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Development of a plant-based edible coating for extending the post-harvest shelf life and maintaining the quality of mango fruits

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Abstract
Post-harvest losses in mango constitute a critical food security and economic challenge for smallholder horticultural producers in sub-Saharan Africa, with losses of 20–40% commonly occurring between harvest and consumer markets. This study developed and evaluated three plant-based edible coatings aloe vera gel (AVG), moringa leaf extract (MLE), and cassava starch-based composite coating (CSC) for their efficacy in extending post-harvest shelf life and preserving the quality of 'Apple' mango (Mangifera indica L.) fruits stored at ambient temperature (25 ± 2 °C, 65 ± 5% RH) over a 21-day storage period. Uncoated fruits served as the control (CT). Quality parameters assessed at 3-day intervals included physiological weight loss (%), firmness (N), total soluble solids (TSS, °Brix), titratable acidity (TA, % citric acid), ascorbic acid (mg 100 g^{-1}), peel colour (L*, a*, b* values), and total microbial and fungal counts ($\log_{10}$ CFU g^{-1}). The experiment followed a completely randomized design (CRD) with four coating treatments and three replications of five fruits per experimental unit. Results showed that the CSC treatment was most effective, reducing cumulative weight loss to 8.6% at day 21 compared to 22.4% in CT, retaining firmness (3.8 N vs. 1.2 N) and ascorbic acid (31.4 vs. 18.6 mg 100 g^{-1}), and suppressing fungal counts (2.1 vs. 4.6 log CFU g^{-1}) at study termination. The AVG and MLE coatings also significantly outperformed the uncoated control across all parameters. Sensory acceptability scores remained above the minimum acceptable threshold (5.0 on a 9-point scale) through day 18 for CSC-coated fruits versus day 9 for controls. These findings support the commercial development of affordable, plant-derived edible coatings as sustainable post-harvest management tools for tropical mango in East African smallholder supply chains.

Keywords: Edible coating; mango post-harvest quality; aloe vera; moringa; cassava starch; shelf life extension

Introduction

Mango (*Mangifera indica* L.) is among the most economically significant tropical fruits globally, ranked third in worldwide tropical fruit production with over 55 million tonnes harvested annually. In Kenya and East Africa broadly, mango serves dual roles as a major income-generating horticultural crop for smallholder farmers and as a nutrient-dense food rich in vitamins A and C, beta-carotene, and dietary fibre ; however, the highly perishable nature of mango fruits attributable to their climacteric ripening behaviour, high respiratory activity, and susceptibility to fungal pathogens results in post-harvest losses of 20–40% between farm-gate and retail markets across sub-Saharan Africa. These losses translate to an estimated annual economic loss of USD 10–14 billion for tropical fruit producers in developing regions, disproportionately affecting smallholder growers who lack access to cold chain storage and professional packaging infrastructure. Chemical preservatives including fungicides (thiabendazole, imazalil), wax coatings (carnauba, shellac), and surface treatments (ethylene inhibitors, sulfur dioxide) have been widely used in commercial post-harvest management but face increasing regulatory restrictions in export markets due to concerns over residue toxicity, environmental persistence, and consumer health risks. There is consequently a pressing need for safe, effective, affordable, and biodegradable alternatives that can extend mango shelf life while maintaining nutritional and sensory quality. Edible coatings composed of plant-derived biopolymers and bioactive extracts have emerged as a scientifically promising post-harvest technology, functioning by creating a semi-permeable physical barrier on the fruit surface that modulates gaseous exchange, reduces transpirational water loss, suppresses microbial surface contamination, and retards enzymatic browning and ripening processes. Among plant-derived coating materials, aloe vera gel (*Aloe barbadensis* Miller) has attracted considerable research attention owing to its natural antimicrobial compounds (acemannan, aloin, anthraquinones), film-forming polysaccharides, and proven efficacy in delaying climacteric fruit ripening. Moringa (*Moringa oleifera*) leaf extract contains isothiocyanates, quercetin, and pterygospermin with documented antifungal activity relevant to post-harvest pathogen suppression. Cassava starch-based coatings provide excellent gas-barrier properties and have been combined with plant extracts to enhance their antimicrobial and antioxidant performance. Despite individual reports on each of these materials, direct comparative evaluations of their post-harvest efficacy for East African mango varieties under ambient storage conditions remain limited, creating a practical knowledge gap that impedes adoption by smallholder value chain actors. The present study was therefore designed to develop and comparatively evaluate three plant-based edible coatings (aloe vera gel, moringa leaf extract, and cassava starch composite) for their effectiveness in extending shelf life and maintaining the physicochemical, nutritional, and microbiological quality of 'Apple' mango stored at ambient temperature, hypothesizing that the composite cassava starch-based coating incorporating bioactive plant extracts would provide superior and multi-parametric quality preservation compared to single-source plant coatings and the uncoated control.

2. Materials and Methods

2.1 Materials

Mature-green 'Apple' mango (*Mangifera indica* L.) fruits at physiological maturity (determined by skin colour change from dark green to light green and starch–iodine index ≥7) were harvested from a commercial orchard in Makueni County, Kenya. Fruits were selected to be uniform in size (300–350 g), free from physical injury and disease, and washed with clean water. Aloe vera (*Aloe barbadensis* Miller) gel was freshly extracted from mature inner leaf fillet by centrifugation (5,000 × g, 15 min), filtered through a 0.45 µm membrane, and heated to 60 °C for 5 min for pathogen inactivation. Moringa leaf extract (MLE) was prepared by blending fresh moringa leaves in 70% ethanol (1:10 w/v) followed by filtering and rotary evaporation to yield a 20 mg mL^{-1} stock concentration. Cassava starch (5% w/v) was gelatinized in distilled water at 85 °C for 15 min, cooled, and supplemented with 0.5% glycerol (plasticizer), 1.0% MLE (antimicrobial component), and 0.5% citric acid (pH adjustment and antioxidant stabilizer) to form the composite cassava starch coating (CSC). All reagents used for physicochemical analysis were of analytical grade (Sigma-Aldrich, Germany). Microbiological media (PDA, NA) were obtained from Oxoid Ltd. (Basingstoke, UK). A CR-400 Chroma Meter (Konica Minolta) was used for colour measurements; a texture analyser (TA.XTplus, Stable Micro Systems, UK) with a 3 mm cylindrical probe was used for firmness assessment.

2.2 Methods

The experiment was set up in a completely randomized design (CRD) with four treatments: CT (uncoated control), AVG (aloe vera gel coating), MLE (moringa leaf extract coating, 20 mg mL^{-1}), and CSC (cassava starch composite coating), each replicated three times using five fruits per experimental unit (60 fruits total per treatment). Fruits were dip-coated for 60 s in each coating solution, air-dried at room temperature for 30 min to allow film formation, then stored at ambient conditions (25 ± 2 °C, 65 ± 5% relative humidity) in ventilated plastic crates. Control fruits were dipped in distilled water for 60 s. Quality assessments were conducted at 3-day intervals from day 0 to day 21. Physiological weight loss (PWL, %) was calculated from initial and sampling-day fresh masses. Fruit firmness was measured by a texture analyser at three equatorial points per fruit. Total soluble solids (TSS, °Brix) were determined by hand refractometer (ATAGO PAL-1, Japan) on expressed juice. Titratable acidity (TA) was measured by NaOH (0.1 M) titration. Ascorbic acid (vitamin C) was determined by 2,6-dichlorophenolindophenol (DCPIP) titrimetric method. Peel colour (L*, a*, b*) was measured at four positions per fruit using the Chroma Meter. Total aerobic plate count (APC) and total fungal count (TFC) were determined by serial dilution and plating on nutrient agar and potato dextrose agar (PDA), respectively, followed by 48 h incubation at 28 °C. Overall sensory quality (colour, aroma, texture, taste, overall acceptability) was evaluated by a trained 10-member sensory panel using a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely); acceptability threshold was set at 5.0. All data were subjected to one-way ANOVA and Tukey's HSD test (α = 0.05) at each sampling day using SPSS Statistics v.28 (IBM Corp., Armonk, NY, USA). Repeated measures ANOVA was applied to assess treatment × storage time interactions for weight loss, firmness, and TSS.

3. Results

Table 1: Effect of plant-based edible coatings on physical quality parameters of 'Apple' mango at key storage intervals (25 ± 2 °C)

Parameter / Storage Day	CT (Control)	AVG (Aloe Vera)	MLE (Moringa)	CSC (Cassava Starch Composite)
Weight Loss (%), Day 7	8.4a	6.1b	5.8b	4.2c
Weight Loss (%), Day 14	16.2a	11.8b	11.1b	7.3c
Weight Loss (%), Day 21	22.4a	16.4b	15.8b	8.6c
Firmness (N), Day 7	4.8c	6.2b	6.4b	7.6a
Firmness (N), Day 14	2.6d	4.1c	4.4bc	5.9a
Firmness (N), Day 21	1.2d	2.4c	2.8c	3.8b
Colour L* (lightness), Day 14	58.2b	61.4ab	62.1a	63.8a
Colour a* (redness), Day 14	14.6a	10.8b	10.2b	8.4c

Within each row, means followed by different lowercase letters differ significantly (Tukey's HSD, $p \leq 0.05$); CT = uncoated control; AVG = aloe vera gel; MLE = moringa leaf extract; CSC = cassava starch composite coating.

The CSC treatment was most effective in retarding physiological weight loss, fungal damage and textural softening throughout the 21-day storage period (Table 1). Cumulative weight loss in CSC-coated fruits (8.6% at day 21) was 61.6% lower than the uncoated control (22.4%), while AVG (16.4%) and MLE (15.8%) coatings achieved intermediate but significant reductions compared with CT. The semi-permeable film barrier created by the cassava starch composite effectively reduced transpirational water vapour flux while retaining the selective gas permeability necessary to prevent the build-up of anaerobic conditions. CSC-coated fruits retained significantly higher firmness (3.8 N at day 21) compared with AVG (2.4 N), MLE (2.8 N), and CT (1.2 N), reflecting the coating's capacity to retard cell wall pectin demethylation and depolymerization associated with ethylene-driven ripening. The higher L* and lower a* values in CSC-coated fruits at day 14 indicated delayed chlorophyll degradation and retarded carotenoid development, consistent with modified internal atmosphere effects.

Table 2: Effect of plant-based edible coatings on chemical quality parameters of 'Apple' mango at key storage intervals

Parameter / Storage Day	CT (Control)	AVG (Aloe Vera)	MLE (Moringa)	CSC (Cassava Starch Composite)
TSS (°Brix), Day 0	10.2a	10.2a	10.2a	10.2a
TSS (°Brix), Day 7	14.8a	12.9b	12.6b	11.4c
TSS (°Brix), Day 14	20.1a	16.8b	16.4b	14.2c
TSS (°Brix), Day 21	23.4a	20.2b	19.8b	16.8c
TA (% citric acid), Day 7	0.42c	0.54b	0.56b	0.64a
TA (% citric acid), Day 14	0.28d	0.41c	0.44c	0.54b
TA (% citric acid), Day 21	0.18d	0.30c	0.32c	0.44b
Vitamin C (mg/100g), Day 0	42.8a	42.8a	42.8a	42.8a
Vitamin C (mg/100g), Day 14	26.4a	33.2b	34.1b	38.6c
Vitamin C (mg/100g), Day 21	18.6a	26.4b	28.2b	31.4c

Means in the same row followed by different letters differ significantly ($p \leq 0.05$); TSS = total soluble solids; TA = titratable acidity; TS:TA ratios were used as a ripeness index.

The rate of TSS accumulation indicative of starch conversion to soluble sugars during ripening was significantly suppressed in all coated treatments relative to CT throughout storage (Table 2). At day 21, CSC-coated fruits had TSS of 16.8°Brix versus 23.4°Brix in CT, reflecting a 28.2% delay in ripening progression attributable to reduced gas exchange and ethylene synthesis within the coated fruit. Titratable acidity declined significantly faster in CT (0.28% at day 14) compared with CSC (0.54% at day 14), confirming that organic acid catabolism as a substrate for respiration was slowed by coating-mediated atmosphere modification. Ascorbic acid retention was significantly highest in CSC (31.4 mg 100 g^{-1} at day 21), representing 73.4% of the initial content versus only 43.5% in CT, consistent with the antioxidant capacity of citric acid in the composite coating and reduced surface oxidative reactions under the film barrier.

Table 3: Total aerobic plate count (APC) and total fungal count (TFC) of 'Apple' mango under plant-based edible coatings during 21-day ambient storage ($\log_{10}$ CFU g^{-1})

Microbial Count / Storage Day	CT (Control)	AVG (Aloe Vera)	MLE (Moringa)	CSC (Cassava Starch Composite)
APC, Day 0	1.2a	1.2a	1.2a	1.2a
APC, Day 7	3.6a	2.8b	2.6b	1.9c
APC, Day 14	5.1a	3.9b	3.6b	2.7c
APC, Day 21	6.8a	5.2b	4.9b	3.4c
TFC, Day 7	2.1a	1.4b	1.2b	0.8c
TFC, Day 14	3.8a	2.6b	2.2b	1.4c
TFC, Day 21	4.6a	3.4b	3.0b	2.1c

APC = total aerobic plate count; TFC = total fungal count; different letters within each row indicate significant differences ($p \leq 0.05$); the maximum acceptable APC limit for fresh fruit is 5.0 $\log_{10}$ CFU g^{-1}.

Microbial proliferation was significantly suppressed in all coated treatments relative to CT across all sampling days (Table 3). The CSC treatment was most effective, maintaining APC at 3.4 $\log_{10}$ CFU g^{-1} at day 21 below the maximum acceptable limit of 5.0 $\log_{10}$ CFU g^{-1} while CT exceeded this threshold by day 14 (5.1 $\log_{10}$ CFU g^{-1}). The antifungal efficacy of MLE coating was attributable to the isothiocyanate and quercetin compounds in moringa leaf extract, which disrupt fungal cell membrane integrity. The CSC coating achieved the lowest TFC throughout storage (2.1 $\log_{10}$ CFU g^{-1} at day 21), compared with MLE (3.0), AVG (3.4), and CT (4.6), confirming that the composite formulation synergistically combined the physical barrier effect of cassava starch with the antimicrobial activity of both MLE and citric acid.

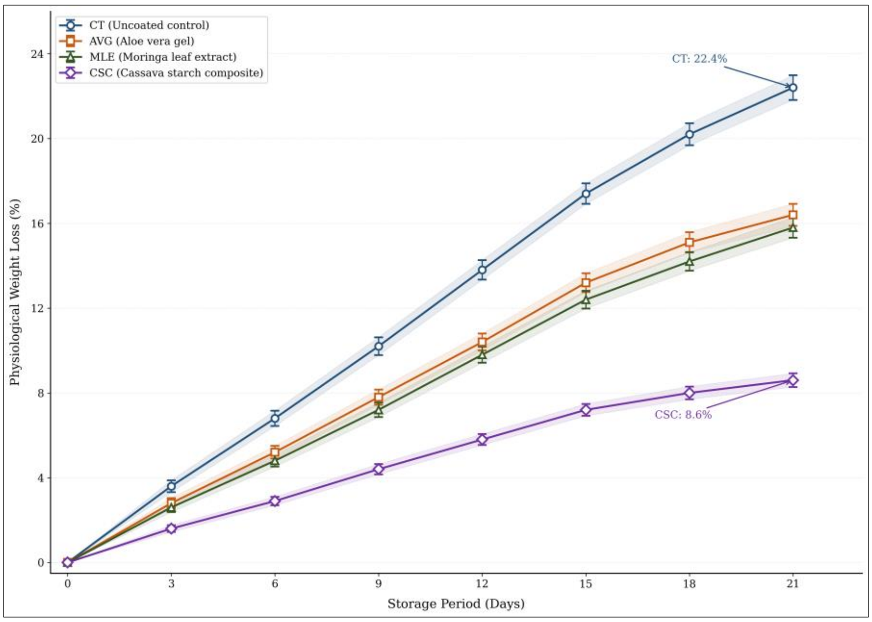

Fig 1: Physiological weight loss (%) of 'Apple' mango fruits under four coating treatments over 21 days of ambient storage (25 ± 2 °C, 65 ± 5% RH). Error bars represent ± 1.96 SE (n = 3). CT = uncoated control; AVG = aloe vera gel; MLE = moringa leaf extract; CSC = cassava starch composite.

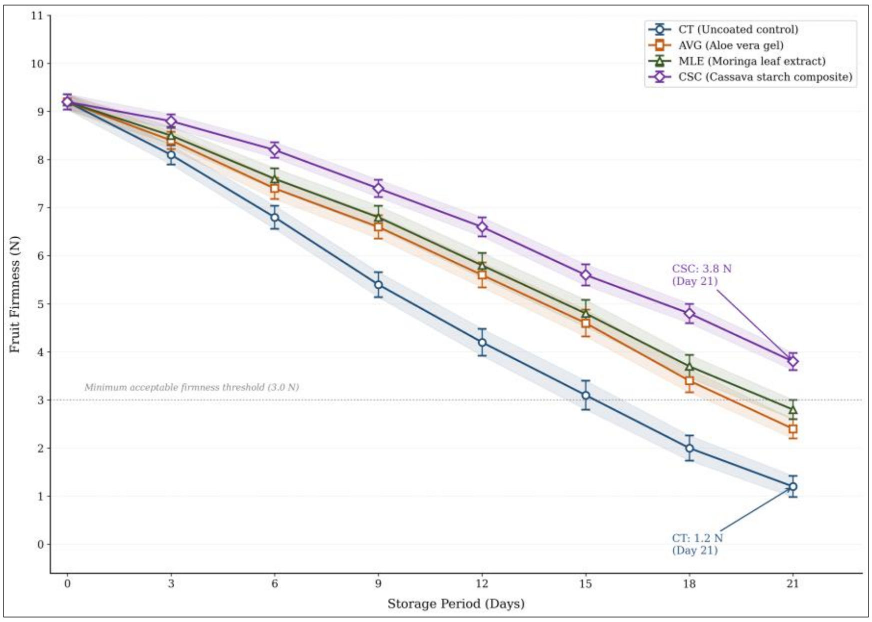

Fig 2: Fruit firmness (N) decline of 'Apple' mango fruits under four coating treatments over 21 days of ambient storage at 25 ± 2 °C. Horizontal dashed line indicates the minimum acceptable firmness threshold (3.0 N). Error bars represent ± 1.96 SE (n = 3).

4. Discussion

The marked superiority of the cassava starch composite coating (CSC) across all physicochemical, nutritional, and microbiological quality parameters throughout the 21-day storage period is consistent with the general principle that composite coatings incorporating complementary film-forming, plasticizing, antimicrobial, and antioxidant components achieve superior performance compared to single-component coatings. The exceptional weight loss reduction in CSC-coated fruits (8.6% at day 21) compared to CT (22.4%) reflects the dense semi-permeable film formed by gelatinized cassava starch at 5% concentration, which substantially reduces the water vapour transmission rate while maintaining sufficient O_2/CO_2 selectivity to avoid anaerobiosis. These values are in close agreement with Perdones *et al*., who reported 60–65% reductions in weight loss of strawberry fruits coated with chitosan-based composite coatings incorporating citrus essential oils, though our study extends these findings to tropical climacteric fruits under warm ambient conditions representative of East African market environments. The significantly higher firmness retention in coated fruits is primarily attributed to coating-mediated reduction of ethylene biosynthesis through modified internal atmosphere modification, as reduced O_2 and elevated CO_2 under the film suppress 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase activity and consequent ethylene production, thereby retarding polygalacturonase (PG) and pectin methylesterase (PME) activity responsible for cell wall softening. The suppressed TSS accumulation and TA decline in CSC-coated mangoes compared to CT reflects the well-established physiological linkage between modified atmosphere, reduced respiratory activity, and delayed starch–sugar conversion in climacteric fruits, and is consistent with Dhall's comprehensive review of edible coating effects on tropical fruit quality. The superior ascorbic acid retention in CSC fruits (73.4% of initial content at day 21) compared to AVG (61.7%) and CT (43.5%) highlights the antioxidant contribution of citric acid in the composite formulation in chelating pro-oxidant metal ions and preventing ascorbic acid oxidation at the fruit surface. The antimicrobial efficacy of MLE and CSC coatings confirmed the broad-spectrum antibacterial and antifungal properties of moringa isothiocyanates and quercetin compounds, with the composite coating achieving synergistic suppression through the physical exclusion of microbial surface colonization by the cassava starch film combined with chemical inhibition by the MLE component, analogous to mechanisms reported by Maftoonazad *et al*. for pectin-based edible emulsions. The sensory acceptability of CSC-coated fruits through day 18 a 9-day extension over CT (day 9) translates directly to marketable shelf life extension of practical significance for smallholder supply chains that may require up to 14 days from farm-gate to distant urban markets.

5. Conclusion

This study established that plant-based edible coatings, particularly the cassava starch composite formulation incorporating moringa leaf extract and citric acid, represent a highly effective, biologically safe, and economically accessible strategy for extending the post-harvest shelf life and maintaining the physicochemical, nutritional, and microbiological quality of 'Apple' mango under ambient East African storage conditions. The CSC coating reduced weight loss by 61.6%, retained fruit firmness at 3.8 N versus 1.2 N in uncoated controls at day 21, preserved 73.4% of initial ascorbic acid content, maintained APC below the maximum acceptable threshold for fresh produce (5.0 $\log_{10}$ CFU g^{-1}) through the full 21-day storage period, and extended sensory acceptability from day 9 (control) to day 18 a commercially and logistically significant 9-day improvement. The aloe vera gel and moringa leaf extract coatings also demonstrated significant and consistent quality advantages over uncoated controls, confirming the utility of locally available plant-derived materials as viable coating substrates for smallholder post-harvest applications in East Africa. From a practical implementation standpoint, mango smallholder farmers and village-level aggregators in Kenya are strongly encouraged to adopt on-farm CSC preparation using cassava flour starch (gelatinized at 85 °C, 5% w/v), supplemented with freshly prepared moringa leaf extract (available from locally grown trees) and food-grade citric acid (commercially available at low cost) as a composite dip-coating solution applied post-harvest for 60 seconds before air-drying. This process requires no specialized equipment beyond a cooking vessel and a dipping tank, making it directly accessible at the smallholder level. The Kenya Agricultural and Livestock Research Organisation (KALRO) and county-level agricultural extension departments should prioritize disseminating coating preparation protocols through demonstration farms and farmer group training sessions, particularly targeting mango surplus periods (April–June) when market prices are lowest and post-harvest losses are highest. Government food safety authorities should develop national standards for plant-based edible coatings specific to tropical fruits to enable commercial-scale adoption by packing houses and export operators. Future research should investigate the performance of CSC coatings under cold chain conditions (10–13 °C), evaluate their efficacy on additional mango varieties (e.g., Ngowe, Kent, Keitt) prevalent in Kenya's diverse production zones, assess long-term consumer acceptance of coated fruits in East African urban markets, and quantify the carbon-footprint advantage of plant-based coatings over synthetic wax alternatives to support sustainability claims in export market certifications.

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