

EVALUATING THE EFFICACY OF THE ALOE VERA-BASED EDIBLE COATING COMBINED WITH LEMON OIL OR GARLIC OIL IN EXTENDING THE SHELF LIFE OF DWARF CAVENDISH BANANA

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ABSTRACT

The aim of this study is to assess the efficacy of the aloe vera - based edible coating (75%) combined with different lemon oil concentrations (0.2, 0.4, 0.6, 0.8 and 1.0%) or garlic oil levels (0.05, 0.1, 0.15, 0.2 and 0.25%) in extending the shelf life of bananas stored at 22 °C. The results indicated that increasing the lemon oil and garlic oil concentration from 0.2% to 0.4% and 0.05% to 0.15% led to an extended storage duration; however, a further increase beyond 0.4 - 1.0% and 0.15 - 0.25%, respectively resulted in a decline in shelf-life extension. The data showed that the edible coating containing 0.4% of lemon oil and 0.15% of garlic oil exhibited the most effective quality preservation, as reflected in key parameters including total acidity ($0.0186 \pm 0.0013\%$ vs $0.0219 \pm 0.0016\%$), total dissolved solid content ($19.00 \pm 0.40\%$ vs $18.13 \pm 0.23\%$), mass loss ($15.81 \pm 0.023\%$ vs $15.32 \pm 0.006\%$), firmness (618.90 ± 4.11 kg/cm³ vs 630.60 ± 1.26 kg/cm³), and color difference ($\Delta E = 15.43 \pm 0.70$ vs 15.70 ± 0.22). These findings demonstrate the potential of the aloe vera-based coatings incorporated with lemon oil or garlic oil as a viable postharvest preservation technique for bananas, offering an environmentally friendly and consumer-safe alternative. The application of this coating technology could benefit stakeholders, including banana producers, processing companies, distributors, etc. by enhancing fruit quality and extending marketability.

Keywords: Aloe vera edible coating, banana, garlic oil, lemon oil, preservation.

1. INTRODUCTION

Banana (*Musaceae* sp. L) is one of the most popular consumed fruits, alongside grapes, oranges and apples. It is cultivated in over 30 countries and ranks as the second most fruit worldwide, with an estimated annual output exceeding 139 million tons [1]. Despite its ease of cultivation, banana is highly susceptible to various insects and pathogens. These include the stem borer (*Cosmopolites sordidus*), which impedes stem development; the fruit borer (*Basilepta* sp.), which may render the fruit toxic and fungal pathogens such as *Colletotrichum musae*, the causative agent of anthracnose lesions [2].

Currently, postharvest disease management in bananas primarily relies on modern techniques such as dipping or spraying with chemical fungicides [3]. However, the growing resistance of insects and pathogens to these agents has led to their excessive application,

raising significant concerns regarding food safety, environmental contamination and human health risks. Consequently, there is increasing interest in natural, plant-based alternatives—such as aloe vera gel and essential oils—which offer promising potential as safe and eco-friendly methods for fruit preservation.

Aloe vera is a natural preservative known for its ability to suppress microbial growth and maintain the post-harvest quality of fresh vegetable and fruit [4]. Its primary bioactive constituents include chromones, anthraquinones, glycoside derivatives, phenylpyrones, flavonoids, phenylpropanoids, coumarins, phytosterols, lipids and various vitamins. Several studies have indicated that aloe vera-based coatings can inhibit fungi such as *Aspergillus niger* and *Penicillium digitatum*, while also limiting respiration and thereby extending fruit shelf life [5].

Lemon oil has been reported to possess strong antibacterial and antifungal properties, largely attributed to compounds such as limonene, γ -terpinene, β -pinene, α -terpineol, α -thujene, decanal, and octanal. Among these, decanal and octanal are particularly effective against fungal growth. Gordana Dimić et al. demonstrated the antifungal efficacy of lemon essential oil against *Aspergillus niger*, *Penicillium chrysogenum* and *Cladosporium cladosporioides* [6].

Garlic oil, extracted from *Allium sativum*, is another potent natural antimicrobial agent, rich in bioactive compounds such as allicin, diallyl disulfide, and ajoene. These components exhibit strong antibacterial, antifungal, antioxidant, and antimicrobial activities, making them promising candidates for reducing postharvest spoilage [7].

Despite the known properties of aloe vera and essential oils, no previous studies have investigated the combined use of aloe vera with either lemon or garlic oil for the preservation of ripe bananas. Therefore, the present study was conducted to evaluate the efficacy of aloe vera-based coatings enriched with lemon or garlic oil in extending the shelf life and maintaining the quality of ripe bananas.

2. MATERIALS AND METHODS

2.1. Banana and Aloe vera

Banana was randomly collected in Thanh Binh ward, Trang Bom district, Dong Nai province, Vietnam. Banana was collected after flowering from 85 to 90 days from the farmer garden with uniform shape and color, without signs of mechanical damage or fungal damage and each bunch was around 1.2–1.5 kg with mean length and diameter of banana fruit collected to be 95.6 ± 1.6 mm and 36.2 ± 1.2 mm, respectively. The samples were packed in sterile polyethylene bags, placed in cartons and transported on the same day to the laboratory of Ho Chi Minh City University of Industry and Trade. Afterwards, the banana was surface-sterilized using a 10% sodium hypochlorite solution (Xilong, China), rinsed thoroughly with sterile distilled water and air – dried at room temperature (29 – 31 °C).

Fresh and mature aloe vera leaves were collected in Ninh Thuan province, Vietnam which cultured from 6-8 month [8], leaf length 30-40 cm, upright leaves and no mechanical damage [9].

2.2. Aloe vera – lemon or garlic oil coating solution

Aloe vera leaves were washed in water (HUIT, Vietnam) containing 10% sodium hypochlorite solution (Xilong, China). The green outer rind was removed, and the inner gel was extracted and blended for 10–15 seconds using a blender (Midea MJ-BL45, China). The mixture was filtered to eliminate fibrous residues, yielding a fresh and pure aloe vera gel. The gel was then pasteurized at 70 °C in 45 minutes. After pasteurization, the aloe vera extract was

diluted with sterile distilled water (HUIT, Vietnam) to obtain the concentration of 75% (v/w). Subsequently, a chitosan solution (Tin Cay company, Vietnam) dissolved in 1% (v/v) acetic acid (Duc Giang, Vietnam) was added to the pure aloe vera extract at a 1:1 (v/v) ratio. This combination aimed to enhance the coating's efficacy by improving its viscosity and stability during application. Afterwards, glycerol (10 g/L) (Xilong, China) was then incorporated as a plasticizer. Next step, 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% of lemon oil and 0.05%, 0.10%, 0.15%, 0.20% and 0.25% of garlic oil (v/v, relative to the aloe vera mixture) (Oilcare, India)—were subsequently added. The final solution was homogenized at 17,000 rpm/10 minutes using a high-speed homogenizer (Ika, Germany).

Bananas mentioned in section 2.1 were immersed in the homogenized coating solution for 3 minutes and then air-dried at room temperature around 1 hour, and then placed in carton boxes for storage and subsequent analysis of postharvest quality parameters.

2.3. Evaluation of monitoring indicators

To assess the effectiveness of the edible coating formulations in extending the shelf life and maintaining the post-harvest quality of bananas, a comprehensive set of physicochemical and sensory parameters was monitored throughout the storage period. The key indicators included total acidity, soluble solid content, mass loss, firmness, and peel color—each providing critical insights into the ripening behavior, biochemical stability, and overall preservation capacity of the coating treatments. Measurements were performed at predetermined intervals (day 0, 4, 8, 12, 16, and 24).

2.3.1. Total acidity determination

A 20 g sample of banana pulp was homogenized and centrifuged to obtain a clear supernatant. One mL of the supernatant was transferred to a conical flask, diluted with an equal volume of distilled water, and made up to 15 mL. Two drops of 1% phenolphthalein indicator were added to the solution. The mixture was titrated with 0.1 N NaOH solution (Xilong, China) until a persistent pink endpoint (lasting 15–30 seconds) was observed. The volume of NaOH consumed was recorded, and total titratable acidity was calculated using the following formula [10]

$$\text{Titratable acid (\%)} = \frac{V_1 \times N_{\text{NaOH}} \times D}{V_0} \times 100$$

Where:

V_1 : Volume of NaOH used (ml).

N_{NaOH} : Concentration of NaOH used for titration.

D: Gram equivalent of the predominant organic acid.

V_0 : Volume of juice sample used for titration (ml).

2.3.2. Total dissolved solid content determination

The total soluble solid content of banana samples was measured using a digital refractometer (Optika HR-120, Italy). The results were expressed in %, which indicates the concentration of total dissolved solids present in the banana.

2.3.3. Mass loss determination

The mass loss of bananas was monitored throughout the storage period by weighing the samples before storage (initial mass) and at subsequent 4-day intervals. The percentage of mass loss was calculated using the following formula [11]:

$$\text{Mass loss(\%)} = \frac{\text{Initial mass} - \text{Mass at each interval}}{\text{Initial mass}} \times 100$$

2.3.4. Firmness determination

The hardness of the banana was determined by the force (N) required to puncture the fruit's surface. This measurement was conducted using a Brookfield CTX Texture Analyzer (USA) with a 2mm diameter, 20mm long probe, connected to a computer system at the Ho Chi Minh City University of Industry and Trade. The penetration depth was set at 13mm. The average hardness was calculated based on three independent measurements taken for each sample.

2.3.5. Color change determination

The peel color of bananas was assessed using a colorimeter (Konica Minolta CR-400, Japan), a device based on spectrophotometric principles. Color measurements were taken at three distinct points on each fruit—both ends and the middle—to ensure consistency and accuracy. The instrument evaluates color using the CIE Lab system (L^* , a^* , b^*), where L represents lightness, a denotes the red-green axis, and b corresponds to the yellow-blue axis. When light is directed onto the sample surface, part of it is absorbed and part reflected; the device quantifies this reflected light to determine the color characteristics of the fruit. This method enables precise monitoring of color changes associated with ripening and senescence during storage [12]

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{\frac{1}{2}}$$

○ ΔE (Color Difference): Represents the total color difference between two measurements and is calculated as the Euclidean distance in the Lab color space. It provides an overall indication of the degree of color change.

○ ΔL : Indicates the change in lightness, ranging from 0 (black) to 100 (white), reflecting the brightness variation of the fruit peel.

○ Δa : Reflects the shift on the green–red axis, where negative values represent green hues and positive values indicate red hues.

○ Δb : Reflects the shift on the blue–yellow axis, where negative values indicate blue tones and positive values represent yellow tones.

2.4. Data analysis

Each experiment was performed in triplicate, and the results are expressed as the mean \pm standard deviation. Statistical analysis was conducted using one-way ANOVA at a 95% confidence level, with differences between treatments compared using the Least Significant Difference (LSD) test. Data calculation and graphing were performed using Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1. Effect of aloe vera - lemon or garlic oils on the total acid content of bananas during storage

Total acid content is a critical indicator of banana quality. Generally, banana with high sugar content and moderate acidity is regarded as having superior sensory and nutritional attributes. Total acidity plays a vital role in sustaining respiratory metabolism, enhancing resistance to spoilage organisms, and preventing microbial invasion during storage [13].

As presented in Table 1, the total acid content of both the control and treated samples generally declined throughout the storage period. Interestingly, a slight increase in acid content was observed from day 0 - 8 across all observed bananas, which may be attributed to initial enzymatic activity and intermediate metabolic conversions. After this period, however, a gradual and consistent decline in total acid levels was observed in all treatments, reflecting the continued degradation of organic acids and their transformation into sugar compounds during the ripening and senescence phases.

On the case of bananas coated with aloe vera and lemon essential oil, no significant differences in total acid content were observed among treatments by the 8th day of storage, with the exception of the control group ($p < 0.05$). The control bananas exhibited a pronounced and rapid decline in acidity, dropping from $0.0290 \pm 0.0000 - 0.0082 \pm 0.0013$ % on the 24th day. From 12th day onwards, total acid content continued to decrease across all samples; however, significant differences between treatments emerged ($p < 0.05$). Notably, the AL04 and AL06 treatments demonstrated a slower rate of acid degradation compared to other treatments. Their initial acid contents were 0.0290 ± 0.0022 % and 0.0283 ± 0.0013 %, respectively and declined only moderately to 0.0186 ± 0.0013 % and 0.0197 ± 0.0008 % on the 24th day. These findings indicate that aloe vera combined with 0.4% and 0.6% of lemon oil was most effective in maintaining banana acidity during storage.

Similarly, for bananas coated with aloe vera combined with garlic oil, no significant differences were detected among treatments during four days ($p > 0.05$). On the 8th day, differences remained statistically insignificant except in the control, which showed a marked decrease in acid content ($p < 0.05$), falling from $0.0290 \pm 0.0000 - 0.0082 \pm 0.0013$ % on the 24th day. From 12th day onwards, significant differences emerged among the garlic oil treatments ($p < 0.05$). The AG015 treatment maintained a significantly higher acidity throughout the storage.

On the 24th day, its total acid content was 0.0219 ± 0.0016 %, compared to 0.0127 ± 0.0013 % (AG005), 0.0171 ± 0.0013 % (AG010), 0.0156 ± 0.0022 % (AG020) and 0.0104 ± 0.0013 % (AG025). These results suggest that aloe vera–garlic oil coatings significantly influenced acid retention, with 0.15% garlic oil (AG015) being the most effective concentration.

The decline in acidity during storage is primarily due to the degradation of organic acids [14]. A temporary increase in acidity observed during on the 2–3th day in control and treated bananas may be attributed to the activity of malate synthase and phosphoenolpyruvate carboxylase—key enzymes in malic acid biosynthesis [15]. Over time, however, enzymatic activity promotes the conversion of organic acids into sugars, resulting in a gradual reduction in total acid content [13].

3.2. Effect of aloe vera – lemon or garlic oil coating on total dissolved solid content of banana during storage

Total dissolved solid content is a critical quality index in bananas, since it directly correlates with fruit sweetness. Generally, the total dissolved solid content of all treatments exhibited a general upward trend throughout the storage period ($p < 0.05$) (Table 2). In the control bananas, this value increased rapidly from $3.27 \pm 0.23 - 28.87 \pm 0.12$ %, indicating accelerated ripening. In contrast, bananas coated with aloe vera combined with lemon oil showed a slower increase in total dissolved solid content with the rate of increase inversely proportional to the lemon oil in the coating. Specifically, AL04 and AL06's total dissolved solid contents rose from $3.33 \pm 0.23 - 19.00 \pm 0.40$ % and from $3.30 \pm 0.26 - 18.33 \pm 0.31$ %, respectively. Although both treatments effectively delayed the accumulation of total dissolved solid contents compared to the control, there was no statistically significant difference between AL04 and AL06 ($p > 0.05$).

Table 1. Total acid level (%) of bananas during storage (days)

Treatments	Storage (days)							
	0	4	8	12	16	20	24	
Lemon oil	Control	0.0290 ^a ± 0.0000	0.0372 ^a ± 0.0013	0.0298 ^b ± 0.0013	0.0223 ^c ± 0.0022	0.0179 ^c ± 0.0022	0.0119 ^c ± 0.0013	0.0082 ^c ± 0.0013
	AL02	0.0283 ^a ± 0.0026	0.0342 ^a ± 0.0013	0.0353 ^a ± 0.0016	0.0275 ^{bc} ± 0.0013	0.0216 ^{bc} ± 0.0013	0.0156 ^{bc} ± 0.0022	0.0112 ^{bc} ± 0.0022
	AL04	0.0290^a ± 0.0022	0.0350^a ± 0.0013	0.0372^a ± 0.0013	0.0320^{ab} ± 0.0026	0.0278^a ± 0.0011	0.0231^a ± 0.0026	0.0186^a ± 0.0013
	AL06	0.0283 ^a ± 0.0013	0.0350 ^a ± 0.0013	0.0383 ^a ± 0.0018	0.0335 ^a ± 0.0022	0.0283 ^a ± 0.0013	0.0249 ^a ± 0.0018	0.0197 ^a ± 0.0008
	AL08	0.0283 ^a ± 0.0026	0.0350 ^a ± 0.0034	0.0350 ^a ± 0.0013	0.0290 ^{ab} ± 0.0022	0.0253 ^{ab} ± 0.0013	0.0194 ^{ab} ± 0.0026	0.0127 ^b ± 0.0013
	AL10	0.0290 ^a ± 0.0022	0.0342 ^a ± 0.0026	0.0356 ^a ± 0.0018	0.0283 ^{ab} ± 0.0013	0.0234 ^b ± 0.0011	0.0171 ^{bc} ± 0.0013	0.0100 ^{bc} ± 0.0011
Garlic oil	Control	0.0290 ^a ± 0.0000	0.0372 ^a ± 0.0013	0.0298 ^b ± 0.0013	0.0223 ^c ± 0.0022	0.0179 ^d ± 0.0022	0.0119 ^d ± 0.0013	0.0082 ^e ± 0.0013
	AG005	0.0283 ^a ± 0.0013	0.0345 ^a ± 0.0021	0.0350 ^a ± 0.0013	0.0278 ^{bc} ± 0.0013	0.0222 ^{cd} ± 0.0011	0.0164 ^c ± 0.0013	0.0127 ^{cd} ± 0.0013
	AG010	0.0283 ^a ± 0.0013	0.0342 ^a ± 0.0013	0.0380 ^a ± 0.0022	0.0335 ^{ab} ± 0.0022	0.0283 ^{ab} ± 0.0013	0.0216 ^a ± 0.0013	0.0171 ^b ± 0.0013
	AG015	0.0286^a ± 0.0024	0.0357^a ± 0.0000	0.0395^a ± 0.0013	0.0350^a ± 0.0034	0.0305^a ± 0.0013	0.0261^a ± 0.0018	0.0219^a ± 0.0016
	AG020	0.0283 ^a ± 0.0026	0.0353 ^a ± 0.0016	0.0365 ^a ± 0.0013	0.0323 ^{ab} ± 0.0011	0.0261 ^{bc} ± 0.0013	0.0194 ^{bc} ± 0.0013	0.0156 ^{bc} ± 0.0022
	AG025	0.0290 ^a ± 0.0022	0.0342 ^a ± 0.0013	0.0357 ^a ± 0.0022	0.0298 ^{ab} ± 0.0013	0.0238 ^c ± 0.0013	0.0171 ^c ± 0.0013	0.0104 ^{de} ± 0.0013

Letters ^{a,b,c,d} point to significant differences ($p < 0.05$); Control: banana untreated or uncoated layer; AL02: 75% of aloe vera + 0.2% of lemon oil; AL04: 75% of aloe vera + 0.4% of lemon oil; AL06: 75% of aloe vera + 0.6% of lemon; AL08: 75% of aloe vera + 0.8% of lemon; AL10: 75% of aloe vera + 1.0% of lemon

AG005: 75% of aloe vera + 0.05% of garlic oil; AG010: 75% of aloe vera + 0.1% of garlic oil; AG015: 75% of aloe vera + 0.15% of garlic oil; AG020: 75% of aloe vera + 0.2% of garlic oil; AG0.25: 75% of aloe vera + 0.25% of garlic oil.

Table 2. Total dissolved solid content (%) of banana during storage (days)

Treatments	Storage (days)							
	0	4	8	12	16	20	24	
Lemon oil	Control	3.27 ^a ± 0.23	7.67 ^a ± 0.31	11.47 ^a ± 0.31	15.60 ^a ± 0.35	18.80 ^a ± 0.20	23.20 ^a ± 0.35	27.87 ^a ± 0.12
	AL02	3.33 ^a ± 0.12	5.21 ^b ± 0.36	7.27 ^b ± 0.23	9.80 ^b ± 0.20	13.00 ^b ± 0.40	18.00 ^b ± 0.20	21.53 ^b ± 0.23
	AL04	3.33 ^a ± 0.23	4.53 ^b ± 0.31	5.93 ^{cd} ± 0.12	8.40 ^{cd} ± 0.40	10.93 ^d ± 0.23	14.00 ^e ± 0.20	19.00 ^d ± 0.40
	AL06	3.30 ^a ± 0.26	4.40 ^b ± 0.35	5.33 ^d ± 0.42	8.07 ^d ± 0.23	10.27 ^d ± 0.12	13.60 ^e ± 0.40	18.33 ^d ± 0.31
	AL08	3.33 ^a ± 0.31	4.80 ^b ± 0.20	6.13 ^c ± 0.31	9.13 ^{bc} ± 0.23	11.80 ^c ± 0.20	14.73 ^d ± 0.12	19.87 ^c ± 0.12
	AL10	3.30 ^a ± 0.26	5.07 ^b ± 0.31	6.47 ^c ± 0.12	9.40 ^b ± 0.20	12.33 ^{bc} ± 0.31	15.53 ^c ± 0.23	20.53 ^c ± 0.31
Garlic oil	Control	3.27 ^a ± 0.23	7.67 ^a ± 0.31	11.47 ^a ± 0.31	15.6 ^a ± 0.35	18.80 ^a ± 0.20	23.20 ^a ± 0.35	27.87 ^a ± 0.12
	AG005	3.33 ^a ± 0.12	6.00 ^b ± 0.35	8.47 ^b ± 0.23	9.80 ^b ± 0.20	12.67 ^b ± 0.12	17.00 ^b ± 0.40	21.27 ^b ± 0.31
	AG010	3.30 ^a ± 0.17	4.93 ^{cd} ± 0.12	6.67 ^{de} ± 0.23	8.67 ^d ± 0.12	10.93 ^d ± 0.23	14.40 ^c ± 0.35	19.07 ^d ± 0.12
	AG015	3.27 ^a ± 0.46	4.47 ^d ± 0.42	6.00 ^e ± 0.35	8.07 ^e ± 0.12	10.20 ^e ± 0.35	13.40 ^d ± 0.35	18.13 ^e ± 0.23
	AG020	3.33 ^a ± 0.31	5.33 ^{bc} ± 0.31	7.20 ^{cd} ± 0.20	9.07 ^{cd} ± 0.12	11.53 ^{cd} ± 0.23	15.00 ^c ± 0.20	19.53 ^d ± 0.12
	AG025	3.27 ^a ± 0.23	5.60 ^{bc} ± 0.20	7.87 ^{bc} ± 0.23	9.47 ^{bc} ± 0.23	12.07 ^{bc} ± 0.31	16.20 ^b ± 0.35	20.33 ^c ± 0.23

Letters ^{a,b,c,d} point to significant differences ($p < 0.05$); Control: banana untreated or uncoated layer; AL02: 75% of aloe vera + 0.2% of lemon oil; AL04: 75% of aloe vera + 0.4% of lemon oil; AL06: 75% of aloe vera + 0.6% of lemon; AL08: 75% of aloe vera + 0.8% of lemon; AL10: 75% of aloe vera + 1.0% of lemon; AG005: 75% of aloe vera + 0.05% of garlic oil; AG010: 75% of aloe vera + 0.1% of garlic oil; AG015: 75% of aloe vera + 0.15% of garlic oil; AG020: 75% of aloe vera + 0.2% of garlic oil; AG0.25: 75% of aloe vera + 0.25% of garlic oil.

Considering the total dissolved solid content of bananas coated by aloe-vera combined with garlic oil, the data in Table 2 showed that this value increased progressively throughout the storage period ($p < 0.05$). In the control, this increase was particularly rapid, rising from $3.27 \pm 0.23 - 28.87 \pm 0.12\%$. In contrast, bananas coated with this combination solution exhibited a slower rate of increase, which was inversely related to the garlic oil concentration in the coating. Among the various treatments, the AG015 formulation demonstrated the most pronounced delay, with total dissolved solid content increasing only from $3.27 \pm 0.46 - 18.13 \pm 0.23\%$ over the storage period. These findings suggest that the aloe vera-essential oil based coating acts as a semi-permeable barrier, reducing gas exchange between the fruit and the external environment, thereby lowering the respiration rate. Moreover, according to Khaliq et al. (2019), essential oil incorporated into coatings can help maintain total dissolved solid content by minimizing water loss and inhibiting degradative enzyme activity [16]. This slows the enzymatic breakdown of starch into sugars, resulting in a more gradual increase in total dissolved solid content compared to uncoated bananas [17]. Similarly, essential oil has been reported to delay ripening by inhibiting enzymes involved in the ripening process [13], further contributing to the slower accumulation of total dissolved solid.

3.3. Effect of aloe vera – lemon or garlic oil coating on mass loss of banana during storage

Mass loss is an unavoidable phenomenon in post-harvest fruits and is a key parameter used to assess the quality and shelf life of fresh products. In this study, the mass loss rate of bananas during storage was evaluated across all treatments. As shown in Table 3, the mass loss rate increased progressively with storage duration. The banana in control exhibited the highest mass loss, rising significantly from $2.49 \pm 0.002 - 29.98 \pm 0.011\%$ over the storage period ($p < 0.05$). In contrast, bananas coated with aloe vera combined with lemon oil—specifically the AL04 and AL06 treatments—demonstrated the slowest rate of mass loss, increasing only from $2.34 \pm 0.001 - 15.81 \pm 0.023\%$ and from $2.35 \pm 0.0 - 15.95 \pm 0.009\%$, respectively. No statistically significant difference was observed between these two treatments ($p > 0.05$), indicating that both concentrations were similarly effective in minimizing mass loss during storage.

In addition to bananas coated with aloe vera–lemon oil, banana coated by aloe vera–garlic oil exhibited a gradual also increased in mass loss rate over the storage period. In detail, in the control, mass loss of banana rose sharply from $2.49 \pm 0.002 - 29.98 \pm 0.011\%$ ($p < 0.05$). Notably, the AG015 showed the slowest increase in mass loss, from $2.36 \pm 0.0 - 15.32 \pm 0.006\%$, with a statistically significant difference compared to other treatments ($p < 0.05$). These findings suggest that the aloe vera–essential oil coating effectively formed a semi-permeable barrier on the banana surface, reducing direct exposure to air, limiting oxidative reactions and inhibiting microbial activity. Furthermore, the coating helped mitigate water loss and slow down the fruit's respiration rate, thereby conserving organic matter and extending storage life. This is also explained by Kaibo Yu et al. [18], who found that coatings enriched with essential oils significantly reduced post-harvest mass loss in mangoes or fruits.

3.4. Effect of aloe vera – lemon or garlic oil coating on banana firmness during storage

Firmness is recognized as one of the most critical physical parameters for assessing banana quality during storage. Hence, in the present study, firmness was evaluated across different treatments. According to Table 4, banana firmness declined progressively during storage in both the control (untreated or uncoated bananas) and the treatment groups. Overall, banana firmness tended to decline throughout the storage period, and no notable differences were observed among treatments on the 4th day. From the 8th day onward, significant differences in firmness emerged among treatments. In fact, in the control, firmness of banana declined rapidly from $839.17 \pm 30.69 - 499.90 \pm 7.54 \text{ kg/cm}^2$ on the 16th day, accompanied by visible spoilage symptoms on the 16th day. Notably, banana treated with ALC04 and AL06 retained higher firmness values on the 24th day compared to other treatments, suggesting a slower rate of structural degradation.

Considering the application of aloe vera incorporating garlic oil had no statistically significant impact on the firmness of bananas during the initial storage period (days 0–4) ($p > 0.05$). However, from the 8th day onward, the coated samples consistently retained higher firmness values compared to the uncoated banana in the control. Firmness declined progressively across all treatments throughout storage, but the rate and extent of softening varied significantly. In the control, firmness decreased sharply.

Table 3. Weight loss (%) of banana during storage (days)

Treatments	Storage (days)						
	4	8	12	16	20	24	
Lemon oil	Control	2.49 ^a ± 0.002	6.15 ^a ± 0.003	13.09 ^a ± 0.003	17.68 ^a ± 0.010	22.92 ^a ± 0.010	29.98 ^a ± 0.011
	AL02	2.35 ^a ± 0.004	4.69 ^b ± 0.004	10.02 ^b ± 0.005	15.10 ^b ± 0.003	17.97 ^b ± 0.007	22.65 ^b ± 0.004
	AL04	2.34^a ± 0.001	4.41^b ± 0.002	7.67^c ± 0.007	9.88^d ± 0.006	12.46^d ± 0.006	15.81^c ± 0.023
	AL06	2.35 ^a ± 0.000	4.45 ^b ± 0.003	7.06 ^c ± 0.004	9.54 ^d ± 0.006	12.28 ^d ± 0.005	15.95 ^c ± 0.009
	AL08	2.34 ^a ± 0.000	4.95 ^b ± 0.002	9.24 ^b ± 0.005	12.24 ^c ± 0.004	15.11 ^c ± 0.006	18.89 ^{bc} ± 0.011
	AL10	2.32 ^a ± 0.003	4.79 ^b ± 0.001	9.45 ^b ± 0.007	13.32 ^c ± 0.006	15.65 ^c ± 0.005	19.98 ^{bc} ± 0.042
Garlic oil	Control	2.49 ^a ± 0.002	6.15 ^a ± 0.003	13.09 ^a ± 0.003	17.68 ^a ± 0.010	22.92 ^a ± 0.010	29.98 ^a ± 0.011
	AG005	2.34 ^a ± 0.000	4.68 ^b ± 0.003	9.49 ^b ± 0.005	13.65 ^c ± 0.007	17.82 ^{bc} ± 0.005	22.90 ^b ± 0.013
	AG010	2.46 ^a ± 0.002	4.65 ^b ± 0.003	7.89 ^b ± 0.005	11.77 ^d ± 0.007	15.40 ^d ± 0.007	17.73 ^{cd} ± 0.009
	AG015	2.36^a ± 0.000	4.32^b ± 0.001	5.24^c ± 0.013	8.77^c ± 0.004	12.43^e ± 0.009	15.32^d ± 0.006
	AG020	2.46 ^a ± 0.002	4.93 ^b ± 0.002	9.86 ^b ± 0.007	15.44 ^b ± 0.007	19.46 ^b ± 0.009	24.91 ^b ± 0.013
	AG025	2.24 ^a ± 0.003	4.73 ^b ± 0.003	8.70 ^b ± 0.009	13.29 ^c ± 0.004	16.47 ^{cd} ± 0.013	19.89 ^c ± 0.014

Letters ^{a,b,c,d} point to significant differences ($p < 0.05$); Control: banana untreated or uncoated layer; AL02: 75% of aloe vera + 0.2% of lemon oil; AL04: 75% of aloe vera + 0.4% of lemon oil; AL06: 75% of aloe vera + 0.6% of lemon; AL08: 75% of aloe vera + 0.8% of lemon; AL10: 75% of aloe vera + 1.0% of lemon; AG005: 75% of aloe vera + 0.05% of garlic oil; AG010: 75% of aloe vera + 0.1% of garlic oil; AG015: 75% of aloe vera + 0.15% of garlic oil; AG020: 75% of aloe vera + 0.2% of garlic oil; AG0.25: 75% of aloe vera + 0.25% of garlic oil

However, bananas treated with the AG015 demonstrated a significantly slower loss of firmness, maintaining values between 834.48 ± 35.14 kg/cm² and 618.90 ± 4.11 kg/cm² on the 24th day storage period ($p < 0.05$). This delayed softening in the AG015 indicates that the aloe vera – lemon or garlic oil coating effectively mitigates structural degradation in banana tissue. Fruit softening is predominantly driven by enzymatic hydrolysis of key cell wall components such as cellulose and hemicellulose [19] during postharvest. The bioactive coating likely formed a semi-permeable barrier around the fruit surface, limiting oxygen availability and ethylene diffusion, which in turn suppressed enzymatic activity responsible for cell wall disassembly. Furthermore, after harvest, bananas continue to produce ethylene, which accelerates respiration and senescence, ultimately compromising the fruit's physical structure. The coating may act as an ethylene antagonist by competing with ethylene receptors, thereby reducing ethylene-induced respiration and delaying softening. These findings are consistent with Kaibo Yu et al. [18], who reported that fruit coatings enriched with essential oils significantly slowed firmness degradation in postharvest product as mentioned above. In addition, Ullah et al. (2003) explains that the low firmness of samples decreased during storage due to dehydration and weakening of banana peel tissues [20]. Furthermore, the degradation of cell walls and starch metabolism in bananas also directly affect the firmness of bananas. Protopectin in banana peel and pulp can be converted into soluble pectin due to the presence of protopectinase in bananas, leading to lower firmness during storage. The reduction of fruit firmness is inevitable, so the use of edible coatings to prolong or enhance fruit firmness is a very necessary trend in the current banana preservation process. These findings underscore the potential of aloe vera-based edible coatings enriched with essential oil to enhance textural stability and extend the postharvest shelf life of climacteric fruits such as bananas.

3.5. Effect of aloe vera – lemon or garlic oil on banana color changes during storage

Peel color is a critical indicator of banana ripeness, reflecting the biochemical transformations associated with chlorophyll degradation and pigment oxidation. The transition from green - yellow and eventually to brown during ripening not only influences consumer perception but also correlates with flavor and texture development.

According to the data presented in Table 5, peel color values in the control increased markedly from 8.65 ± 0.55 - 26.92 ± 0.57 ΔE over 16 days of storage, indicating rapid chlorophyll breakdown and advanced ripening. In contrast, bananas treated with aloe vera–lemon essential oil coatings at concentrations of 0.4% (AL04) and 0.6% (AL06) exhibited significantly lower color values over the same period, with respective increases from 7.56 ± 0.22 - 15.43 ± 0.70 ΔE and from 7.35 ± 0.86 - 15.54 ± 0.21 ΔE . No statistically significant differences were observed between these two treatments ($p > 0.05$), suggesting that both concentrations were comparably effective in delaying peel color development.

Similarly, bananas coated with aloe vera containing 0.15% garlic essential oil (AG015) displayed a reduced rate of color change, with values increasing only from 8.31 ± 0.27 - 15.70 ± 0.22 ΔE over 24 days of storage, compared to rapid darkening in the control. These observations indicate that both lemon and garlic oil-based coatings effectively slowed pigment degradation.

This delay in peel discoloration can be attributed to the formation of a semi-permeable aloe vera-based coating that limits oxygen diffusion, thereby inhibiting enzymatic oxidation and chlorophyll degradation. Furthermore, the antioxidant properties of lemon and garlic essential oils—particularly their capacity to scavenge free radicals—likely contributed to preserving pigment integrity. The synergistic effects of aloe vera gel and essential oils not only suppressed oxidative browning but also moderated respiratory activity, thus retarding ripening and extending the visual and sensory quality of the bananas during storage [21].

Table 4. Firmness (kg/cm²) of banana during storage

Treatments	Storage (days)							
	0	4	8	12	16	20	24	
Lemon oil	Control	839.17 ^a ± 30.69	807.09 ^a ± 4.36	704.39 ^b ± 10.52	602.88 ^c ± 7.33	499.90 ^c ± 7.54	-	-
	AL02	839.41 ^a ± 10.98	816.74 ^a ± 3.10	788.48 ^a ± 12.63	739.73 ^b ± 7.59	651.40 ^b ± 3.66	550.00 ^b ± 5.84	447.10 ^b ± 11.73
	AL04	834.48^a ± 35.14	817.07^a ± 23.49	806.48^a ± 5.47	794.07^a ± 6.27	749.80^a ± 15.78	696.90^a ± 2.84	618.90^a ± 4.11
	AL06	839.27 ^a ± 12.63	817.05 ^a ± 14.66	807.96 ^a ± 12.09	792.02 ^a ± 8.84	748.40 ^a ± 7.43	691.00 ^a ± 4.79	620.10 ^a ± 2.14
	AL08	842.84 ^a ± 24.84	816.50 ^a ± 9.50	791.94 ^a ± 3.28	762.42 ^b ± 9.07	642.60 ^b ± 16.44	558.90 ^b ± 1.48	455.80 ^b ± 8.00
	AL10	840.34 ^a ± 3.15	816.07 ^a ± 4.77	790.51 ^a ± 9.10	758.25 ^b ± 6.54	653.00 ^b ± 0.57	554.60 ^b ± 3.41	464.10 ^b ± 4.20
Garlic oil	Control	839.17 ^a ± 30.69	807.09 ^a ± 4.36	704.39 ^b ± 10.52	602.88 ^b ± 7.33	499.90 ^d ± 7.54	-	-
	AG005	839.41 ^a ± 10.98	818.00 ^a ± 12.27	803.70 ^a ± 14.60	791.80 ^a ± 13.18	699.40 ^{bc} ± 7.30	597.00 ^b ± 14.16	462.20 ^c ± 7.58
	AG010	834.49 ^a ± 35.12	813.40 ^a ± 34.82	800.90 ^a ± 35.13	785.30 ^a ± 36.46	692.10 ^{bc} ± 6.49	603.70 ^b ± 0.49	500.60 ^b ± 2.64
	AG015	839.29^a ± 12.63	825.00^a ± 12.42	816.50^a ± 14.95	809.80^a ± 16.05	792.90^a ± 13.64	727.80^a ± 6.91	630.60^a ± 1.26
	AG020	842.85 ^a ± 24.84	824.30 ^a ± 30.32	809.00 ^a ± 27.99	801.30 ^a ± 30.74	720.10 ^b ± 9.04	607.20 ^b ± 3.12	499.30 ^b ± 2.42
	AG025	840.34 ^a ± 3.15	823.80 ^a ± 4.64	810.20 ^a ± 5.38	779.80 ^a ± 7.68	677.10 ^c ± 13.03	596.20 ^b ± 12.35	424.50 ^d ± 5.57

Letters ^{a,b,c,d} point to significant differences ($p < 0.05$); Control: banana untreated or uncoated layer; AL02: 75% of aloe vera + 0.2% of lemon oil; AL04: 75% of aloe vera + 0.4% of lemon oil; AL06: 75% of aloe vera + 0.6% of lemon; AL08: 75% of aloe vera + 0.8% of lemon; AL10: 75% of aloe vera + 1.0% of lemon; AG005: 75% of aloe vera + 0.05% of garlic oil; AG010: 75% of aloe vera + 0.1% of garlic oil; AG015: 75% of aloe vera + 0.15% of garlic oil; AG020: 75% of aloe vera + 0.2% of garlic oil; AG0.25: 75% of aloe vera + 0.25% of garlic oil

Table 5. The color change (ΔE) of banana during storage (days)

Treatments	Storage (days)						
	4	8	12	16	20	24	
Lemon oil	Control	8.65 ^{ab} ± 0.55	31.91 ^a ± 0.13	33.19 ^a ± 0.41	26.92 ^b ± 0.57	-	-
	AL02	8.34 ^{ab} ± 0.64	15.52 ^b ± 0.01	21.65 ^b ± 0.34	28.48 ^a ± 0.65	30.26 ^b ± 0.71	25.61 ^a ± 0.16
	AL04	7.56^{ab} ± 0.22	13.69^c ± 0.27	19.64^c ± 0.76	23.26^c ± 0.50	32.21^a ± 0.10	15.43^b ± 0.70
	AL06	7.35 ^b ± 0.86	13.50 ^c ± 0.07	19.12 ^c ± 0.25	22.76 ^c ± 0.50	32.30 ^a ± 0.73	15.54 ^b ± 0.21
	AL08	8.56 ^{ab} ± 0.28	15.95 ^b ± 0.73	21.74 ^b ± 0.41	28.55 ^a ± 0.35	30.29 ^b ± 0.73	25.79 ^a ± 0.42
	AL10	8.78 ^a ± 0.09	15.74 ^b ± 0.28	21.22 ^b ± 0.19	28.53 ^a ± 0.38	30.28 ^b ± 0.73	25.67 ^a ± 0.39
Garlic oil	Control	8.65 ^a ± 0.55	31.91 ^a ± 0.13	33.19 ^a ± 0.41	26.92 ^b ± 0.57	-	-
	AG005	8.93 ^a ± 0.19	15.76 ^b ± 0.50	21.61 ^b ± 0.33	28.62 ^a ± 0.38	30.52 ^b ± 0.52	25.92 ^a ± 0.37
	AG010	8.54 ^a ± 0.24	16.14 ^b ± 0.36	21.97 ^b ± 0.48	28.79 ^a ± 0.36	30.68 ^b ± 0.21	25.79 ^a ± 0.38
	AG015	8.31^a ± 0.27	13.50^c ± 0.20	19.27^c ± 0.47	23.25^c ± 0.36	32.41^a ± 0.20	15.70^b ± 0.22
	AG020	8.80 ^a ± 0.37	15.77 ^b ± 0.26	21.99 ^b ± 0.12	28.87 ^a ± 0.06	30.50 ^b ± 0.17	25.71 ^a ± 0.35
	AG025	9.10 ^a ± 0.06	16.18 ^b ± 0.32	22.25 ^b ± 0.27	29.10 ^a ± 0.57	30.58 ^b ± 0.52	25.92 ^a ± 0.05

Letters ^{a,b,c,d} point to significant differences ($p < 0.05$); Control: banana untreated or uncoated layer; AL02: 75% of aloe vera + 0.2% of lemon oil; AL04: 75% of aloe vera + 0.4% of lemon oil; AL06: 75% of aloe vera + 0.6% of lemon; AL08: 75% of aloe vera + 0.8% of lemon; AL10: 75% of aloe vera + 1.0% of lemon; AG005: 75% of aloe vera + 0.05% of garlic oil; AG010: 75% of aloe vera + 0.1% of garlic oil; AG015: 75% of aloe vera + 0.15% of garlic oil; AG020: 75% of aloe vera + 0.2% of garlic oil; AG025: 75% of aloe vera + 0.25% of garlic oil.

4. CONCLUSION

This study demonstrated that an aloe vera-based edible coating enriched with 0.4% of lemon oil or 0.15% of garlic oil effectively preserved the quality of bananas stored at 22 °C for up to 24 days. These treatments significantly maintained key post-harvest attributes, including nutritional value, peel color, firmness, and overall structural integrity. The findings underscore the potential of aloe vera–essential oil composite as natural, biodegradable, and non-toxic alternatives to synthetic preservation methods. Given their efficacy, safety, and environmental sustainability, these coatings offer a practical solution for stakeholders across the banana supply chain—including growers, processors, and distributors—to extend shelf life and reduce postharvest losses. Future implementation of this technique may enhance marketability and reduce reliance on chemical-based preservation systems.

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TÓM TẮT

ĐÁNH GIÁ HIỆU QUẢ CỦA MÀNG BAO LÔ HỘI KẾT HỢP VỚI TINH DẦU CHANH HOẶC TỎI ĐỂ KÉO DÀI THỜI GIAN BẢO QUẢN CỦA CHUỐI TIÊU CHÂU PHI (*DWARF CAVENDISH*)

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Mục tiêu của nghiên cứu này là đánh giá hiệu quả của màng bao lô hội (75%) kết hợp với các nồng độ khác nhau của tinh dầu chanh (0,2, 0,4, 0,6, 0,8 và 1,0%) hoặc tinh dầu tỏi (0,05, 0,1, 0,15, 0,2 và 0,25%) trong việc kéo dài thời gian bảo quản chuối ở nhiệt độ 22 °C. Kết quả cho thấy khi tăng nồng độ tinh dầu chanh và tinh dầu tỏi từ 0,2% lên 0,4% và từ 0,05% lên 0,15% đã giúp kéo dài thời gian bảo quản; tuy nhiên, việc tăng nồng độ vượt quá 0,4 – 1,0% và 0,15 – 0,25% lại dẫn đến hiệu quả bảo quản giảm. Dữ liệu cho thấy màng bao chứa 0,4% tinh dầu chanh và 0,15% tinh dầu tỏi có khả năng duy trì chất lượng tốt nhất, được thể hiện qua các chỉ tiêu quan trọng như: hàm lượng acid tổng ($0,0186 \pm 0,0013\%$ so với $0,0219 \pm 0,0016\%$), hàm lượng tổng chất rắn hòa tan ($19,00 \pm 0,40\%$ so với $18,13 \pm 0,23\%$), khối lượng hao hụt ($15,81 \pm 0,023\%$ so với $15,32 \pm 0,006\%$), độ cứng ($618,90 \pm 4,11 \text{ kg/cm}^3$ so với $630,60 \pm 1,26 \text{ kg/cm}^3$) và sự thay đổi màu sắc vỏ quả ($\Delta E = 15,43 \pm 0,70$ so với $15,70 \pm 0,22$). Những phát hiện này chứng minh tiềm năng của màng bao lô hội kết hợp với tinh dầu chanh hoặc tinh dầu tỏi như một kỹ thuật bảo quản sau thu hoạch hiệu quả cho chuối, thân thiện với môi trường và an toàn cho người tiêu dùng. Việc ứng dụng công nghệ bao này có thể mang lại lợi ích cho người trồng chuối, các công ty chế biến, nhà phân phối v.v. thông qua việc nâng cao chất lượng quả và kéo dài thời gian tiêu thụ.

Từ khóa: Lô hội, màng bao, chuối, tinh dầu tỏi, tinh dầu chanh, bảo quản.