36% in T0 (Table 3; Fig. 1c). Slower loss of acidity in coated fruit is consistent with a reduced rate of ripening, as commonly reported for coatings that modify the internal atmosphere of fruit [28, 29]; respiration rate and internal gas composition were not measured here, so this mechanism was not tested directly.

3.6 Effect of Coating on Fibre Content

Crude fibre decreased slightly during storage, reaching 1.00% in T0, 1.18% in T1 and 1.23% in T2 on day 21 (Table 3; Fig. 1d). Ripening-related softening of tomato involves cell-wall disassembly, in which pectin solubilisation plays a major role [4, 30]. The higher fibre values of coated fruit are consistent with slower ripening; however, firmness and cell-wall enzyme activities were not measured, and crude fibre is only an approximate indicator of cell-wall integrity, so this result should be interpreted with caution.

3.7 Effect of Coating on Total Soluble Solids

Total soluble solids decreased slightly from an initial 5.2–5.3 °Brix in all treatments. On day 21, TSS was 4.5 °Brix in T0, 4.6 °Brix in T1 and 4.8 °Brix in T2 (Table 3; Fig. 1e). The decline is consistent with respiratory consumption of sugars in over-ripening fruit, and the smaller decline in T2 suggests slower metabolic activity; the absolute differences were small (0.3 °Brix), so this difference should be interpreted with caution.

3.8 Effect of Coating on Sensory Characteristics

Sensory scores for colour, appearance, texture and overall acceptability of tomato fruit under the three treatments are summarised in Table 4 and Fig. 3.

Table 4
Effect of cassava starch–tea extract coating on sensory attributes of tomato fruit during storage (5-point hedonic scale; mean of 10 panellists)

Storage day	Treatment	Colour	Appearance	Texture	Overall acceptability
Day 1	T0 (uncoated)	4.8	4.8	4.8	4.8
	T1 (0.5% TE)	4.8	4.9	4.9	4.9
	T2 (1.0% TE)	4.9	4.9	5.0	4.9
Day 7	T0 (uncoated)	4.2	4.1	4.0	4.1
	T1 (0.5% TE)	4.5	4.6	4.6	4.5
	T2 (1.0% TE)	4.7	4.8	4.8	4.7
Day 14	T0 (uncoated)	3.3	3.2	3.0	3.1
	T1 (0.5% TE)	4.1	4.1	4.2	4.1
	T2 (1.0% TE)	4.4	4.4	4.5	4.4
Day 21	T0 (uncoated)	2.2	2.1	1.9	2.0
	T1 (0.5% TE)	3.5	3.5	3.6	3.5
	T2 (1.0% TE)	4.0	4.0	4.1	4.0

Values are means of 10 panellists (1 = dislike very much; 5 = like very much). T0, T1, T2 as in Table 2.

All treatments scored close to 5 on day 1, confirming similar initial quality. Scores decreased with storage in all treatments but more slowly in coated fruit (Table 4; Fig. 3). Taking an overall acceptability score of 3.0 (neither like nor dislike) as the limit of sensory acceptability [31], uncoated fruit reached this limit between day 14 (3.1) and day 21 (2.0) – at about day 15 by linear interpolation – whereas T1 (3.5) and T2 (4.0) remained above it on day 21. Under the conditions tested, the coatings therefore extended sensory shelf life by at least about one week. The lower colour, appearance and texture scores of the control are consistent with its greater weight loss and visual deterioration. Because the panel was small (10 semi-trained panellists) and evaluated coded samples in the laboratory, these results indicate potential consumer acceptability but do not demonstrate market acceptance or willingness to pay.

3.9 General Discussion and Limitations

For all measured attributes the treatments ranked in the same order (T2 > T1 > T0), and the differences generally widened with storage time, which supports the conclusion that the cassava starch–tea extract

coating delayed quality deterioration of tomato under ambient storage. Starch-based coatings have been shown to reduce weight loss, respiration and ethylene production of climacteric fruit [32], and tea phenolics are well-documented antioxidants [33, 34]. The present results are therefore compatible with a barrier effect of the starch–glycerol film together with an additional effect of the tea extract. However, because no starch–glycerol coating without tea extract was included, the two contributions cannot be separated, and the effects reported here should be attributed to the coating system as a whole rather than specifically to tea polyphenols.

The reductions in weight loss and quality decline observed here are of a similar order to those reported for other starch- or polysaccharide-based coatings containing plant extracts on climacteric fruit [35, 36], although direct comparison is limited by differences in cultivar, coating composition and storage conditions. Cassava and tea are both produced in Rwanda and the coating requires only simple equipment, which makes it of interest for settings without cold storage [37]; however, locally extracted cassava starch can vary in composition with genotype and extraction method [38], so the starch should be characterised in future work.

This study has several limitations. (i) The design did not include a starch–glycerol coating without tea extract or more than two tea-extract levels, so the specific contribution of the extract could not be determined. (ii) Firmness, instrumental colour (L*, a*, b*), lycopene, respiration rate, ethylene production, decay incidence and microbial counts were not measured; the mechanisms discussed are therefore based on the literature and should be regarded as hypotheses. (iii) Neither the tea extract (total phenolics, catechins) nor the coating film (thickness, water-vapour and oxygen permeability, mechanical properties) was characterised. (iv) Only one cultivar, one storage condition and a small laboratory sensory panel were used. (v) Biodegradability and cost of the coating were not assessed; the coating is made from biodegradable, food-grade materials, but its biodegradation and economic feasibility remain to be tested. (vi) Weight loss was measured repeatedly on the same tagged fruits, and the two-way ANOVA used here does not account for this repeated-measures structure, so the weight-loss p-values should be interpreted with caution. These points should be addressed before the coating is recommended for commercial use.

4 Conclusions

A coating prepared from locally extracted cassava starch, glycerol and aqueous tea extract reduced the weight loss of tomato fruit during 21 days of storage at 25 ± 2°C: on day 21, weight loss was 7.26% with 1.0% tea extract and 10.72% with 0.5% tea extract, compared with 15.94% for uncoated fruit. Coated fruit also retained more vitamin C, titratable acidity and crude fibre, had lower visual deterioration scores and remained above the sensory acceptability limit on day 21, whereas uncoated fruit fell below it after about two weeks. The coating therefore shows promise as a simple, low-cost postharvest treatment for tomato where cold storage is unavailable. Because the study did not include a starch-only coating and did not measure firmness, colour, respiration, microbial load, biodegradability or cost, further work is needed to establish the role of the tea extract, confirm the mechanisms involved and evaluate the

coating under commercial handling conditions. Because the coating can be prepared and applied with simple equipment, it could be integrated into farm-level and cooperative collection-centre handling of tomato without additional infrastructure, which should be tested in on-farm trials.

Declarations

Competing Interests.

The authors declare that they have no competing financial or non-financial interests relevant to this work.

Ethics Approval and Consent to Participate.

This study did not involve animal experimentation. Sensory evaluation involved human panellists who provided written informed consent before participation; no personally identifiable information was collected, and the evaluation posed no more than minimal risk. The protocol for sensory evaluation involving human panellists was approved by the INES-Ruhengeri Research Ethics Committee (Approval No. INES/RW/908/2026) in accordance with the Declaration of Helsinki and applicable national research ethics guidelines of Rwanda. Cassava roots and tea leaves used to prepare the coating were sourced from Musanze District (cassava roots) and from smallholder tea farms in Nyabihu District (tea leaves), Rwanda, in accordance with applicable national and local agricultural produce regulations; no wild, endangered, or protected plant species were collected, and no special collection permits were required for this cultivated plant material.

Clinical Trial Number.

Not applicable.

Consent for Publication.

Not applicable.

Funding.

This research received no external, institutional or grant funding; materials and analyses were self-funded by the authors.

Author Contribution

J.H. and M.A.N. conducted the laboratory work, collected and analysed the data, and drafted the manuscript. F.G. contributed to the conception and design of the study, supervised the work, and critically reviewed and edited the manuscript. J.C.D. supervised the study, contributed to its conception and design, and critically reviewed the manuscript. E.K., C.M. and B.M. contributed to data verification and interpretation of the

Acknowledgements.

The authors thank the Department of Biotechnology, INES-Ruhengeri, for laboratory access and technical support during this study.

Data Availability.

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Tutu CO, et al. Postharvest strategies for indigenous fruits and vegetables in West Africa: linking food loss reduction, nutrient retention and diet quality. Food Energy Secur. 2026;15(3):e70275. 10.1002/fes3.70275.
2. Bechoff A, et al. Estimation of nutritional postharvest losses along food value chains: A case study of three key food security commodities in sub-Saharan Africa: Nutritional postharvest loss estimation tool. Food Secur. 2022;14(3):571–90.
3. Kitinoja L, Odeyemi O, Dubey N, Musanase S, Gill GS. Commodity system assessment studies on the postharvest handling and marketing of tomatoes in Nigeria, Rwanda and Maharashtra, India. J Hortic Postharvest Res. 2019;2:1–14. 10.22077/jhpr.2019.2060.1040. Special Issue.
4. Liu H, et al. Research Progress on the Mechanism of Fruit Ripening and Softening. Russ J Plant Physiol. 2026;73(3):110.
5. Khatana JP, et al. A Review of Understanding and Mitigating Post-Harvest Losses in Horticulture: From Metabolic Pathways to Emerging Technologies. Eur J Nutr Food Saf. 2026;18(3):253–68.
6. Becerra-Sanchez F, Taylor G. Reducing post-harvest losses and improving quality in sweet corn (Zea mays L.): challenges and solutions for less food waste and improved food security. Food Energy Secur. 2021;10(3):e277.
7. Owino W, Kahenya P, Wafula E, Otieno G. Food loss and waste reduction in specific fruit and vegetable value chains in Eastern Africa. Foods. 2025;14(22):3938.
8. Odeyemi OM, Kitinoja L, Dubey N, Musanase S, Gill GS. Preliminary study on improved postharvest practices for tomato loss reduction in Nigeria, Rwanda and India. Afr J Sci Technol Innov Dev.

2022;14(6):1500–5.

9. Kocira A, Kozłowicz K, Panasiewicz K, Staniak M, Szpunar-Krok E, Hortyńska P. Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review. Agronomy. 2021;11(5):813.
10. Tian X, Dong H, Fang Q, Zhang X, Dai C, Aheto JH. Harnessing the synergy between edible coatings and non-thermal technologies for improved food quality and sustainable preservation. Horticulturae. 2025;11(12):1466.
11. Nian L, et al. Biodegradable active packaging: Components, preparation, and applications in the preservation of postharvest perishable fruits and vegetables. Crit Rev Food Sci Nutr. 2024;64(8):2304–39.
12. Pan J, et al. Polysaccharide-based packaging coatings and films with phenolic compounds in preservation of fruits and vegetables—A review. Foods. 2024;13(23):3896.
13. Selvam T, Rahman NMMA, Olivito F, Ilham Z, Ahmad R. A. Q. I. Wan-Mohtar, Agricultural waste-derived biopolymers for sustainable food packaging: challenges and future prospects. Polym (Basel). 2025;17(14):1897.
14. Mbonambi NP, Adeyemi JO, Seke F, Fawole OA. Fabrication and application of bio-based natural polymer coating/film for food preservation: a review. Processes. 2025;13(8):2436.
15. Scaria SS, et al. Cassava (Manihot esculenta Crantz)—A potential source of phytochemicals, food, and nutrition—An updated review. Efood. 2024;5(1):e127.
16. Borku AW. Cassava (Manihot esculenta Crantz): its nutritional composition insights for future research and development in Ethiopia. Discov Sustain. 2025;6(1):404.
17. Romão S, Bettencourt A, Ribeiro IAC. Novel features of cellulose-based films as sustainable alternatives for food packaging. Polym (Basel). 2022;14(22):4968.
18. Zhang J, et al. Advances in Controlled-Release Packaging for Food Applications. Compr Rev Food Sci Food Saf. 2025;24(6):e70311.
19. Singh AK, Kim JY, Lee YS. Phenolic compounds in active packaging and edible films/coatings: natural bioactive molecules and novel packaging ingredients. Molecules. 2022;27(21):7513.
20. Tammina SK, Krishnamoorthy R, Manzoor A, Priyadarshi R, Sridhar K, Banat F. A Comprehensive Review on the Significance of Antioxidants and Their Influence on Biopolymer Packaging Films: Recent Advances and Challenges. Food Front. 2026;7(2):e70227.
21. Rashid A, Li M, Hou H, Ren X, Ma H, Dabbour M. Engineering Starch for Sustainable Food Packaging: A Critical Review of Structural Limitations, Modification Techniques, and Emerging Active and Intelligent Applications. Compr Rev Food Sci Food Saf. 2026;25(4):e70573.
22. Ribeiro AM, Estevinho BN, Rocha F. Preparation and incorporation of functional ingredients in edible films and coatings. Food Bioprocess Technol. 2021;14(2):209–31.
23. Javed MA et al. Novel Colocasia esculenta starch–clove extract packaging films for enhanced oxidative stability, microbial quality, and sensory acceptability of chicken, J. Food Process. Preserv.,

vol. 2025, no. 1, p. 5563606, 2025. 10.1155/jfpp/5563606

24. Moeini A, Pedram P, Fattahi E, Cerruti P, Santagata G. Edible polymers and secondary bioactive compounds for food packaging applications: Antimicrobial, mechanical, and gas barrier properties. Polym (Basel). 2022;14(12):2395.
25. Lara-Gomez AB, Castro-Rosas J, Hernandez-Hernandez E, Cadena-Ramirez A, Hernández-Cruz MÁ, Gomez-Aldapa CA. Mechanical and barrier properties of films containing bioactive compounds with antimicrobial and antioxidant activity. Food Bioprocess Technol. 2025;18(10):8260–90.
26. Gonçalves EM, Silva M, Andrade L, Pinheiro J. From fields to films: exploring starch from agriculture raw materials for biopolymers in sustainable food packaging. Agriculture. 2024;14(3):453.
27. Oyom W, Zhang Z, Bi Y, Tahergorabi R. Application of starch-based coatings incorporated with antimicrobial agents for preservation of fruits and vegetables: A review. Prog Org Coat. 2022;166:106800.
28. Gidado MJ, et al. Effect of hydrophobic deep eutectic oil-in-water nano coating on the quality preservation of postharvest 'Harumanis' mango. Colloids Surf Physicochem Eng Asp. 2024;691:133818.
29. Hou C-Y, et al. Postharvest quality and prolong storage time of atemoya (Annona squamosa x A. cherimola hybrids) fruit: coating with D-limonene nanoemulsion edible film. Int J Food Prop. 2023;26(1):1098–113.
30. Wang D, Yeats TH, Uluisik S, Rose JKC, Seymour GB. Fruit softening: revisiting the role of pectin. Trends Plant Sci. 2018;23(4):302–10.
31. Lawless HT, Heymann H. Sensory Evaluation of Food: Principles and Practices. 2nd ed. New York, NY, USA: Springer; 2010.
32. Thakur R, et al. Development and application of rice starch based edible coating to improve the postharvest storage potential and quality of plum fruit (Prunus salicina). Sci Hortic. 2018;237:59–66.
33. Wang W, et al. A modern scientific perspective on the flavor and functional properties of diverse teas in traditional cuisine 'tea-flavored fish': From macroscopic quality to microscopic variations. Food Chem X. 2025;25:102122.
34. Jiang C, et al. Phenolic Acids and Their Derivatives in Tea: Chemical Diversity, Processing Changes, Sensory Contributions, and Health Implications—A Comprehensive Review. Compr Rev Food Sci Food Saf. 2026;25(4):e70553.
35. Saleem MS, et al. Biocomposite coatings delay senescence in stored Diospyros kaki fruits by regulating antioxidant defence mechanism and delaying cell wall degradation. Horticulturae. 2023;9(3):351.
36. Odetayo T, Tesfay S, Ngobese NZ. Nanotechnology-enhanced edible coating application on climacteric fruits. Food Sci Nutr. 2022;10(7):2149–67.
37. Boudalia S, et al. The valorization of agrifood byproducts and waste to advance the sustainable development goals: Current state and new perspectives. Sustainability. 2026;18(5):2165.

38. Akonor PT, Osei Tutu C, Arthur W, Adjebeng-Danquah J, Affrifah NS, Budu AS, Saalia FK. Granular structure, physicochemical and rheological characteristics of starch from yellow cassava (Manihot esculenta) genotypes. Int J Food Prop. 2023;26(1):259–73. 10.1080/10942912.2022.2161572.
39. Osei Tutu C, Amissah JGN, Amissah JN, Akonor PT, Arthur W, Budu AS, Saalia FK. Physicochemical and microstructural characteristics of Frafra potato (Solenostemon rotundifolius) starch. Int J Food Prop. 2023;26(1):1624–35. 10.1080/10942912.2023.2228513.
40. International AOAC. Official Methods of Analysis of AOAC International. 21st ed. Gaithersburg, MD, USA: AOAC International; 2019.

Figures

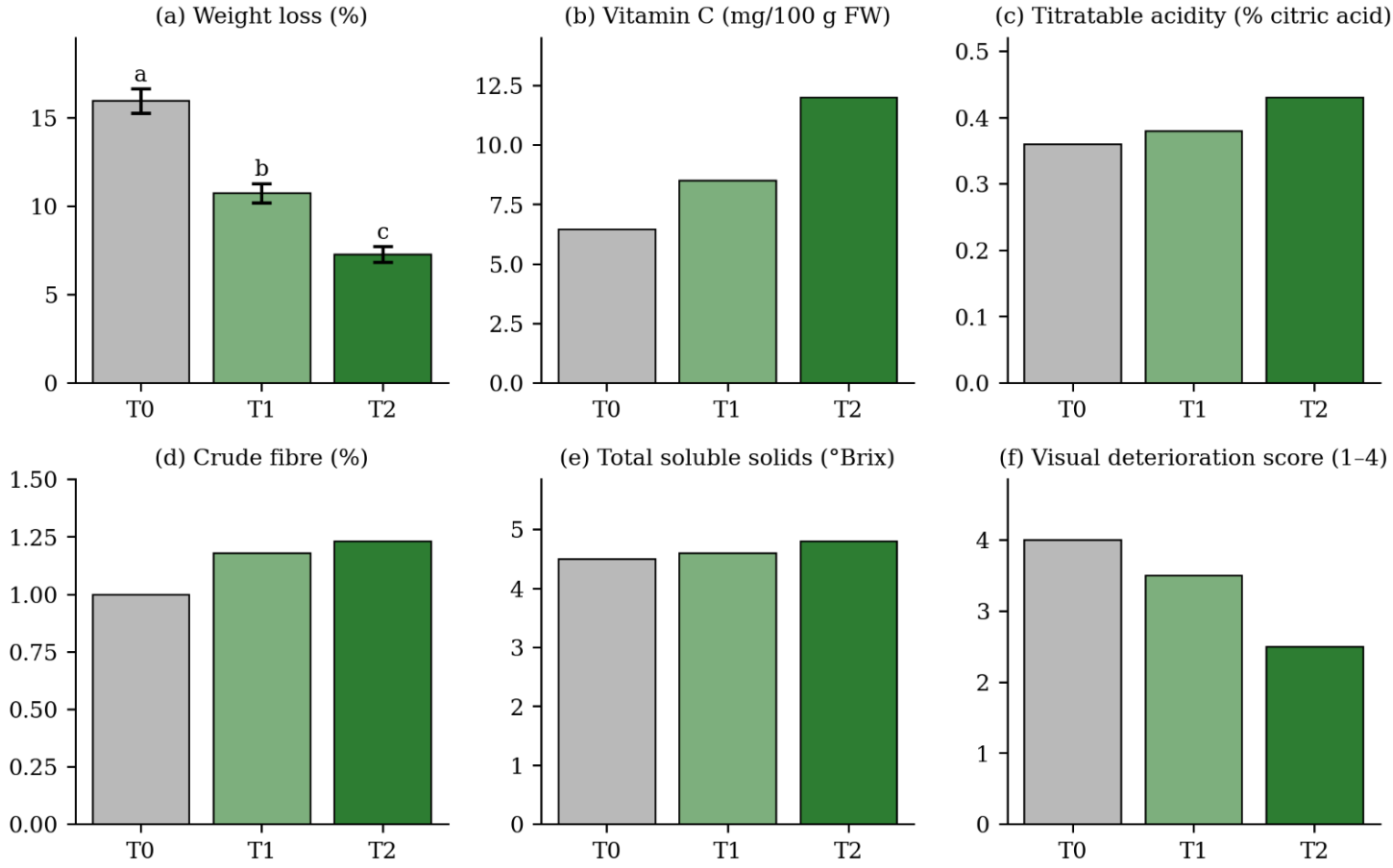


Figure 1

Quality attributes of tomato fruit on day 21 of storage at 25 ± 2 °C: (a) weight loss, (b) vitamin C, (c) titratable acidity, (d) crude fibre, (e) total soluble solids and (f) visual deterioration score. T0, uncoated; T1 and T2, coating with 0.5% and 1.0% tea extract. Error bars in (a) are SD (n = 3); different letters indicate significant differences (Tukey's HSD, $p < 0.05$). Panels (b)–(f) show means of three replicate lots (Table 3).

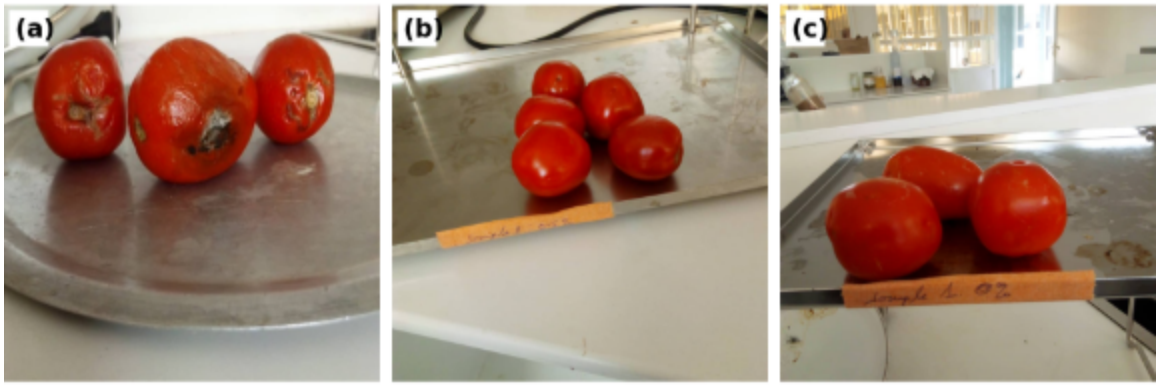


Figure 2

Appearance of tomato fruit after 21 days of storage at ambient conditions: (a) uncoated control (T0), (b) T1 (0.5% tea extract) and (c) T2 (1.0% tea extract).

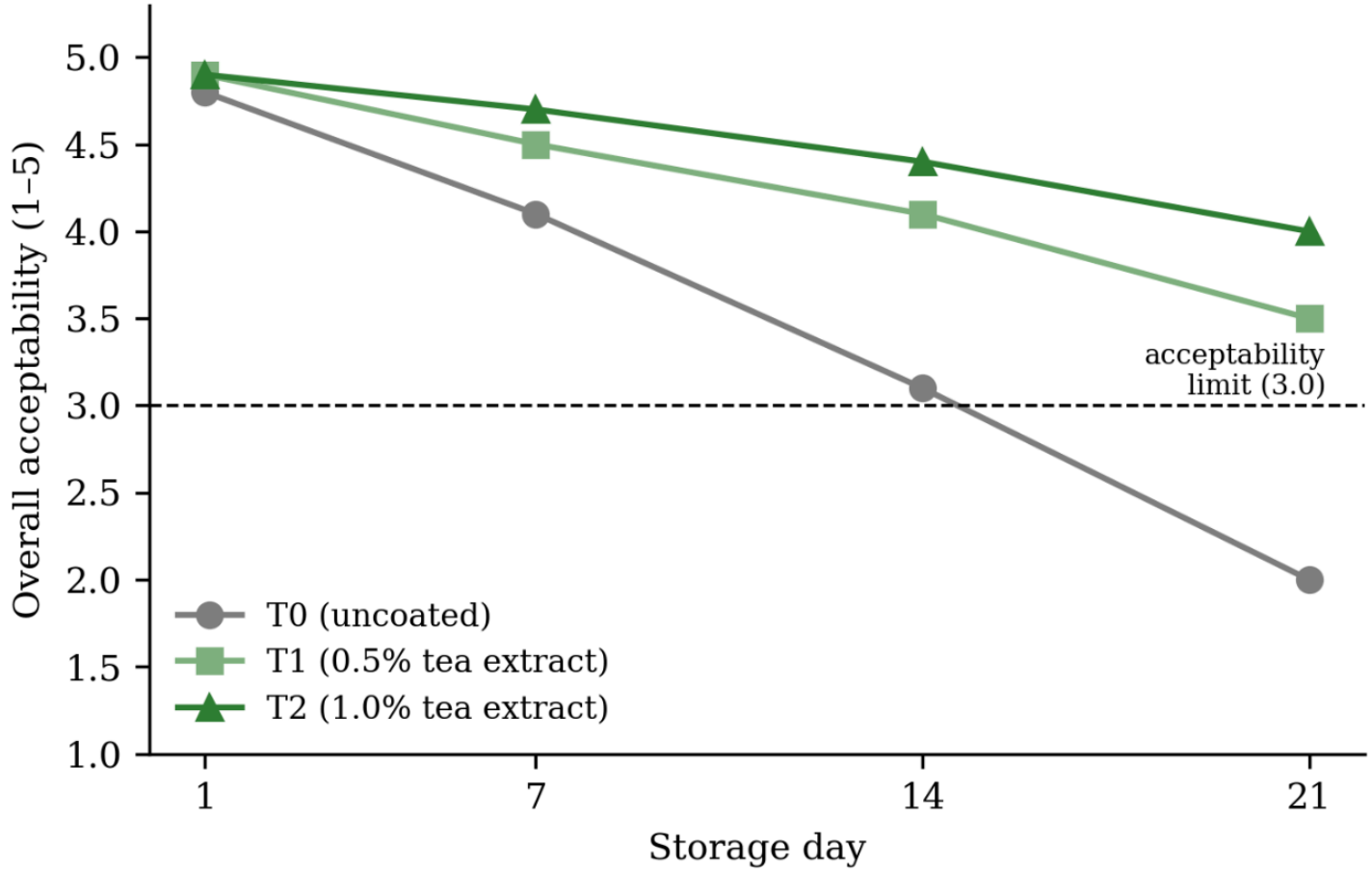


Figure 3

Change in overall sensory acceptability of uncoated and cassava starch–tea extract-coated tomato fruit during 21 days of storage. The dashed line marks a score of 3 (neither like nor dislike), taken as the limit of sensory acceptability.