Original Research Article

Effectiveness of Aloe Vera Gel Coating and Optimized Packaging Materials on Postharvest Quality and Shelf Life of Bananas (Musa acuminata)

ABSTRACT

To reduce post-harvest losses and extend shelf life, bananas (Musa acuminata cv. 'Cavendish') were treated with Aloe Vera Gel (AVG) coating and stored under ambient conditions (30 ± 2°C, 70 ± 5% relative humidity) for 9 days. This study compared uncoated controls with AVG-coated bananas stored in three conditions: unpackaged, packaged in kraft paper bags (25 x 40 cm), and packaged in low-density polyethylene (LDPE) bags (25 x 40 cm) with 1% perforation area (0.5 cm diameter holes). The assessment of the coating's effect on key quality parameters, including weight loss, change of colors, total soluble solids (TSS), titratable acidity (TA), shrinkage, and disease severity was done. The results demonstrated that AVG-coated bananas, particularly when paired with perforated LDPE packaging, significantly reduced weight loss (14% vs. 31% in controls), maintained better TSS (23.5% vs. 28% in controls) and TA changes, and markedly extended shelf life (10 days vs. 6 days in controls) compared to uncoated controls. Microbial analysis showed that AVG-coated fruits in LDPE packaging had significantly lower fungal growth compared to uncoated controls at 9 days after storage. These findings demonstrate that AVG coating offers a sustainable alternative to synthetic polymers for food preservation. The study concludes that AVG coatings, paired with suitable packaging, can effectively extend shelf life and maintain the quality of perishable produce such as bananas.

Keywords:Musa, Aloe, Shelf-life, Edible films, Product packaging

1. INTRODUCTION

Bananas (Musa acuminata) are the most widely cultivated and consumed fruit in tropical and subtropical regions, serving as a staple food for millions. They are rich in calories and nutrients, providing five times more vitamin A and iron, four times more protein, three times more phosphorus, and twice the carbohydrates of apples, along with other essential vitamins and minerals. They benefit patients with peptic ulcers, infant diarrhea, celiac disease, and colitis, and are also effective for gout, arthritis, kidney disorders, high blood pressure, and heart conditions (Robinson and Galán Saúco, 2010). As climacteric fruits, bananas are highly perishable, experiencing rapid biochemical changes after harvesting that significantly impact their storage quality, shelf life, and marketability (Mohapatra et al., 2010). During ripening, they undergo changes such as increased membrane permeability, reduced flesh firmness, starch depletion, higher sugar levels, color change, increased respiration, and loss of turgor, all of which affect consumer acceptance.

Skin color is a key ripening indicator and crucial for consumer acceptance, with bananas typically losing marketability within 1 to 3 days after turning yellow (Ahmed and Palta, 2016). Extending shelf life, even modestly, can significantly reduce losses, especially in regions lacking refrigerated storage, where bananas face the highest postharvest loss (22%) among fruits (Peroni-Okita et al., 2013). These losses are primarily due to rapid ripening, which involves complex physiological and biochemical processes (Jiang et al., 2000). Edible coatings effectively extend shelf life by protecting nutrients, reducing dehydration, suppressing respiration, enhancing texture, retaining flavor, and reducing microbial growth. These coatings create a modified atmosphere around the fruit, reducing respiration and oxidation rates (Ghasemzadeh et al., 2008)

Traditional synthetic coatings, mainly polyethylene-based, have been used to preserve perishable foods, but their associated chemical residues, including imazalil, thiabendazole, and sodium ortho-phenylacetate, and the rise of resistant pathogens have raised health and environmental concerns (Palou et al., 2015). Edible coatings from agricultural sources and food industry waste offer a safer alternative, modifying the atmosphere to reduce dehydration, slow respiration, improve texture, retain flavors, and inhibit microbial growth (Hassan et al., 2018). These coatings, made from biodegradable polysaccharides, lipids, and proteins, are environmentally friendly and consumable with the product (Khan et al., 2013).

Aloe vera (AV) is a short-stemmed succulent from the Asphodelaceae (formerly Liliaceae) family, grown in the dry regions of Africa, Asia, Europe, and the Americas, has shown efficacy in reducing respiration rates, preventing microbial spoilage, and maintaining firmness in fruits. It serves as an antifungal coating for fruits like avocados, bananas, blueberries, and strawberries (M. S. Benítez et al., 2013; Bill et al., 2014; Martínez-Romero et al., 2013; Vieira et al., 2016). AV also contains essential oils that enhance fruit appearance and inhibit Gram-positive and Gram-negative bacteria, making it an effective antifungal agent against postharvest diseases. As an edible coating, Aloe vera gel (AVG) significantly extends fruit shelf life by preserving firmness, color, and moisture, and preventing bacterial growth, offering a safe, eco-friendly alternative to synthetic preservatives (Habeeb et al., 2007; Parven et al., 2020). However, the effectiveness of AVG coatings on bananas, particularly in combination with different packaging materials, remains understudied. While traditional options such as the use of dried banana leaves have yet to be studied in depth, modified atmosphere packaging (MAP) shows promise by creating a low O2 and high CO2 environment (Mahajan et al., 2014), enhancing storability by affecting metabolism and decay-causing organisms (Workneh et al., 2009). The synergistic effect of AVG coating and various packaging materials on banana shelf life and quality has not been thoroughly investigated. This gap in knowledge is particularly relevant for countries like Bangladesh, where cold storage facilities are often unavailable near production centers due to frequent power shortages. Therefore, this study aims to address the effectiveness of AVG coating in extending the shelf life and quality of bananas under ambient conditions. It also examines whether combining AVG coating with various packaging materials (paper and perforated low-density polyethylene) improves its efficacy and explores the impact on key quality parameters in bananas.

2. MATERIAL AND METHODS

2.1 Collection of Materials and Sample Preparation

Freshly harvested mature bananas (Musa acuminata cv. 'Cavendish') and AV were collected from a local market of Rajshahi (24° 36′ 59.423″ N, 88° 59′ 74.665″ E), Bangladesh. This variety of banana was chosen due to its commercial importance and widespread cultivation in the region. Sorting was carried out manually based on freedom-free diseases and mechanical injuries. The selected bananas were washed, drained, sterilized with 0.1% sodium hypochlorite, rinsed with distilled water, and air-dried on filter paper before use, following the method described by Parven et al., (2020).

2.2 Preparation of Edible Coating of AVG

Aloe vera leaves were washed with a mild 100 ppm chlorine solution to prepare the gel. The extracted colorless hydro-parenchyma was homogenized and filtered to remove fibers. The mixture was further pasteurized at 70 ℃ for 45 min, cooled, and stabilized with ascorbic acid (2.0 ± 0.1 g/L). Citric acid (4.5 ± 0.1 g/L) was added to maintain pH at 4.0, as described by Martínez-Romero et al. (2006). A 1% (w/v) commercial gelling agent CMC was used to enhance coating efficiency and viscosity. This concentration was chosen based on preliminary experiments and previous literature demonstrating its effectiveness in fruit coatings (Parven et al., 2020).

2.2 Experimental Design and Treatments

Bananas were coated by dipping in undiluted AVG for 5 min and left to dry at room temperature (30 ± 2 °C), following the method of Parven et al., (2020). The study examined the impact of packaging materials on banana storage ability, following a completely randomized design (CRD) with four treatments:
T1 = Control (uncoated)
T2 = AVG coated
T3 = AVG coated and packed with perforated low-density polyethylene (LDPE)
T4 = AVG coated and packed with kraft paper bag
The LDPE bags (25 x 40 cm) had a 1% perforation area, consisting of 0.5 cm diameter holes evenly distributed across the surface. The kraft paper bags were of the same dimensions (25 x 40 cm). Each treatment involved four bananas to ensure statistical validity and account for variability in ripening and quality parameters.

2.3 Determination of Physical and Chemical Quality of the Fruits

2.3.1 Colour Change

Banana peel colour changes were evaluated visually during study period by keeping them under the light of same intensity and categorized into the following: entirely green, greenish-yellow, light greenish-yellow, and yellow, based on the Royal Horticultural Society colour chart (Sharmin et al., 2015). Skin color was subjectively assessed on a scale from 1 to 5, as defined by CSIRO (1971): 1 = Entirely green, 2 = Greenish yellow, 3 = Yellow, 4 = Yellow with dark freckles, 5 = Entirely dark. Observations were made at 1, 3, 5, 7, and 9 days after storage (DAS).

2.3.2Weight Loss (WL)

Bananas from each treatment were periodically removed, weighed, and returned to their original positions for subsequent measurements until the last day of storage. The weight loss percentage (WLP) was calculated by comparing the initial and final weights of the tested banana (Gol and Ramana Rao, 2011).

Weight loss (%)=(initial weight - final weight)/initial weight ×100%

2.3.3Total Soluble Solid (TSS)

Banana juice TSS was monitored using a refractometer (Model: Digital Hand-held Mode S Pocket Refractometer – ICPAL - S). Drops of juice from each fruit in all treatments (T1, T2, T3, T4) were evaluated for %TSS (%Brix) over the 9 days of storage. The refractometer was calibrated with distilled water before the analysis of samples for better accuracy (Sharmin et al., 2015).

2.3.4Titratable Acidity (TA)

After homogenization and centrifugation at 2000 rpm to remove fibers, the upper supernatant was filtered. 2 ml of the filtered juice was diluted to 25 ml and then titrated with 0.1 N NaOH using 3–4 drops of 1% phenolphthalein as an indicator until pink color appeared, signaling the endpoint. Results were expressed as the percentage of citric acid per 100 g of fresh weight (Gol and Ramana Rao, 2011).

Titratable Acidity = (equivalent weight of acid titre value × volume made up × normality of NaOH)/(volume taken for estimation × WT of sample × 1000)×100%

2.3.5Shelf Life

The shelf life of a fruit is typically defined as the number of days required to fully ripe, while maintaining its optimal marketing and eating qualities, starting from the day of harvest. In this study, however, the banana's shelf life was calculated from the day of treatment application until they held edible quality (Gol and Ramana Rao, 2011).

2.3.6Shrinkage

Shrinkage, resulting from moisture loss, affects the quality of any fruit by altering its volume. It can be measured by water displacement and is expressed as the ratio of the initial volume to the volume after moisture loss. This method almost entirely compensates for the volume lost due to moisture removal, with volume changes reflecting the removed water. A measuring cylinder was used for this purpose. A certain volume of water was placed into the cylinder, a banana sample was added, and the water volume was gradually increased. Different Banana samples gave different volume increases, enabling the calculation of individual shrinkage levels.

2.3.7Disease Incidence and Severity

Disease incidence and severity were visually observed and recorded throughout the 9-day storage period and ranked as 0–4 where: 0 = Healthy fruit with no lesions, 1 = 1%–25% of the fruit's surface covered with lesions, 2 = 26%–50% of the fruit's surface covered with lesions and soft rot, 3 = 51%–75% of the fruit's surface covered with water-soaked lesions and necrosis around the lesions, and 4 = 76%–100% of the fruit's surface covered with water-soaked lesions (Mendy et al., 2019). The percentage of disease incidence was calculated using equation:

Disease incidence (%) = (Number of tomato infected)/(Number of total tomato) × 100%

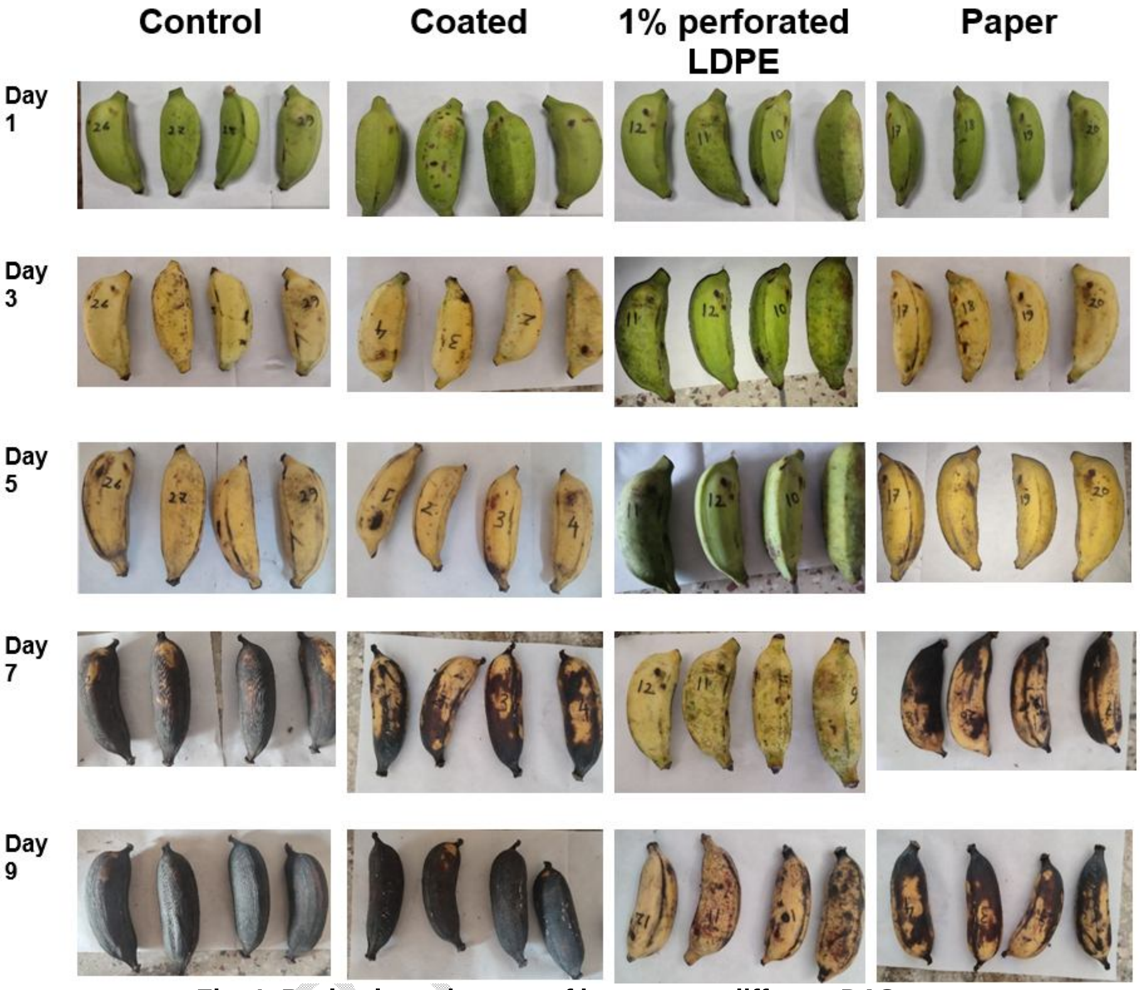

Fig. 1. Peel colour changes of bananas at different DAS

2.3.8Statistical Analysis

Analyses were performed in triplicate and results were expressed as the mean ± standard deviation (SD). All data were statistically evaluated using the SPSS program (IBM SPSS Statistic 25). The mean difference was compared using Duncan's new multiple range tests (DMRT) at a significance level of $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Colour Change

The peel color of all the stored bananas transitioned from green to yellow to dark, with treatment influence evident (Table 1). The uncoated control fruits (T1) exhibited quicker color changes and ripening than those exposed to the other treatments. At 5 days after storage (DAS), all fruits had turned yellow, except T3. Subsequently, T3 retained its edible quality till 9 DAS, while other treatments were severely affected and rotten. (Figure 1).

In bananas, peel color change during ripening results from chlorophyll degradation or the transformation of green pigments into other pigments. Coatings applied to fruits act as barriers that alter gas permeability, increasing internal CO2 levels. This modified atmosphere slowed ethylene production, delaying ripening and color change by inhibiting chlorophyll degradation, anthocyanin accumulation, and carotenoid synthesis (Parven et al., 2020). This mechanism slows down external and internal color changes by delaying chlorophyll degradation and carotenoid synthesis (Ergun and Satici, 2012). Coated carambola fruits have reported Similar color retention effects (Gol et al., 2015). Previous studies have showed that treatments with AVG and chitosan delay the loss of green color on fruit skins. Specifically, AVG on kiwifruits prevent browning and maintain green color by protecting chlorophyll from degradation (S. Benítez et al., 2013). The color was also better retained in papaya fruits noted by Brishti et al., (2013).

Table 1. Peel colour change of bananas during storage

Storage Period	1 DAS	3 DAS	5 DAS	7 DAS	9 DAS
Change of Peel Colour					
T1	Green	Yellow	Yellow with dark freckles	Entirely dark	Entirely dark
T2	Green	Yellow	Yellow	Yellow with dark freckles	Entirely dark
T3	Green	Green	Greenish yellow	Yellow	Yellow with dark freckles
T4	Green	Greenish yellow	Yellow	Yellow with dark freckles	Yellow with dark freckles

3.2 Weight Loss

During storage, all treatments experienced an increase in weight loss, notably mitigated in T3. T1 displayed the highest weight loss, peaking at around 31% at 9 DAS, while T3 exhibited the least weight loss, only 14%, attributed to the barrier effect of the polythene bag limiting gaseous exchange (**Table 2**). Differences between T2 and T4 were insignificant at 9 DAS, with T4 (30%) showing slightly lower weight loss compared to T2 (35.15%).

Weight loss in fruits typically results from dehydration and surface water loss. The reduction in weight loss can be attributed to the biopolymer coating, acting as a barrier to O_2, CO_2, and moisture, thereby lowering respiration, water loss, and oxidation reactions. Previous studies on citrus fruits, such as mangoes, have shown that prolonged ripening and storage periods lead to increased weight loss. (Abbasi et al., 2011). Moreover, AV's hygroscopic properties create a barrier to water diffusion, reducing weight loss in coated fruits. Similar reductions in weight loss have been observed in AVG-coated sweet cherries, table grapes, strawberries, and kiwifruits by maintaining surface moisture and creating a protective layer that minimizes water loss (Martínez-Romero et al., 2006; Valverde et al., 2005).

3.3 Total Soluble Solid (TSS)

Throughout the storage, TSS levels increased gradually in all fruits. T1 exhibited significantly higher TSS levels, reaching 28% at 9 DAS, while the coated treatments showed lower values, with T3 (23.5%) being the most effective in maintaining TSS levels throughout the storage period (Table 3). The increase in free sugar concentrations was delayed notably by the AVG, probably due to the semi-permeable film formed on the fruit surface, altering internal atmosphere conditions, and suppressing ethylene production, thus slowing ripening (Gol and Ramana Rao, 2011). AVG-coated sweet cherries and table grapes (Martínez-Romero et al., 2006; Valverde et al., 2005), and starch-coated strawberries (Mali et al., 2005) had been found to delay the increase in TSS. Similarly, Mendy et al., (2019) reported that papayas retained total TSS more effectively with AVG coating. While ripening typically increases TSS in fruits such as bananas, the lower TSS levels in this study may be due to reduced metabolic activity caused by the control of gas exchange from the coating. Conversely, the higher TSS values in uncoated fruits may result from the hydrolysis of starch and other compounds into soluble sugars, acids, vitamin C, amino acids, and pectin. (Peter et al., 2007).

Table 2. Weight loss (%) of bananas during storage

Storage Period	1 DAS	3 DAS	5 DAS	7 DAS	9 DAS
Weight Loss (%)					
T1	0.00^{a}	6.51 ± 0.06^{b}	15.99 ± 0.14^{b}	24.12 ± 0.14^{b}	31.77 ± 0.09^{b}
T2	0.00^{a}	7.77 ± 0.07^{a}	17.18 ± 0.15^{a}	26.24 ± 0.09^{a}	35.15 ± 0.08^{a}
T3	0.00^{a}	2.77 ± 0.11^{c}	6.74 ± 0.09^{d}	10.91 ± 0.08^{d}	14.47 ± 0.08^{d}
T4	0.00^{a}	6.48 ± 0.07^{b}	14.83 ± 0.06^{c}	22.68 ± 0.11^{c}	30.00 ± 0.09^{c}

**Values with different superscript letters a column are significantly different (P<0.05).*

3.4Titratable Acidity (TA)

Bananas see a rise in acid levels during ripening, mainly from malic, citric, and oxalic acids. Malic and citric acids contribute to the tartness of unripe bananas, while oxalic acid is responsible for their astringency. As ripening progresses, these acids decrease, yielding a sweeter taste from the hydrolyzed sugar produced from the starch degradation. In this study, TA increased gradually during storage, with T3 showing slower ripening compared to other treatments (**Table 3**). The AVG is likely to modify the internal atmosphere, reducing ripening and maintaining TA (Nabigol and Asghari, 2013). Acidity is crucial in fruit quality and acceptability, as excessively high and low acidity levels can negatively impact fruit quality.

Table 3. TSS (˚Brix) and TA (%) of bananas during storage interval

Storage Period	1 DAS	3 DAS	5 DAS	7 DAS	9 DAS
Total Soluble Solids (˚Brix)					
T1	0.40 ± 0.04^{a}	17.53 ± 0.13^{a}	23.60 ± 0.07^{a}	25.01 ± 0.08^{a}	28.19 ± 0.04^{a}
T2	0.40 ± 0.07^{a}	16.90 ± 0.08^{b}	22.54 ± 0.06^{b}	23.61 ± 0.08^{c}	25.40 ± 0.06^{c}
T3	0.40 ± 0.05^{a}	14.11 ± 0.08^{d}	18.40 ± 0.07^{c}	22.21 ± 0.10^{d}	23.52 ± 0.05^{d}
T4	0.40 ± 0.04^{a}	15.12 ± 0.08^{c}	23.54 ± 0.06^{a}	24.41 ± 0.08^{b}	26.12 ± 0.07^{b}
Titratable Acidity (%)					
T1	0.51 ± 0.06^{b}	0.84 ± 0.03^{b}	1.34 ± 0.05^{a}	1.67 ± 0.06^{a}	1.99 ± 0.07^{a}
T2	0.67 ± 0.06^{a}	1.06 ± 0.08^{a}	1.22 ± 0.05^{b}	1.38 ± 0.06^{b}	1.64 ± 0.05^{b}
T3	0.40 ± 0.03^{c}	0.77 ± 0.07^{b}	1.01 ± 0.05^{d}	1.17 ± 0.06^{d}	1.31 ± 0.06^{c}
T4	0.50 ± 0.03^{b}	0.83 ± 0.07^{b}	1.13 ± 0.05^{c}	1.28 ± 0.05^{c}	1.55 ± 0.08^{b}

**Values with different superscript letters a column are significantly different (P<0.05).*

3.5 Shrinkage

Shrinkage normally increases over time due to moisture loss during storage. In this study, the water displacement method was used to measure shrinkage based on weight loss, with T3 exhibiting slower shrinkage development compared to other treatments (**Table 4**).

AVG coating significantly retained fruit firmness during ripening compared to uncoated fruit, likely by reducing ethylene production and delaying ripening. (Arowora et al., 2013). Generally, fruit softening involves structural and compositional changes in the cell wall carbohydrates, partly due to the action of fruit-softening enzymes (Abbasi et al., 2011). This softening results from cell wall digestion by enzymes such as pectinesterase and polygalacturonase, a process accelerated by increased storage temperatures (Ahmed et al., 2009). Martínez-Romero et al., (2006) and Valverde et al., (2005) similar outcomes were reported in sweet cherries and table grapes.

3.6 Disease Incidence and Severity

During storage, disease incidence and severity indicated microbial infection of the banana. Although T1 began to show signs of disease at 3 DAS, reaching 27% incidence at 9 DAS, AVG-coated fruits were able to suppress disease development, with lower levels maintained by T3 (**Table 4**). This suggests aloe vera's antimicrobial potential to delay fungal growth and ripening. AVG coating decrease disease incidence by inhibiting the growth of spoilage organisms. Its antimicrobial properties help to maintain fruit integrity and extend storage life (Valverde et al., 2005). Moreover, the antimicrobial activity offers an extra layer of protection against common pathogens (Hassanpour, 2015). The outcome of Bautista-Baños et al., (2006) and Benhamou's, (1996) study also suggests the effectiveness of biopolymer coating in reducing microbial growth due to their antimicrobial properties, where they applied chitosan coating on tomatoes.

Table 4. Volume shrinkage (%) and Disease Incidence (%) of bananas during storage interval

Storage Period	**1 DAS**	**3 DAS**	**5 DAS**	**7 DAS**	**9 DAS**
Volume Shrinkage (%)					
T1	**0.00**^{a}	**8.25 ± 1.70**^{b}	**19.75 ± 2.50**^{a}	**33.25 ± 1.70**^{a}	**40.50 ± 2.65**^{a}
T2	**0.00**^{a}	**11.50 ± 2.08**^{a}	**20.50 ± 2.38**^{a}	**30.7 ± 3.30**^{ab}	**36.25 ± 2.75**^{b}
T3	**0.00**^{a}	**8.00 ± 1.82**^{b}	**12.75 ± 1.50**^{b}	**17.00 ± 1.82**^{c}	**20.25 ± 2.22**^{c}
T4	**0.00**^{a}	**9.50 ± 2.08**^{ab}	**17.75 ± 0.95**^{a}	**28.25 ± 1.71**^{b}	**36.75 ± 1.70**^{b}
Disease Incidence (%)					
T1	**0.00**^{a}	**6.25 ± 1.70**^{a}	**15.75 ± 2.50**^{a}	**22.25 ± 1.71**^{a}	**26.75 ± 3.50**^{a}
T2	**0.00**^{a}	**1.50 ± 1.30**^{b}	**7.25 ± 1.70**^{b}	**14.50 ± 2.94**^{b}	**22.75 ± 1.71**^{ab}
T3	**0.00**^{a}	**0.00**^{b}	**1.50 ± 1.30**^{c}	**8.00 ± 2.16**^{c}	**17.25 ± 2.74**^{c}
T4	**0.00**^{a}	**0.00**^{b}	**4.00 ± 2.16**^{c}	**10.00 ± 2.58**^{c}	**20.50 ± 2.89**^{bc}

**Values with different superscript letters a column are significantly different (P<0.05).*

3.7Shelf Life

Shelf life is a key quality of all fruits and crucial for reducing biochemical reactions. The shelf life of bananas varied significantly among the four treatments. The shelf life of bananas varied considerably across the four treatments (**Table 5**). The longest shelf life (10 days) was seen in T3, while T1 had the shortest (6 days). The antimicrobial properties of the coating might have helped to prevent fungal infections, preserving freshness and quality during storage (Hassanpour, 2015). A similar result was noted by S. Benítez et al., (2013) to extend the shelf life of kiwifruit by reducing weight loss and delaying ripening.

Table 5. Shelf life of bananas for different treatments

Treatments	Shelf Life (Days)
Weight Loss (%)	
T1	6
T2	7
T3	10
T4	8

4. CONCLUSION

AVG coating shows promise as a bio-preservative, significantly extending banana shelf life up to 10 days. Using a completely randomized design with four replications, this experiment assessed various treatments' effects on banana quality during storage. The results showed that the AVG coating, especially when combined with 1% perforated LDPE, performed best over the storage period. T3 also exhibited superior colour retention and lower disease incidence, with all treatments demonstrating similar effects on TSS, TA, and shrinkage. Thus, applying AVG coating with effective packaging materials can be a viable method to extend the shelf life of bananas.

AUTHORS' CONTRIBUTIONS

Tahmid Al Rifat and SK Fahim Tahmid Boni designed the study, performed the statistical analysis, wrote the protocol, andwrote the first draft of the manuscript. Md. Sajjad Hossain supervised the study. and S M Sohanur Rahman & S. M. Johir Rayhan managed the analyses ofthe study. Md. Zahir Mahmud managed the literature searches. All authors read and approved the final manuscript."

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