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Formulation of a Protective Non-Edible Coating Incorporating Dawul Kurudu (*Neolitsea cassia*) Leaf Extract and Flaxseed (*Linum usitatissimum*) Gel for Extending the Postharvest Shelf Life of Bananas

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Abstract

Bananas are one of the most popular fruits in the world due to their delicious flavour, smooth texture, and high nutritional content. However, they are extremely susceptible to microbial contamination and post-harvest degradation during storage and transit, leading to large post-harvest losses. This study aimed to develop a non-edible protective coating using Dawul Kurudu (DK) leaf extract and flax (FX) seed gel to extend the shelf life of bananas. Cavendish bananas were harvested at 15 days after flowering and coated with formulations with varying FX gel-to-DK leaf extract ratios of 4:1, 3:2, 2:3, and 1:4. Changes in weight loss, pH, titratable acidity (TA), total soluble solids (TSS), and microbial colony counts were evaluated over a 15-day storage period in both coated and uncoated bananas. All treatments were performed in triplicate. When compared to the uncoated control, the coated bananas had significantly ($p < 0.05$) less weight loss, TA, and TSS over the storage time. The coating with an FX gel-to-DK leaf extract ratio of 2:3 exhibited the most effective efficacy among the tested formulations. Overall, the coatings made of FX seed gel and DK leaf extract effectively extended the shelf life of bananas. The best preservation effectiveness was observed with the FX gel-to-DK leaf extract ratio of 2:3, maintaining acceptable fruit quality for more than 12 days. These findings suggest that this natural, non-edible coating has the potential to serve as an effective and environmentally friendly method for extending the post-harvest shelf life of bananas.

Keywords: Banana; post-harvest loss; non-edible coatings; keeping quality; shelf life

1. Introduction

Banana (*Musa* spp.) is one of the most widely cultivated and consumed fruit crops in tropical and subtropical regions, serving as a major staple food and an important source of income for millions of people worldwide [1]. It contains nutrients in more balanced proportions than many other fruits [2]. Bananas are unique for their high caloric and nutritional value compared to many other fruits [3]. Despite their nutritional and economic value, bananas are extremely perishable due to their climacteric nature, which causes a rapid increase in respiration and ethylene production during ripening [4]. Consequently, they undergo rapid physiological and biochemical changes after harvest, including moisture loss, tissue softening, starch hydrolysis, chlorophyll degradation, and increased susceptibility to microbial spoilage, all of which significantly reduce marketable shelf life [3].

Postharvest deterioration of bananas is more severe in tropical environments, where high temperatures and relative humidity promote fruit ripening and microbial growth. These losses degrade fruit quality, limit marketability, and provide considerable economic challenges to farmers and distributors [5]. As a result, extending the banana postharvest shelf life has emerged as a primary objective in postharvest management in order to minimize losses and satisfy high demand in local and international markets.

Several preservation strategies have been developed to minimise fruit ripening and preserve quality throughout storage. These include refrigeration, chemical and thermal treatments, controlled and modified environment storage, and the use of antioxidants [4]. Although these methods can effectively extend shelf life, their practical application is frequently restricted by high operational costs, chilling injury during low-temperature storage, safety concerns about chemical preservatives, and undesirable changes in fruit flavour, texture, aroma, and overall consumer acceptability [6]. As a result, there is a growing interest in establishing natural, safe, and ecologically sustainable alternatives for postharvest preservation.

Among methods, edible and non-edible surface coatings have emerged as a cost-effective and environmentally friendly method for preserving the freshness of fresh fruits and vegetables [7, 8]. These coatings form a thin semi-permeable barrier on the fruit's surface, controlling gas exchange and water vapour transmission, reducing moisture loss, reducing respiration and transpiration, delaying ripening, maintaining firmness, preserving volatile flavour compounds, and inhibiting microbial growth [9]. In recent years, the integration of plant-derived extracts with antibacterial and antioxidant characteristics into coating formulations has received considerable attention as a viable technique to increase their protective performance and extend the shelf life of fresh produce [6].

In the current investigation, flaxseed (*Linum usitatissimum*) - (FX) gel and leaf extract from Dawul Kurudu (*Neolitsea cassia*) (DK) were used to develop a natural banana protective coating. DK is an underutilized plant species endemic to Sri Lanka that has bioactive chemicals in its leaves that have been shown to have antifungal and antibacterial properties. Previous studies have demonstrated that its leaf extract effectively suppresses spoilage microorganisms, thereby reducing postharvest microbial deterioration of fresh produce [10]. FX seed gel is a naturally occurring polysaccharide-rich hydrocolloid that has superior film-forming, water-holding, and gelling properties, making it a perfect coating matrix. Furthermore, FX seed gel enhances the structural integrity of coating films, reduces moisture loss, and shields fruit tissues from oxidative degradation, all of which contribute to better fruit quality and a longer shelf life [9]. The combination of these two natural materials is expected to provide a sustainable and environmentally friendly alternative to conventional postharvest preservation methods.

Therefore, the objective of this study was to develop a natural non-edible coating incorporating DK leaf extract and FX seed gel and to evaluate its effectiveness in extending the postharvest shelf life and maintaining the quality of bananas stored under ambient conditions.

2. Materials and Methods

2.1 Selection of materials

Bananas (Cavendish variety) at a correct maturity stage (12 weeks after flowering) were selected based on the harvest colour maturity guide and collected from a home garden in Badulla, Sri Lanka; DK leaves were collected from the Uva Wellassa University Garden; and FX seeds were obtained from an Ayurvedic medical store in Hambantota. The raw materials were carefully cleaned before extraction. The leaf extract was obtained by cutting 500 g of DK leaves into small pieces, blending, and filtering them through muslin material at room temperature. FX seed gel was made by boiling 300 g of FX seeds with 100 g of water (3: 1 seed-to- water ratio) in a water bath at 85 °C until the gel was released. Then gel was strained through a muslin cloth to separated. Extracted DK laves gel and FX seed gel were stored at 4 °C inside the refrigerator until further use [10].

2.2 Preparation of coating blends

Plant extracts were combined with food-grade glycerol to prepare four distinct coating formulations, as shown in Table 1. The resulting mixtures were stirred continuously for one hour to ensure complete dissolution of all components and to obtain uniform, homogeneous coating solutions. The prepared coating mixes were then kept at 4°C until use [10].

Table 1
Coating formulations with DK leaf extract and FX seed gel

Coating	Ratio	FX seed gel (g)	DK leaf extract (g)	Glycerol (g)
Coating 1 (C1)	1:4	10	40	10
Coating 2 (C2)	3:2	30	20	10
Coating 3 (C3)	2:3	20	30	10
Coating 4 (C4)	4:1	40	10	10

2.3 Determinations of the properties of formulated coating solutions

2.3.1. Viscosity Test

The viscosity of the coating solutions was measured according to the method described in [11] with a viscometer (Model No: 299300 · Brookfield, LVT). Freshly produced samples were allowed to equilibrate to room temperature (25 ± 2°C) before analysis. Approximately 100 mL of each solution was transferred to a clean beaker, and the appropriate spindle was selected based on the expected viscosity range. The spindle was submerged in the sample until the designated point, ensuring that no air bubbles were trapped. The viscometer was adjusted at 60 rpm and the viscosity was recorded in millipascal-seconds (mPa·s) when the reading stabilised. Measurements were taken in triplicate, and the mean viscosity with standard deviation was obtained.

2.3.2. Antioxidant activity

The antioxidant activity was determined with the ABTS radical cation scavenging assay [12]. The ABTS solution was prepared by dissolving ABTS salt in distilled water to obtain a 7 mM stock solution. The ABTS radical cation ($ABTS^{•+}$) was generated by reacting the ABTS stock solution with potassium persulfate at a concentration of 2.45 mM. To ensure complete radical formation, the mixture was incubated in the dark at room temperature for 12-16 hours. The $ABTS^{•+}$ solution was diluted with phosphate-buffered saline (PBS) to attain an absorbance of 0.70 ± 0.02 at 734 nm. The resulting coating solutions were then evaluated for antioxidant activity. The coated extract (100 μL^{-1} mL) was combined with the diluted $ABTS^{•+}$ solution and incubated at room temperature for 6 minutes. The absorbance of the reaction mixture was then measured at 734 nm with a spectrophotometer. The reduction in absorbance was utilized to determine the antioxidant capability of the coating formulations.

2.3.3. Transmittance test

The transmittance of the coating formulations was determined by preparing a series of dilutions (10^{-1} to 10^{-3}) with glycerol [13]. The absorbance spectra of the diluted coating solution were then measured with a spectrophotometer across a wavelength range of 400-734 nm. The transmittance properties of the coating were evaluated using the absorbance measurements obtained.

2.4 Application of coating on bananas

Disease-free Cavendish bananas with uniform size and at the same maturity stage (Stage 1; fully green, immediately after harvesting) were selected to ensure consistency among treatments. The fruits were properly cleaned with tap water to remove any adhered dirt and debris, followed by a rinse with distilled water to remove any remaining contaminants. The cleaned bananas were allowed to air-dry before being coated. The prepared coating formulations (Table 1) with varying ratios of DK leaf extract and FX seed gel were applied by immersing the bananas in the respective coating solution separately for 2 minutes to confirm uniform covering of the fruit surface. After coating, the fruits were removed and air-dried at room temperature until a thin, continuous coating layer developed. After that, the coated bananas were kept for 15 days at room temperature (25 ± 2 °C) for the evaluation of different parameters. Uncoated bananas were kept in the same environmental conditions as the control. The experiment was conducted in triplicate [13].

2.5 Determination of the physicochemical properties

2.5.1. Weight loss

Postharvest weight loss of coated and uncoated bananas was calculated by measuring each fruit every three days for the duration of the 15-day storage period. Before storage, the initial weight of each banana was recorded using a calibrated digital analytical balance. Subsequently, the fruits were weighed on days 3, 6, 9, 12, and 15 under the same conditions. The effectiveness of the coating formulations in reducing postharvest water loss was evaluated by comparing the percentage weight loss of coated fruits with that of the uncoated control. The percentage weight loss was calculated as the difference between the initial and final weights relative to the initial weight [14].

2.5.2. Titratable Acidity (TA), Total Soluble Solids (TSS) and pH

After the application of coatings, bananas were tested for titratable acidity (TA), total soluble solids (TSS), and pH at three-day intervals for 15 days, along with the control treatments. To determine the TA, TSS, and pH, bananas were crushed in a blender and filtered to obtain homogeneous samples for analysis. TSS was measured using a digital brix meter, and pH was measured using a digital pH meter. The TA was measured by titrating 10 mL extract with 0.1 N NaOH using phenolphthalein as an indicator [1].

2.5.3. Shelf life

Visual changes in texture and colour were observed, and microbial growth was monitored by culturing the inoculum in potato dextrose agar (PDA) medium at ambient temperature 25 ± 1 °C, which was taken from the surface of bananas. The cultured plates were observed after 48 hours' incubation [15].

2.6. Statistical analysis

Descriptive statistics, including mean, standard deviation, and graphs, were statistically assessed using MINITAB 17 software, and the significant differences among the treatments were analyzed by one-way ANOVA mean comparison for each coating with the control.

3. Results and discussion

3.1 Properties of the coating solutions

3.1.1 Viscosity, antioxidant activity, pH and transmittance

Table 2
Viscosity, Antioxidant activity, pH and Transmittance of the coating solutions

Coating property	C1	C2	C3	C4
Viscosity (mPa·s)	328 ± 4.5^a	265 ± 3.9^b	285 ± 4.1^b	176 ± 2.5^c
Antioxidant (%)	93.04 ± 0.02^a	92.72 ± 0.01^a	93 ± 0.04^a	92.8 ± 0.08^a
pH	7.54 ± 0.02^a	7.5 ± 0.04^a	7.51 ± 0.04^a	7.52 ± 0.02^a
Transmittance (%)	46 ± 0.01^b	46 ± 0.04^b	37 ±0.01^a	53 ± 0.02^c

C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4
Data represented as Mean ± standard deviation

According to Table 2, the viscosity of the formulated coatings ranged from 176 ± 2.48 to 328 ± 4.55 mPa·s, with significant differences observed among the formulations ($p < 0.05$). Coatings 1, 2, and 3 had much greater viscosity than C4. Increased viscosity is desired for edible and protective coatings, as it enhances the ability of the coating to uniformly cover and adhere to the fruit surface, resulting in the formation of a continuous protective film that reduces moisture loss and gas exchange [9]. The viscosity of the coating formulations followed the order C1 > C3 > C2 > C4. Among the treatments, C4 exhibited the lowest viscosity, which may have resulted in reduced coating adherence and film-forming ability on the banana surface.

The C3 formulation, including DK leaf extract and FX seed gel in a 2:3 ratio, exhibited the highest antioxidant activity with a value of 93.91 ± 0.04 %. However, all four formulations exhibited strong radical scavenging activity, indicating a high antioxidant capacity. High antioxidant activity in coating materials is an important functional property because antioxidants scavenge free radicals, suppress oxidative reactions, and reduce oxidative deterioration of fruit tissues, all of which help to maintain quality attributes and extend shelf life [14]. The high antioxidant capacity of the coatings can be attributed to the bioactive phytochemicals present in DK leaf extract, including phenolic compounds and flavonoids, while FX seed gel provides a stable polysaccharide matrix capable of retaining these active compounds [16]. In addition, DK leaf extract possesses excellent film-forming properties, making it a suitable natural material for the development of protective fruit coatings [4].

The pH values of all coating formulations were slightly alkaline and did not vary significantly between treatments. This pH range is unlikely to have a negative impact on the external appearance or internal texture of bananas during storage. Furthermore, slightly alkaline coatings are often compatible with fruit surfaces and do not accelerate tissue degradation or cause undesirable physicochemical changes [13].

The optical characteristics of the coatings also differed significantly between formulations. The maximum transmittance was recorded in C4, whereas C3 had the lowest, with a value of 39 ± 0.01%. A lower transmittance indicates a denser and more opaque coating matrix, which can offer better protection against UV and visible light penetration. Light exposure can influence chlorophyll breakdown and the development of yellow coloration in the banana peel and direct sunlight can heat the fruit, and higher temperatures can accelerate respiration and ripening. These coatings may also delay the chlorophyll breakdown in bananas [17]. In contrast, higher transmittance shown by C4 indicates a thinner and less thick film structure, allowing for greater light transmission and perhaps higher oxygen permeability. Consequently, coatings with lower transmittance are expected to provide better protection against environmental stresses while also improving banana postharvest preservation and shelf life [18].

3.2. Properties of the coated and uncoated bananas during storage time

3.2.1. Weight loss of bananas

The percentage weight loss of both coated and uncoated bananas increased progressively throughout storage, as predicted due to continual transpiration and respiration processes (Fig. 1). There was a significant difference ($p < 0.05$) between the coated treatments and the uncoated control in weight loss, indicating that the developed coatings effectively reduce postharvest moisture loss. Uncoated bananas exhibited the greatest weight loss during storage, whereas all coated fruits showed a reduced rate of weight loss, indicating that the coatings operated as semi-permeable barriers to water vapor and gas exchange. Coating C3 had the lowest postharvest weight loss (33.6 ± 0.04%), outperforming the other formulations. This higher performance of C3 is due to the synergistic combination of FX seed gel and DK leaf extract in a 2:3 ratio, which resulted in a cohesive covering with improved barrier properties. The gel of FX seeds generates a polysaccharide-rich matrix that efficiently reduces moisture migration, and the DK leaf extract provides film-forming properties that enhance the structural integrity of the coating [1]. The relatively higher viscosity and lower transmittance of C3 indicate the formation of a denser and more compact layer, decreasing water vapor permeability and respiration-driven weight loss.

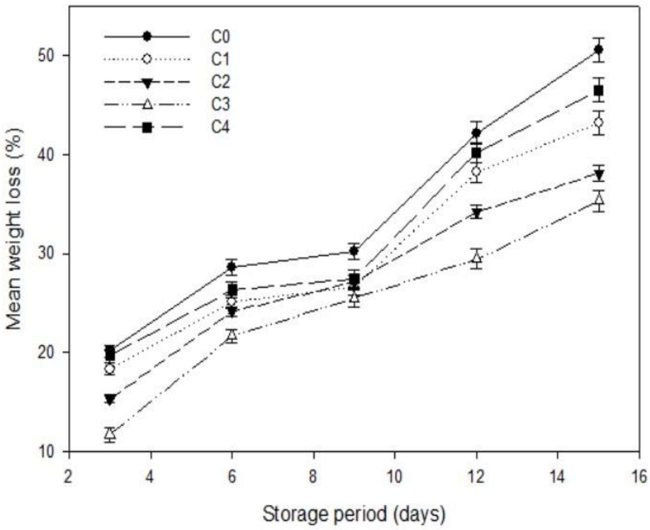

Fig. 1. Weight loss of coated and uncoated bananas during storage time (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4). Columns sharing the same letter are not significantly different at the 5% probability level ($P < 0.05$). Error bars represent the standard deviation of the mean.

The decrease in weight loss observed in coated bananas suggests that the coating successfully preserved fruit moisture content while delaying postharvest degradation [6]. By restricting moisture evaporation and decreasing metabolic activity, the coating helped preserve fruit quality and extended banana storage life when compared to the uncoated control. These findings indicate that the FX seed gel-DK leaf extract coating, especially at a 2:3 ratio, has great potential as a natural postharvest coating for reducing weight loss and preserving banana quality throughout storage.

3.2.2. pH.

The pH values of both coated bananas (C1, C2, C3, and C4) and the uncoated control were in the acidic range on the first day of storage (Fig. 2). However, the pH of all samples gradually increased over the storage time, indicating the natural ripening process of bananas. During fruit ripening, organic acids undergo metabolism by respiration and other biochemical processes, resulting in a steady decrease in acidity and an increase in pH [13]. The pH levels of coated bananas differed significantly ($p < 0.05$) from the uncoated control throughout storage. The edible coatings effectively delayed the pH increase compared to the control, indicating that the coatings acted as semi-permeable barriers to oxygen and carbon dioxide diffusion. This altered interior environment decreased respiration rates and delayed the metabolic consumption of organic acids, allowing fruit acidity to be maintained for a longer period of time [8]. The C3 was the most effective treatment in preventing the increase in pH during storage. The optimized combination of FX seed gel and DK leaf extract, which probably produced improved barrier qualities and reduced gas exchange, may be responsible for this better performance. In comparison to the other coating treatments, the slower respiration and delayed organic acid breakdown contributed to better preservation of the physicochemical quality of fruits and delayed the ripening process [13, 18].

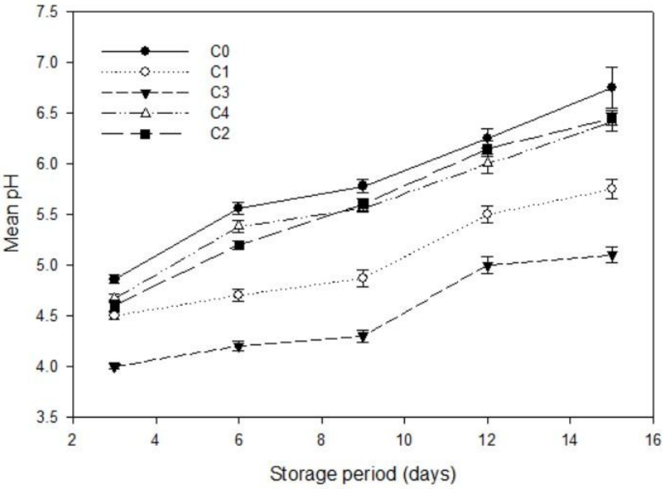

Fig.2. pH of coated and uncoated bananas during storage time (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4). Columns sharing the same letter are not significantly different at the 5% probability level ($P < 0.05$). Error bars represent the standard deviation of the mean.

3.2.3. Acidity

The TA of both coated and uncoated bananas progressively decreased over the period, as shown in Fig. 3. This decline is a characteristic phenomenon during fruit ripening since organic acids are continuously utilized as respiratory substrates and intermediates in various metabolic pathways [14]. During storage, a significant difference ($p < 0.05$) was observed in TA between the coated and untreated bananas. The uncoated control exhibited a greater reduction in TA than all coated treatments, indicating a more rapid progression of ripening. In contrast, the coated bananas maintained a higher TA during the course of storage, indicating that the coatings were successful in maintaining fruit quality. The metabolic consumption of organic acids during respiration is responsible for the decrease in TA. The edible coatings likely acted as semi-permeable barriers to oxygen and carbon dioxide, thereby reducing the respiration rate and slowing the metabolic utilization of organic acids [12,19]. Consequently, coated bananas exhibited a slower decline in TA than the control, indicating delayed ripening and improved maintenance of postharvest quality [6].

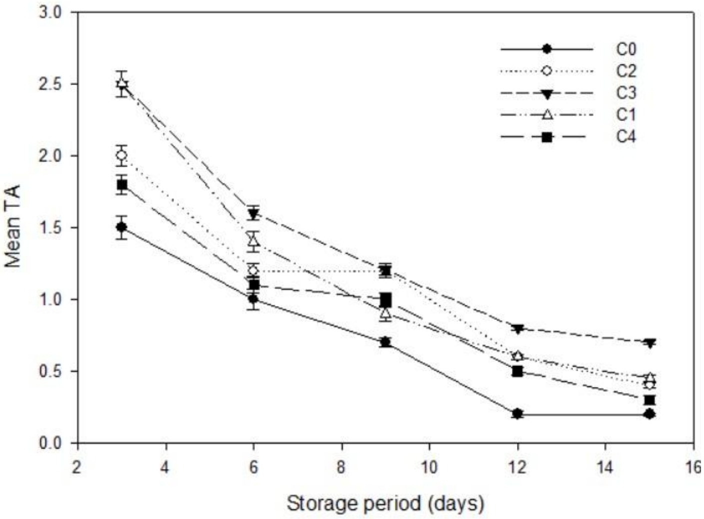

Fig. 3. Titratable acidity (TA) of coated and uncoated bananas during storage time (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4). Columns sharing the same letter are not significantly different at the 5% probability level ($P < 0.05$). Error bars represent the standard deviation of the mean.

3.2. 4. Total soluble Sugar content (TSS)

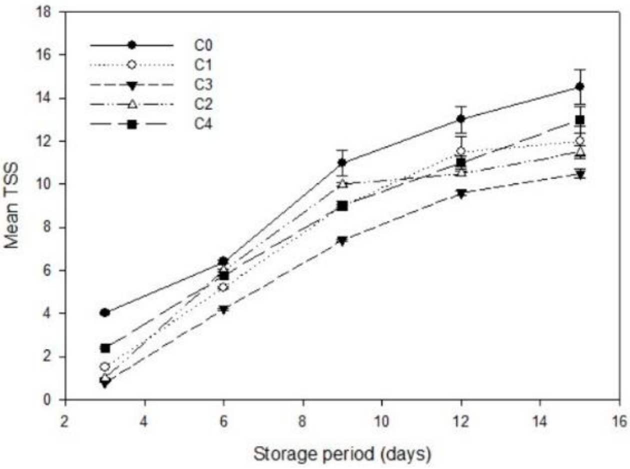

Fig. 4. Total soluble sugar (TSS) of coated and uncoated bananas during storage time (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4). Columns sharing the same letter are not significantly different at the 5% probability level ($P < 0.05$). Error bars represent the standard deviation of the mean.

The TSS level of both coated and uncoated bananas gradually increased over the period, as shown in Fig. 4, indicating the typical ripening process. All coated bananas showed a significantly lower ($p < 0.05$) increment in TSS when compared to the uncoated bananas, indicating that the coatings effectively delayed fruit ripening. Among the coated treatments, C3 had the lowest TSS levels during storage. The slower accumulation of soluble solids in C3 indicates that this formulation was more effective in lowering ripening-related physiological and biochemical alterations. As ripening progresses, the enzymatic breakdown of starch into soluble sugars, such as sucrose, is primarily responsible for an increase in TSS during storage [20]. The edible coatings most likely acted as semi-permeable barriers that regulate carbon dioxide and oxygen diffusion, reducing respiration rates and the activity of enzymes that hydrolyse starch. Consequently, the conversion of starch into soluble sugars was delayed, leading to a slower increase in TSS in the coated fruits compared with the control [13].

3.2.5. Shelf life

During storage, visual evaluation of banana morphology showed noticeable differences between the coated and uncoated fruits, especially on the third, ninth, and fifteenth days (Fig. 5a-c). As storage continued, the uncoated control showed fast degradation, including increased peel yellowing, extensive browning, surface shrinking, and loss of firmness. In contrast, bananas treated with the various coating formulations showed delayed ripening and senescence while maintaining a better external appearance. Among the coating treatments, C3 exhibited the best overall morphological characteristics throughout the storage period. In contrast to the other treatments and the uncoated control, bananas treated with C3 maintained their original peel colour, smooth surface, attractive form, and firm texture until the 12th day of storage. The synergistic effects of FX seed gel and DK leaf extract are responsible for the increased morphological quality shown in bananas treated with C3. The semi-permeable coating generated by the FX seed gel reduces respiration and transpiration rates by regulating oxygen and carbon dioxide exchange and preventing moisture loss [20]. In the meantime, the antibacterial and antioxidant bioactive chemicals found in DK leaf extract probably inhibited the growth of microbes and reduced oxidative degradation of the banana's surface. Together, these actions reduced peel discoloration and shriveling, postponed ripening, and preserved the overall marketable appearance of the bananas during storage [1,3,13].

Fig. 5a. Morphology of the banana after 03 days (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4).

Fig. 05b. Morphology of the banana after 09 days (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4).

Fig. 05c. Morphology of the banana after 15 days (C0- uncoated sample, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4).

3.3.2. Microbiology Analysis

The microbiological analysis showed that the coating formulations clearly had a significant ($p < 0.05$) impact on reducing microbial growth during storage (Table 03). On the third day of storage, microbial colonies were first observed on the uncoated control, indicating rapid microbial proliferation in the absence of a protective barrier. In contrast, with the exception of the C3 treatment, no apparent microbial colonies were found on any of the coated banana samples until the ninth day of storage. The C3 treatment had the highest level of antimicrobial efficacy among the coating formulations, leading to the maximum shelf life of 12 days. The delayed onset of microbial growth in the coated bananas indicates that the edible coatings modify the internal atmosphere of the fruit by reducing respiration and moisture loss, which creates an unfavorable environment for microbial growth [21]. This might be due to the presence of secondary metabolites with antibacterial and antioxidant properties in DK leaf extract [3,22]. The synergistic interaction of the coating components successfully postponed microbiological colonization and fruit rotting, prolonging the marketable shelf life of bananas compared with the uncoated control.

Table 3
Microbial Counts of the coated and non-coated samples within 15 days

Colony Forming Units (log CFU /g)	Storage Period (days)				
	3	6	9	12	15
C0	4.000 ± 0.04	4.30 ± 0.08	4.47± 0.04	4.88 ± 0.01	5.72 ± 0.06
C1	NG	NG	4.000 ± 0.01	4.48 ± 0.01	4.78 ± 0.02
C2	NG	NG	4.000± 0.02	4.30 ± 0.005	4.62 ± 0.01
C3	NG	NG	NG	4.00 ± 0.004	4.27 ± 0.01
C4	NG	4.30 ± 0.05	4.46 ± 0.01	4.85 ± 0.03	5.14 ± 0.05

C0 – Non coated, C1- coating 1, C2- coating 2, C3- coating 3, C4- coating 4
NG=Not Growing
Data represent as Mean ± standard deviation

5. Conclusion

The coated Cavendish banana with the FX seed gel and DK extract extended the shelf life compared to the uncoated banana. Among the coating formulations, the FX seed: DK ratio 2: 3 demonstrated the highest shelf life and keeping quality over a period of 12 days. To improve the shelf life and preserve the quality of the banana, this non-edible coating can provide significant protection against microbial development

Competing Interests
The authors have no competing interests to declare

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