ISSN: 2621-4709 E-ISSN: 2621-2528
Journal of Applied Agricultural Science and Technology
Vol. 10 No. 3 (2026): 496-512

Edible Coating from Cassava Peel Starch and *Elephantopus scaber* Leaf Extract on Cavendish Banana Preservation

Desi Rejeki [a,*], Luqi Khoiriyah Latif [a], Anjakasi Mar'atul Ula [a], Robby Akroman [a]

[a] Department of Agrotechnology, Sekolah Tinggi Ilmu Pertanian, Jember, Indonesia

Abstract. *Bananas (Musa spp.) are highly nutritious tropical fruits with significant commercial value, but their short shelf life poses a major challenge due to rapid climacteric ripening, increased respiration, ethylene production, and susceptibility to microbial spoilage. However, many synthetic coatings currently used to extend fruit shelf life raise health and environmental concerns, creating an urgent need for safe, biodegradable, and effective edible coating alternatives. This study evaluated the efficacy of an edible coating based on cassava peel starch extract enriched with Elephantopus scaber extract in preserving the quality of Cavendish bananas over 15 days of storage. The experiment included four treatments: a negative control (uncoated), a positive control (coated with cassava peel starch only), and two concentrations of Elephantopus scaber extract—5 mg/mL (Es 5) and 10 mg/mL (Es 10)—added to the cassava starch coating. Parameters assessed included weight loss, moisture content (peel and pulp), fruit firmness, and functional group characterization using FTIR spectroscopy. The results showed that the Es 10 treatment was most effective, reducing weight loss to just 29.66% by day 15, markedly lower than the negative control (47.33%) and positive control (33.01%). Moisture retention was also superior in Es 10-treated bananas, with pulp moisture remaining at 86.00% on day 15, indicating the coating's role as an effective barrier against water loss. Firmness measurements revealed a controlled increase in Es 10 samples, reaching 31.2 kPa/cm² by the end of storage, suggesting delayed senescence. FTIR analysis confirmed the successful incorporation of the extract into the starch matrix, highlighting bioactive compound signatures that suggest the presence of flavonoids and phenolic compounds, which may confer antioxidant and antimicrobial properties. Nevertheless, the food safety and regulatory status of Elephantopus scaber extract for direct food contact applications has not yet been established, which represents a key limitation for practical adoption and requires future toxicological evaluation. The combination of cassava peel starch and 10 mg/mL Elephantopus scaber extract offers a promising natural coating to extend the shelf life of Cavendish bananas by synergistically limiting transpiration and modulating ripening processes.*

Keywords: *edible coating; cassava peel starch; elephantopus scaber extract; shelf-life extension; cavendish banana.*

Type of the Paper: Regular Article.

1. Introduction

Bananas (*Musa* spp.) are among the most widely cultivated and consumed tropical fruits globally, valued for their nutritional richness and economic importance. Indonesia is the world's fourth-largest banana producer, with an annual production of approximately 8.7 million tons [1]. Cavendish bananas, as the leading commercial variety, hold a strategic position in the Indonesian

https://doi.org/10.55043/jaast.v10i3.531
Received November 26, 2025; Received in revised form June 18, 2026; Accepted June 23, 2026; Published August 21, 2026
* Corresponding author
Email: desy.rejeky@gmail.com

agribusiness sector. Nutritionally, this fruit contains essential nutrients, including carbohydrates, micronutrients, vitamins, minerals, and dietary fiber, all of which contribute to human health [2].

However, postharvest losses of bananas in Indonesia can reach 20-40% of total production [3]. As a climacteric fruit, bananas undergo rapid ripening after harvest, characterized by increased respiration rate, ethylene production, cell wall degradation, chlorophyll breakdown, soluble sugar accumulation, and microbial colonization [4], which ultimately lead to quality deterioration [5,6].

To extend shelf life, synthetic preservatives, including fungicides and wax coatings, have been conventionally used [7]. However, these synthetic materials raise health and environmental concerns due to potential chemical residues [5]. Therefore, a natural preservation approach through edible coating technology emerges as a promising alternative solution. Various biopolymers have been previously studied for fruit coatings, including chitosan, carrageenan, aloe vera gel, and starch-based formulations [6]. Each material offers distinct advantages and limitations in term of film-forming ability, gas permeability, and antimicrobial activity. Among these, cassava peel starch offers advantages as a natural coating matrix due to its good film-forming characteristics, abundant raw material availability, and competitive economic aspects, particularly as it utilizes agricultural waste [6].

Elephantopus scaber is a medicinal plant known for its rich phytochemical content, including flavonoids, tannins, and alkaloids [8]. Previous research by Rejeki et al. [8] demonstrated that *Elephantopus scaber* methanol extract effectively inhibited the bacterial pathogens *Ralstonia solanacearum* and *Xanthomonas oryzae*, as well as the fungal pathogen *Phytopthora nicotianae*, with 5 mg/ml showing the best antimicrobial performance [8]. Based on this evidence *Elephantopus scaber* was selected as the bioactive additive for this study, with concentrations of 5 mg/mL (Es 5) and 10 mg/mL (Es 10) chosen to evaluate dose-dependent effects.

The use of *Elephantopus scaber* extract in coating application remains very limited. Previous studies have focused on combining starch with other materials such as chitosan, essential oils, or nanoparticles [9,10]. However, the synergy between *Elephantopus scaber* extract and cassava peel starch has not been widely explored. Therefore, a clear research gap exists the development of an edible coating combining cassava peel starch (agricultural waste) with *Elephantopus scaber* extract (local medicinal plant) for banana preservation.

The utilization of *Elephantopus scaber* extract is not yet commonly used in fruit coatings; thus, this research offers a locally sourced natural material that remains underutilized. Additionally, the use of cassava peel starch (agricultural waste) as a coating matrix adds value from both economic and environmental (biodegradable) perspectives [11]. This specific combination remains largely unexplored. The holistic approach to preserving bananas in this study not only focuses on a single aspect, such as antimicrobial properties, but also integrates the antioxidant effects, respiration inhibition, and the physical protection provided by the coating to extend the shelf life of Cavendish bananas.

The purpose of this study is to develop an edible coating derived from cassava peel starch and fortified with *Elephantopus scaber* leaf extract at two concentrations (5 mg/mL and 10 mg/mL). FTIR spectroscopy was used to characterize the functional groups present in the coating. The analysis aimed to: 1) identify the main functional groups (O-H, C-O, C=O, C-O) in both extracts, 2) confirm the successful incorporation of the *Elephantopus scaber* extract in to the starch matrix by detecting additional absorption bands; and 3) detect absorption bands consistent with the presence of phenolic and aromatic compounds. It is important to note that FTIR analysis alone cannot definitively confirm the presence of specific bioactive compounds such as flavonoids or phenolics; further quantitative analyses (e.g., Folin–Ciocalteu for total phenolic content, DPPH for antioxidant activity) would be required for definitive confirmation [12].

This study also evaluates the efficacy of the coating in preserving the postharvest quality of Cavendish bananas over a 15 days of storage by monitoring key physiological parameters, including weight loss, moisture content (peel and pulp), and fruit firmness. Ultimately, this research aims to establish a correlation between the functional properties of the coating—identified through the presence of bioactive compounds—and its performance in reducing ripening-related degradation and moisture loss. These findings contribute to the development of a natural, sustainable fruit preservation method.

2. Materials and Methods

2.1 Plant Material and Research Location

Fresh leaves of *Elephantopus scaber* L. were collected from the surrounding area of the Sekolah Tinggi Ilmu Pertanian campus in Jember, East Java, Indonesia. Plant species identification was performed morphologically based on local flora and taxonomic keys [13]. No voucher specimen was deposited for this study. Cassava peels were obtained as agricultural waste from a local cassava processing unit in Jember. The cassava variety used was *Manihot esculenta Crantz* var. local. The experimental work was performed at the Plant-Microbe Interaction Laboratory, Center for Development of Advanced Sciences and Technology (CDAST), University of Jember.

2.2 Extraction of Elephantopus scaber

Fresh *Elephantopus scaber* leaves were cut into small pieces, washed with tap water followed by distilled water, and dried in a forced-air laboratory oven at 32°C ± 2°C for 14 days until constant weight was achieved. The dried leaf samples were ground using a blender and sieved through an 80-mesh sieve (177 µm opening) to obtain a simplicia powder. The simplicia powder (50 g) was subjected to maceration using methanol as the extraction solvent with a solvent-to-material ratio of 3:1 (v/w) was used, meaning 150 mL of methanol was added to 50 g of simplicia powder. The mixture was incubated for 48 hours at room temperature (25°C ± 2°C) with continuous shaking at 120 rpm using an orbital shaker. No additional extraction cycles were performed; single cycle maceration was used. After incubation, the liquid extract was filtered through Whatman No. 1 filter paper. The filtrate was then concentrated using a rotary evaporator (Buchi R-300, Switzerland) under reduced pressure at 50°C, with rotation speed set at 80 rpm, for approximately 45 minutes until a dry paste was obtained. The resulting paste was further dried in a vacuum oven at 45°C for 24 hours to remove residual solvent. The dried extract was stored in an airtight container at 4°C until further use [8]. The extraction yield was calculated using the Eq. (1).

$$\text{Yield (\%)} = \left(\frac{Weight\ of\ extract}{Weight\ of\ dry\ powder}\right) \times\ 100\% \tag{1}$$

The extraction yield of *Elephantopus scaber* extract was 12.4% (w/w) based on dry plant material. This information is important for reproducibility and for interpreting the extract concentrations used in this study. This value is consistent with previous studies, which reported extraction yields ranging from 10.5–13.2% depending on extractions [8,14].

2.3 Extraction of Cassava Peel Starch

Fresh cassava peels were collected from a local cassava processing unit in Jember, East Java, Indonesia. The peels were thoroughly washed to remove dirt and other contaminants. The outer brown layer of the peel was discarded, and only the inner white layer (phelloderm) was taken for starch extraction. To remove hydrogen cyanide (HCN) content, the inner peel layer was soaked in tap water (1:3 w/v ratio, 1 kg peels in 3 L water) at room temperature (25°C ± 2°C) for 24 hours. The soaking water was replaced every 8 hours to facilitate HCN removal [9]. After the soaking period, the peel pieces were rinsed thoroughly with distilled water. The soaked and rinsed peel pieces were ground by blending with distilled water at a water-to-peel ratio of 5:1 (v/w), meaning 500 mL of distilled water was added for every 100 g of inner peel layer. The resulting slurry was filtered using a cloth, and the filtrate was allowed to settle undisturbed for 24 hours at room temperature. Following this period, the clear supernatant was carefully decanted. The remaining sediment (starch) was then collected and oven-dried at 50°C for 8 hours. The dried starch was then ground and sieved using an 80-mesh sieve [15].

2.4 Coating Solution Preparation

Cassava peel starch powder (10 g) was dissolved in 100 mL of distilled water and stirred until homogeneous. Subsequently, 0.1 g of carboxymethyl cellulose (CMC) and 1 mL of glycerol were added as plasticizers while heating and stirring continuously. The mixture was heated to 70°C and maintained at this temperature for 30 minutes to allow gelatinization. After that, *Elephantopus scaber* extract was added at concentrations of 0 mg/mL (positive control, designated as C+), 5 mg/mL (Es 5), and 10 mg/mL (Es 10) based on the final volume of the coating solution. The extract concentrations (5 mg/mL and 10 mg/mL) were selected based on previous research by Rejeki et al. [8], which demonstrated that 5 mg/mL of *Elephantopus scaber* extract exhibited the best antimicrobial activity against plant pathogens, including both fungal and bacterial species. These concentrations were chosen to ensure that the coating formulation would possess adequate antimicrobial properties to protect banana fruits during storage. The extract was added gradually while continuing to heat and stir until the suspension became viscous (approximately 10–15 minutes). Once the process was complete, the solution was cooled to 30°C before application [15]. All coating solutions were prepared fresh on the day of application.

2.5 Application of Coating on Bananas

Fresh, unripe Cavendish bananas of uniform size, color (green, maturity stage 2), and free from visible defects were selected for this study. Before application, the bananas were weighed individually. Four treatment groups were prepared as follows:

Negative control (uncoated): Bananas were dipped in distilled water for 1 minute to account for the dipping effect, then air-dried under the same conditions as the coated samples.

Positive control (coated with cassava peel starch only, 0 mg/mL extract): Bananas were dipped in the starch coating solution without *Elephantopus scaber* extract for 1 minute.

Es 5 treatment: Bananas were dipped in the coating solution containing cassava peel starch with 5 mg/mL *Elephantopus scaber* extract for 1 minute.

Es 10 treatment: Bananas were dipped in the coating solution containing cassava peel starch with 10 mg/mL *Elephantopus scaber* extract for 1 minute.

The coating was applied by dipping each banana into the respective solution for 1 minute until the peel surface was fully covered. After dipping, all bananas (including the negative control) were air-dried at 25°C ± 2°C and 60% ± 5% relative humidity (RH) for 1 hour and subsequently stored at room temperature (28°C ± 2°C, 70%–80% RH). The bananas were then weighed again. Subsequent weighings were conducted on days 0, 5, 10, and 15 [16]. Each treatment consisted of three replications (n = 3), with three bananas per replication.

2.6 Fourier Transform Infrared (FTIR) Test

Sample preparation: FTIR analysis was performed on two types of samples: (1) pure cassava peel starch powder and (2) *Elephantopus scaber* extract powder. Coated banana peel samples were not analyzed in this study. All FTIR spectra were recorded using a Shimadzu IRTracer-100 FTIR spectrophotometer (Shimadzu Corporation, Kyoto, Japan) equipped with a deuterated triglycine sulfate (DTGS) detector. The samples were ground with spectroscopic grade KBr powder at a ratio of 1:100 (sample: KBr) and pressed into transparent pellets using a hydraulic press at 10 tons/cm^2 for 2 minutes. All spectra were recorded in transmittance mode over the wavenumber range of 4000-400 cm^{-1} at a resolution of 4 cm^{-1} with 32 co-added scans per sample. The background spectrum was recorded before each sample measurement and automatically subtracted from the sample spectrum using the instrument's software (Shimadzu IR solution) to eliminate atmospheric interference (CO_2 and H_2O). The purpose of FTIR analysis was to characterize the functional groups of the coating components and to identify sigantures (flavonoids and phenolics) from the extract [12,17] .

2.7 Parameters Evaluated

During banana ripening, the following parameters were evaluated: visual changes, weight loss, moisture content (pulp and peel), and firmness.

2.7.1 Weight Loss

Weight loss was measured based on the method described by Pham et al. [18] where changes in sample weight were determined by weighing the coated samples on predetermined days during storage. The initial sample weight was recorded on Day 0. Weight loss was calculated using Eq. (2).

$$Weight\ Loss\ (\%) = \frac{(W^0 - Wt)}{W^0} \times 100 \quad (2)$$

Description:
W_0 = Sample weight on day 0 (g)
Wt = Sample weight on day *n* (g)

2.7.2 Moisture Content

The moisture content of the bananas was measured using the gravimetric method (oven drying) according to the Association of Official Analytical Chemists (AOAC) [19]. Fresh banana samples were peeled and thinly sliced (± 2 mm) or homogenized to ensure even drying. A sample of 5–10 grams (W_1) was weighed using an aluminum dish of known empty weight (W_0). Drying was performed in an oven at 105°C for 24 hours or until a constant mass was attained. Following drying, the sample dish was allowed to cool in a silica gel desiccator for 15 minutes to prevent the uptake of atmospheric moisture. The weight of the dried sample (W_2) was then re-weighed using an analytical balance with an accuracy of 0.001 g. Moisture content was calculated using Eq. (3):

$$Moisture\ Content\ (\%) = \frac{(W^1 - W^2)}{(W_1 - W_0)} \times 100 \quad (3)$$

2.7.3 Firmness

Fruit firmness was measured using a penetrometer (Fruit Penetrometer GY3 Hardness Tester). Measurements were taken at the top, middle, and bottom portions of each fruit, and the average of the three readings was recorded as the firmness value. The result was expressed in kilopascals per square centimeter (kPa/cm^2) [20].

2.8 Statistical Analysis

The experiment was arranged using a Completely Randomized Design (CRD) with a factorial pattern consisting of two factors: extract concentration (0 mg/mL, 5 mg/mL, 10 mg/mL) and storage duration (0, 5, 10, and 15 days). Each treatment combination was replicated three times ($n = 3$). The data obtained were analyzed using two-way Analysis of Variance (ANOVA) at $\alpha = 0.05$ (5% significance level) and $\alpha = 0.01$ (1% significance level). When significant ($p < 0.05$) or highly significant ($p < 0.01$) differences were detected for either factor, the analysis was continued with Duncan's Multiple Range Test (DMRT) as the post hoc test to determine which specific treatment means differed significantly at $p < 0.05$.

3. Results and Discussion

Fig. 1 illustrates the color changes observed in Cavendish bananas over 15 days of storage under various coating treatments. The treatments included a negative control without coating (C−), a positive control with cassava peel starch coating only (C+), cassava peel starch coating with 5 mg/mL *Elephantopus scaber* extract (Es 5), and cassava peel starch coating with 10 mg/mL *Elephantopus scaber* extract (Es 10). The color transition of bananas from green to yellow and eventually to brown is a primary indicator of ripening and quality decline, mainly attributed to polyphenol oxidase activity and chlorophyll degradation. By day 5, bananas in the C− treatment already exhibited signs of accelerated ripening compared to the coated treatments.

The C+, Es 5, and Es 10 treatments were more effective in maintaining green or light yellow color compared to C−, indicating that coatings containing cassava peel starch and *Elephantopus scaber* extract can inhibit the ripening process. This is likely due to the presence of antioxidant compounds and the film-forming properties of cassava peel starch, which creates a semi-permeable layer that reduces respiration and transpiration rates. After 10 days of storage, the differences became more distinct. Bananas from the C− treatment developed significant brown spots, while the Es 5 and Es 10 treatments maintained a fresher appearance with more uniform yellow color. By day 15, bananas from the C− treatment exhibited severe browning, whereas the Es 10 treatment showed the greatest effectiveness in preserving visual quality. The positive control C+ also performed well, but the Es 10 coating appeared superior in inhibiting color changes. These findings align with Maqbool et al. [21], who demonstrated that natural-based edible coatings—

including those derived from cassava peel starch and plant extracts—can extend fruit shelf life by reducing respiration rate and inhibiting enzyme activity. Similarly, Versino et al. [22] reported that starch coatings act as effective oxygen barriers, thereby slowing oxidation and color changes.

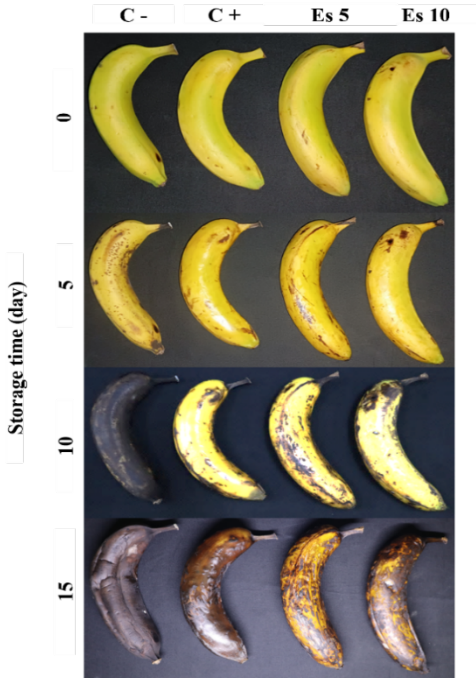

Fig. 1. Visual changes of Cavendish bananas during 15 days of storage at room temperature.

Table 1. The two-way ANOVA result for weight loss in Cavendish bananas.

Source of Variation	SS	Df	MS	F-Value	Significance
Treatment	234.78	3	78.26	4.02	p < 0.05
Day	12456.90	3	4152.30	289.45	p < 0.01
Interaction	98.34	9	10.93	1.89	ns
Error	276.50	48	5.76	-	-

Note: *ns = not significant.*

As described in Section 2.3, the concentrations of 5 mg/mL and 10 mg/mL were selected based on the study by Rejeki et al. [8], which demonstrated that 5 mg/mL of *Elephantopus scaber* extract provided the best antimicrobial activity against plant pathogens. Previous research has shown that *Elephantopus scaber* extract effectively inhibits the growth of *Phytophthora nicotianae, Ralstonia solanacearum*, and *Xanthomonas oryzae* [8]. By suppressing microbial growth on the fruit surface, the coating reduces respiration and transpiration rates, thereby minimizing weight loss. Based on the weight loss observations of Cavendish bananas across four treatments over 15 days of storage, a pattern consistent with postharvest theory was observed: weight loss increased with storage duration. This is attributed to two main physiological processes: transpiration (evaporation of water from the fruit tissue) and respiration (breakdown of metabolites to produce energy).

The ANOVA results (Table 1) showed that the treatment factor had a significant effect ($p < 0.05$) on weight loss, with an F-value of 4.02, while the storage day factor had a highly significant effect ($p < 0.01$), with an F-value of 289.45. The interaction between treatment and day was not significant ($p > 0.05$), indicating that the effect of treatment on weight loss was consistent across storage days.

Table 2. Duncan's Multiple Test post hoc for weight loss at day 15.

Treatment	Mean (%)	DMRT Notation ($p < 0.05$)
Es 10	29.66	a
Es 5	32.45	ab
C+	33.01	b
C-	47.33	c

Table 3. Duncan's Multiple Test post hoc for weight loss across storage days (all treatment combined).

Day	Mean (%)	DMRT Notation ($p < 0.05$)
H0	00.00	a
H5	10.38	b
H10	21.86	c
H15	35.61	d

The negative control C−, which received no protective treatment, exhibited the highest weight loss (47.33% at day 15). Based on Table 2, Es 10 (29.66%) was significantly different (denoted by "a") from C+ (33.01%, "b") and C− (47.33%, "c"), while Es 5 (32.45%, "ab") was not statistically different from either Es 10 or C+. As shown in Table 3, weight loss increased significantly ($p < 0.05$) with each storage day, from 0.00% at Day 0 to 35.61% at Day 15. These results indicate that Es 10 was statistically superior to C+ and C− in reducing weight loss.

The superior performance of Es 10 over Es 5 can be explained by the characteristics of the formed layer. A higher coating concentration tends to form a thicker and more compact film, thereby exhibiting lower water vapor permeability compared to the thinner layer from a lower concentration. The ability of Es 5 and Es 10 to reduce weight loss can be attributed to the antimicrobial properties of *Elephantopus scaber* previously documented [8]. Research has shown that crude methanol extract of *Elephantopus scaber* at 15% concentration can inhibit mycelial growth of postharvest pathogenic fungi such as *Colletotrichum sp., Fusarium solani*, and *Pyricularia oryzae* [8]. The antimicrobial activity of edible coatings has been widely reported, with various biopolymers demonstrating effectiveness in reducing microbial spoilage and extending fruit shelf life [23].

Regarding the performance of the plain starch coating (C+) compared to Es 5, Table 2 shows that C+ (33.01%) and Es 5 (32.45%) were not statistically different (sharing notation b and ab). This phenomenon can be explained by the plasticizing effect or threshold concentration effect. At low concentration, Es 5 *Elephantopus scaber* extract may act as a plasticizer that disrupts the starch polymer network, creating micro-channels or increasing free volume within the film, thereby increasing its water vapor permeability [18,20]. Conversely, at 10 mg/mL Es 10, the concentration of bioactive compounds reaches a threshold where they can effectively interact with the starch polymer matrix, possibly through cross-linking interactions, creating a more compact and less permeable film [22,24].

All coating treatments demonstrated the ability to inhibit moisture loss compared to the uncoated control (C−).

Table 4. The two-way ANOVA results for pulp moisture content of Cavendish bananas.

Source of Variation	SS	Df	MS	F-Value	Significance
Treatment	96.34	3	32.11	2.89	ns
Day	3421.20	3	1140.40	48.12	p < 0.01
Interaction	101.45	9	11.27	1.34	ns
Error	283.40	48	5.90	-	-

Table 5. Duncan's Multiple Test post hoc results for pulp moisture content across storage days.

Days	Mean (%)	DMRT Notation (p < 0.05)
H0	75.50	a
H5	86.05	b
H10	90.35	c
H15	90.33	c

The ANOVA results (Table 4) showed that the storage day factor had a highly significant effect ($p < 0.01$) on pulp moisture content, while the treatment factor was not significant ($p > 0.05$). Table 5 confirms that moisture content increased significantly from Day 0 (75.50%, notation a) to Day 5 (90.35%, notation c) and Day 10 (90.33%, notation c), then decreased at Day 15 (86.05%, notation b). This pattern was consistent across all treatments.

Table 6. The two-way ANOVA results for peel moisture content.

Source of Variation	SS	Df	MS	F-Value	Significance
Treatment	424.67	3	141.56	16.72	p < 0.01
Day	462.89	3	154.30	34.56	p < 0.01
Interaction	213.45	9	23.72	5.89	p < 0.01
Error	192.30	48	4.01	-	-

Table 6 shows a different pattern. Both treatment and storage day had highly significant effects ($p < 0.01$), and their interaction was also significant ($p < 0.01$), indicating that treatment effects on peel moisture content varied across storage days.

For peel moisture content, as presented in Tables 7 and 8, the data show that Es 5 and C+ performed differently across storage days due to the significant interaction effect. At Day 10, C+ (83.44%) was significantly higher than Es 5 (80.23%). This suggests that the addition of a low concentration of *Elephantopus scaber* extract (5 mg/mL) may actually be counterproductive to film integrity and peel moisture retention. This phenomenon can be explained by the plasticizing effect at suboptimal concentrations [24,25]. At 5 mg/mL, the extract may disrupt the starch polymer network, creating micro-channels that increase water vapor permeability [26,27]. Conversely, at 10 mg/mL (Es 10), the concentration is sufficient to form a homogeneous distribution within the starch matrix, resulting in a more compact and less permeable film [28].

The ability of *Elephantopus scaber* extract to maintain moisture content is also supported by its antifungal activity [8], which reduces fungal infection and maintains peel integrity, thereby reducing water loss through transpiration [24].

Table 7. Duncan's Multiple Range Test post hoc results for peel moisture content by treatment and storage day.

Treatment	H0	H5	H10	H15
C-	89.4a	83.2b	80.6c	82.8b
C+	89.4a	86.8b	83.44c	79.2d
Es 5	73.6a	83.2c	80.23b	74.4a
Es 10	79.6a	84.8b	80.49a	80.2a

Note: *Different letters within each treatment indicating significant differences between storage days at p < 0.05*

Table 8. Duncan's Multiple Range Test post hoc results for peel moisture content between treatments for each storage day.

Day	DMRT Notation between Treatment			
H0	C- a	C+ a	Es 10 b	Es 5 c
H5	C+ a	Es 10 ab	C- b	Es 5 b
H10	C+ a	C- b	Es 5 b	Es 10 b
H15	C- b	Es 10 b	C+ c	Es 5 d

The ANOVA results (Table 9) showed that the storage day factor had a significant effect ($p < 0.05$) on fruit firmness, while the treatment factor and interaction were not significant. Table 10 shows that Day 5 had the lowest firmness (4.45 kPa/cm^2), denoted by "a," and was significantly different from Day 0, Day 10, and Day 15 (all denoted by "b").

Table 9. Two-way ANOVA results for fruit firmness.

Source of Variation	SS	Df	MS	F-Value	Significance
Treatment	82.45	3	27.48	1.25	ns
Day	624.32	3	208.11	4.89	$p < 0.05$
Interaction	241.10	9	26.79	2.10	ns
Error	510.60	48	10.64	-	-

Table 10. Duncan's Multiple Range Test post hoc results for fruit firmness across storage days.

Days	Mean (kPa/cm^2)	DMRT Notation ($p < 0.05$)
H5	4.45	a
H10	11.36	b
H0	15.82	b
H15	17.79	b

The initial decrease in firmness at Day 5 aligns with findings that the decrease in firmness during early storage is related to peak activity of pectinolytic enzymes [29,30]. On day 10, an increase in firmness was observed in all treatments, which may be attributed to changes in water content and soluble solids that affect firmness readings [31]. It is important to note that higher firmness at later storage days is not necessarily an indicator of better quality. Prolonged storage leads to water loss through transpiration, causing dehydration that can cause fruit tissue to deteriorate [32]. Therefore, firmness data must be interpreted together with moisture content data. By day 15, C− showed high firmness (19.9 kPa/cm^2), which likely indicates advanced dehydration. Es 10 showed the highest firmness (31.2 kPa/cm^2), but this should be interpreted cautiously as it may partially result from dehydration-induced toughening [29]. Direct measurement of cell turgor pressure and histological analysis would be needed to confirm whether this high firmness represents maintained freshness or advanced dehydration. The preservation of fruit firmness by Es 10 can also be associated with the antimicrobial properties of *Elephantopus scaber* documented in the literature [8], which may suppress cell wall-degrading enzyme activity [15,16]. However, this mechanism requires further investigation through direct enzyme activity assays. Overall, while Es 10 showed promising results in maintaining moisture content and reducing weight loss, the firmness data should not be overinterpreted as definitive evidence of quality improvement without supporting physiological data [31].

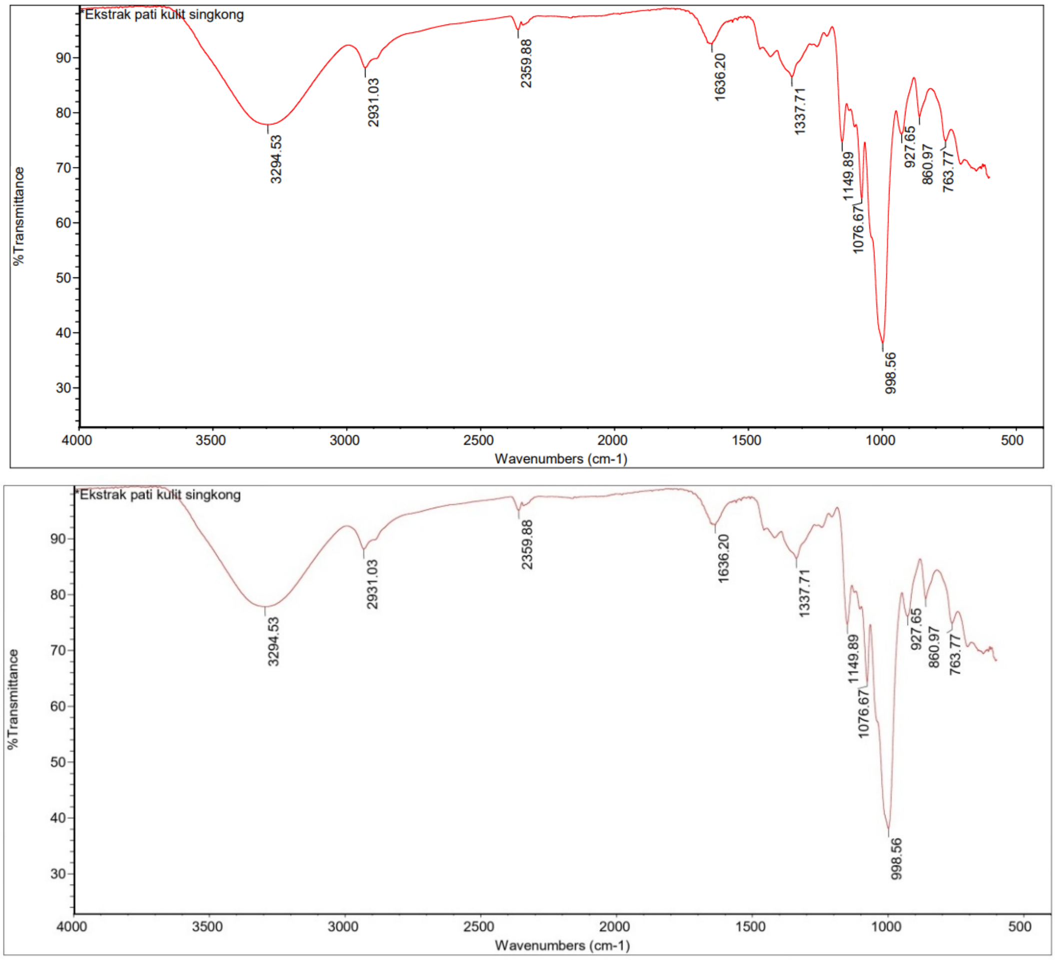

Fig. 2. FTIR spectrum of cassava peel starch extract.

The FTIR analysis of cassava peel starch presented in Fig. 2 shows the presence of functional groups that are relevant to edible coating applications. The absorption at 3294.53 cm^{-1} is characteristic of the O–H group involved in hydrogen bonding. Other absorptions include 2931.03 cm^{-1} (C–H stretching), 1636.20 cm^{-1} (C=O carbonyl), and peaks at 1076.67 cm^{-1}, 998.56 cm^{-1}, and 927.65 cm^{-1} (C–O stretching from the glycosidic bonds). These findings are consistent with previous research showing typical polysaccharide patterns [33]. The spectrum confirms that the extract is predominantly composed of starch, which has good potential as a base material for forming a film layer.

The absorption information in Fig.3. shows a peak absorption at 3324.80 cm^{-1}, characteristic of an O–H group. Previous research has shown that *Elephantopus scaber* contains bioactive compounds such as alkaloids, flavonoids, and tannins [8]; therefore, this O–H group is consistent with what would be expected from phenolic compounds. This is reinforced by absorption at 1733.49 cm^{-1} from the C=O bond of esters or carbonyls, which shows strong intensity, and absorption at 1615.54 cm^{-1}, characteristic of aromatic C=C bonds. Flavonoid compounds are known to contain aromatic rings. Meanwhile, absorptions consistent with C–O groups were found at 1234.32 cm^{-1} and 1027.09 cm^{-1}.

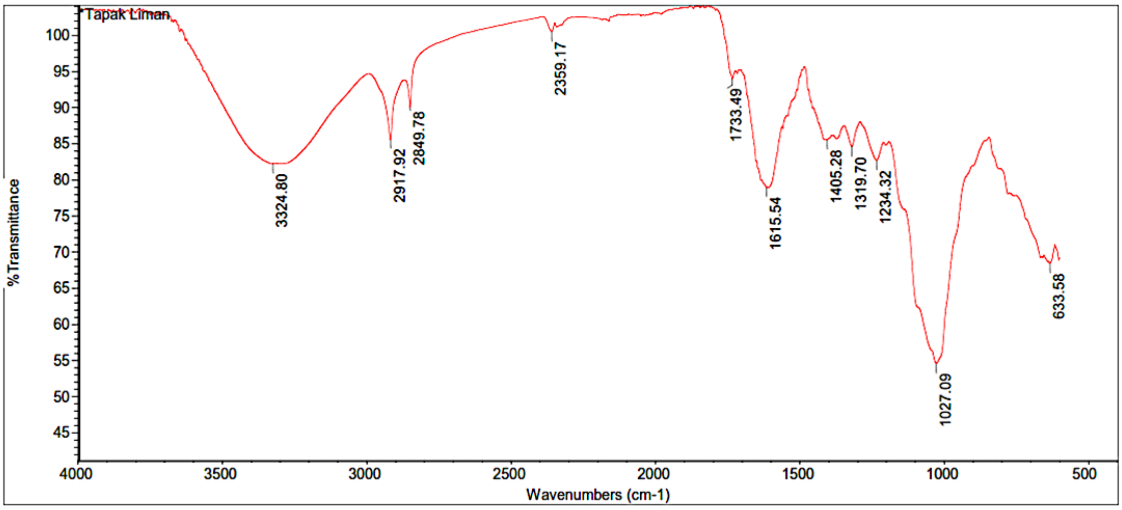

Fig. 3. FTIR spectrum of *Elephantopus scaber* extract.

The antimicrobial activity of *Elephantopus scaber* has been reported and attributed to these functional groups, particularly phenolic of groups and aromatic rings, which can interact with microbial cell membranes, causing disruption and cell death [34]. Research by Rejeki et al. [8] demonstrated that *Elephantopus scaber* extract at 5 mg/mL showed the best performance inhibiting plant pathogens, including *Phytophthora nicotianae*, *Ralstonia solancearum*, and *Xanthomonas oryzae*. However, it must be emphasized that direct antimicrobial assays were not conducted in this study, which is acknowledged as a limitation. Trace elemental analysis from previous research has also revealed that *Elephantopus scaber* leaves contribute to its biological activities [35]. FTIR analysis alone cannot confirm the specific presence of phenolic or flavonoid compounds. Further quantitative analyses (e.g. total phenolic content by Folin-Ciocalteu method, DPPH radical scavenging assay) are needed for definitive confirmation [36].

4. Conclusions

This study demonstrates that the combination of cassava peel starch and 10 mg/mL *Elephantopus scaber* extract (Es 10) offers a promising natural coating for extending the shelf life of Cavendish bananas. Statistical analysis (ANOVA and Duncan's Multiple Range Test at $p < 0.05$) revealed that Es 10 significantly reduced weight loss (29.66%) and preserved moisture content compared to controls, while the low-concentration extract (Es 5) was counterproductive due to the plasticizing effect. FTIR analysis confirmed cassava peel starch as a film-forming material and identified peaks in *Elephantopus scaber* consistent with phenolic compounds, though direct antioxidant assays are needed for confirmation. Future research should include respiration rate measurements, histological analysis, and food safety evaluations to fully validate the coating's commercial potential.

Abbreviations

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Desi Rejeki: Conceptualization, Data curation, Writing – original draft, Writing – review and editing. **Luqi Khoiriyah Latif**: Formal analysis, Funding acquisition, Supervision, Validation. **Anjakasi Mar'atul Ula**: Investigation, Methodology, Project administration. **Robby Akroman**: Resources, Software, Visualization

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.

Declaration of Use of AI in the Writing Process

The author(s) used Chat GPT during the preparation of this manuscript to [e.g., improve grammar, paraphrase text, enhance clarity]. After using the tool, the author(s) carefully reviewed and edited the content and take full responsibility for the content of the publication.

Acknowledgement

The authors gratefully acknowledge the financial support from Directorate of Research and Community Service, Directorate General of Research and Development, Ministry of Higher Education, Sciences, Research, and Technology of the Republic of Indonesia through the Beginner Lecture Research (PDP) grant (Contract No. 120/LL7/DT.05.00/PL/2025). We also extend our sincere appreciation to Hardian Susilo Addy, S.P., M.P., Ph.D for his technical contributions and valuable advice during this research.

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