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(RESEARCH ARTICLE)

# Extending shelf-life and preserving the quality of lady finger banana (*Musa acuminata*) via various postharvest treatments

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## Abstract

Lady finger banana (*Musa acuminata*) is a popular fruit worldwide but tends to ripen and spoil quickly within a week after harvest. Postharvest treatment is a key factor in extending their shelf-life. This study aimed to determine the most suitable postharvest treatment for prolonging the shelf-life and maintaining the quality of lady finger bananas when combined with polyethylene bags. A 30-day storage study was conducted using 216 bananas arranged in a completely randomized design, with four treatments: T0 (control), T1 (3% citric acid), T2 (3% sodium benzoate), and T3 (0.022% sodium hypochlorite). Peel color, weight loss, pH, sugar content, and spoilage were measured every five days. The results showed that T3 (sodium hypochlorite) was the most effective treatment for extending shelf-life and maintaining quality. While variations in peel color, weight loss, pH, and sugar content across treatments were not statistically significant ($p > 0.05$), the percentages of spoiled bananas were significantly different ($p < 0.01$). Compared with other treatments, T3 resulted in the lowest percentage of spoilage (36.11% ± 8.81%). Additional findings for T3 included a weight loss of 2.53 ± 0.44%, a pH of 5.60 ± 0.06, and a sugar content of 16.2 ± 1.59 after 30 days. However, citric acid and sodium benzoate treatments were not effective at extending shelf-life or maintaining quality when used with polyethylene bags. In conclusion, sodium hypochlorite combined with polyethylene packaging was more effective at extending the shelf-life and preserving the quality of lady finger bananas.

**Keywords:** *Musa acuminata*; Postharvest treatments; Citric acid; Sodium benzoate; Sodium hypochlorite; Shelf-life extension

## 1. Introduction

Lady finger banana (*Musa acuminata*) is a widely cherished fruit variety renowned for its small size, sweet flavor, and high nutritional value. This banana variety is rich in vitamins and minerals, notably vitamins A, B1, B2, B6, B12, and C, which make it a staple food for many populations across the globe (Mubarok et al., 2022). In addition to being consumed fresh, Lady Finger Bananas are processed into a variety of value-added products, such as banana chips, dried bananas, and beverages such as juices, further increasing their economic importance in both local and international markets (Crismas et al., 2018). Particularly in Southeast Asia, including Cambodia, Lady Finger Bananas contribute significantly to agricultural output and rural livelihoods. Export volumes of bananas have been steadily increasing in recent years, underscoring the growing demand for this fruit in global trade (Schall, 2020). Despite its economic importance, the Lady

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Finger Banana faces substantial postharvest challenges, primarily its short shelf-life and rapid quality deterioration. As a climacteric fruit, the ripening process of lady finger bananas accelerates after harvest due to increased ethylene production and respiration rates (Ilyas et al., 2007). This process is associated with significant physiological and biochemical changes, including softening of the fruit, changes in peel color from green to yellow, increased sugar content, and the development of characteristic aromas and flavors. While these changes increase fruit palatability, they also make fruit highly perishable, resulting in significant postharvest losses (Ramírez-Sánchez et al., 2018a). Postharvest losses in bananas are exacerbated by improper handling, storage, and transportation conditions, which often expose the fruit to mechanical damage, microbial infections, and unfavorable environmental factors. These issues not only diminish the quality and market value of bananas but also contribute to food waste and economic losses (Gol & Rao, 2011 and Ramírez-Sánchez et al., 2018b). Addressing these challenges is crucial for the sustainable production and marketing of bananas. Effective postharvest management strategies are needed to extend shelf-life, preserve fruit quality, and ensure that bananas reach consumers under optimal conditions. To this end, various postharvest treatments have been developed to mitigate quality deterioration and prolong the storage life of bananas (Akter et al., 2013). Chemical treatments, in particular, have shown significant potential in reducing spoilage and maintaining the postharvest quality of fruits. Citric acid, for example, is widely recognized for its antimicrobial and antioxidant properties. By lowering the pH and creating an unfavorable environment for microbial growth, citric acid effectively reduces spoilage and enhances the longevity of fruits (Yang et al., 2019). Sodium benzoate, a food preservative commonly used in the food industry, inhibits the growth of bacteria, yeast, and molds, thereby extending the shelf-life of perishable products such as bananas (Kaur et al., 2019). Sodium hypochlorite, another widely used postharvest treatment, is valuable for its efficacy in controlling fungal infections and microbial contamination. As a disinfectant, it not only reduces the microbial load but also helps maintain the physical appearance and firmness of the fruit during storage (Arienzo et al., 2019). While these treatments offer promising solutions, their efficacy can vary depending on factors such as concentration, application method, and storage conditions. Furthermore, the compatibility of these treatments with consumer safety and environmental sustainability remains a critical consideration. Therefore, it is essential to evaluate and optimize these treatments to achieve a balance between extending shelf-life, maintaining quality, and ensuring safety (Ungureanu et al., 2023).

This study evaluated the effectiveness of citric acid, sodium benzoate, and sodium hypochlorite in delaying ripening, inhibiting microbial growth, and preserving the nutritional quality of Lady finger bananas during storage. By identifying optimal treatments, this research aims to improve postharvest management, reduce losses, and enhance the marketability of high-quality bananas locally and internationally.

## 2. Materials and methods

### 2.1. Raw material preparation

A total of 216 finger bananas (*Musa acuminata*) were procured from a local farm in Kbal Koh village, Koh Trong Commune, Kratie district, Kratie Province, Cambodia. The bananas were uniform in terms of age, size, length, and color and were at optimum maturity for harvest. The fruits were transported to the laboratory, where they were cleaned with distilled water to remove any foreign materials. To prevent fungal contamination, the bananas were treated with citric acid, sodium benzoate, and sodium hypochlorite. Following the treatment, the bananas were packed in polyethylene plastic bags to reduce respiration and stored at room temperature.

### 2.2. Experimental design

The experiment was designed to assess the efficacy of various treatments in extending the shelf-life and preserving the quality of finger bananas (Musa acuminata) while preventing contamination. The study employed a completely randomized design (CRD) with four treatment groups, each consisting of three replicates, for a total of 12 experimental units.

- T1: Bananas without any chemical treatment (control).
- T2: Bananas treated with a 3% of citric acid solution(Yang et al., 2017).
- T3: Bananas treated with a 3% of sodium benzoate solution (Kaur et al., 2019).
- T4: Bananas treated with a 0.022% of sodium hypochlorite solution (Arienzo et al., 2019).

### 2.3. Citric acid, sodium benzoate, and sodium hypochlorite treatment

The bananas were divided into four treatment groups, with 54 bananas per group. Each treatment group was dipped in one of the following solutions for 5 minutes: 3% citric acid solution, 3% sodium benzoate solution, or 0.022% sodium hypochlorite solution. After treatment, all bananas were rinsed with distilled water, dried with tissue paper, and packed in polyethylene plastic bags. The packaged bananas were then stored at room temperature for further observation.

### 2.4. Peel color changes

The peel color of the bananas was captured via a digital camera (Model IM015, PIX8). Images were taken every 5 days across all the treatments and replicates to compare the rates of color change, as shown in **Figure 1**.

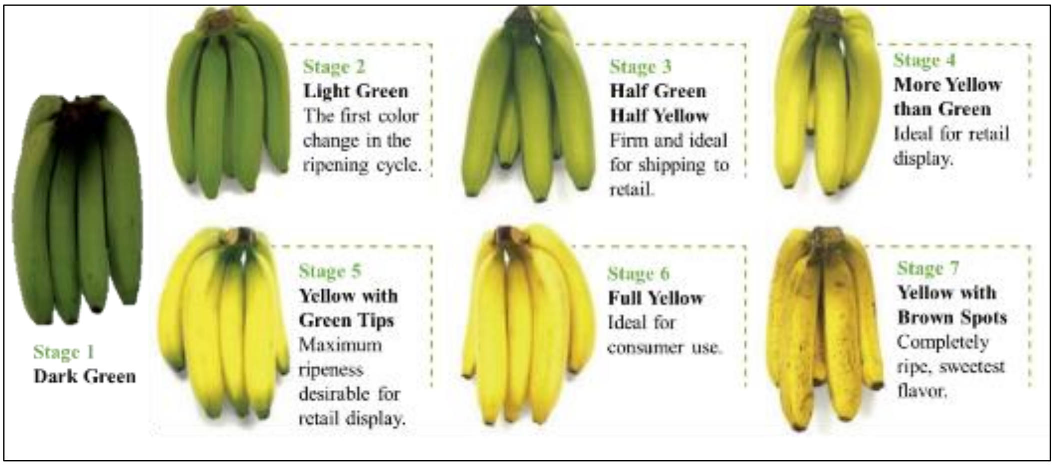


**Figure 1** The stages of banana colour change during ripening (Siddiqui, 2015).

### 2.5. Weight loss percentage

Banana weight loss was evaluated every 5 days over a 30-day period. The evaluation days were days 0, 5, 10, 15, 20, 25, and 30. On each evaluation day, the percentage of weight loss was calculated via the following formula:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight (day 0)} - \text{Weigh on evaluation day}}{\text{Initial weight (day 0)}} \times 100$$

(Lustriane et al., 2018)

### 2.6. pH changes

To measure the pH accurately, a digital pH meter was calibrated with standard buffer solutions (pH values of 4, 7, and 10). The electrode was rinsed with distilled water and gently dried before being immersed in the buffer solution, following the calibration instructions provided by the manufacturer. Once calibrated, the sample was prepared by removing the banana peel, weighing it, and adding an equal ratio of distilled water. The mixture was ground thoroughly until it became homogenous. Then, the electrode was dipped into the prepared solution and allowed to stand until the reading on the screen stabilized, and the data were recorded.

### 2.7. Sugar content changes

To measure the sugar content in the bananas, a refractometer was used. The device should first be cleaned with distilled water and calibrated to the zero point to ensure accuracy. A drop of the banana liquid mixture was then placed on a glass prism (lens), covering the surface completely. The refractometer is directed toward a light source, and the reading is observed through the eyepiece. The value is recorded at the line that separates the dark and light areas (Mazumdar & Majumder, 2003).

### 2.8. Percentage of spoiled bananas

The percentages of spoiled bananas were determined by inspecting the bananas at specific intervals throughout the storage period. At each interval, the total number of bananas showing visible signs of spoilage, such as black spots, fungal growth, discoloration, and softening, was recorded. The spoilage percentage was then calculated via the following formula:

$$\text{Spoiled bananas (\%)} = \frac{\text{Number of spoiled bananas}}{\text{Total number of bananas}} \times 100$$

(Nath et al., 2012).

### 2.9. Data analysis

All the data were initially entered into Microsoft Excel Professional Plus 2021 for cleaning and organization. Statistical analysis was performed via GraphPad Prism software (Version 10.2.0, Windows, San Diego, California, USA; www.graphpad.com). The data are presented as the means ± standard deviations (SDs). Differences among treatment means were analyzed via one-way ANOVA, followed by Tukey's HSD multiple comparisons test. The significance level for all tests was set at $p < 0.01$.

## 3. Results

### 3.1. Temperature change

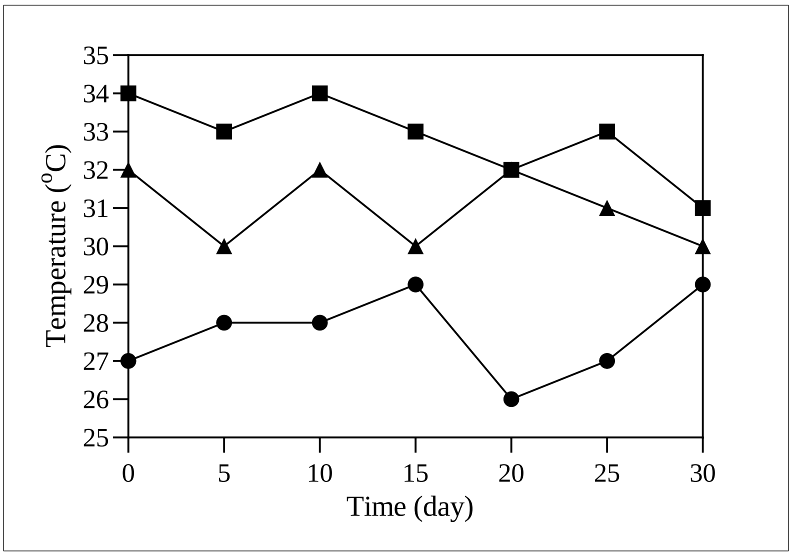


**Figure 2** Temperature changes during storage in the experiment. The circle symbol represents the temperature recorded in the morning, the square symbol represents the temperature recorded at noon, and the triangle symbol represents the temperature recorded in the evening.

**Figure 2** shows the temperature variations during the 30-day storage period of the chicken eggs. The results indicated that in the morning, the temperature fluctuated between 26°C and 29°C. At noon, the temperature ranged from 31°C to 34°C, whereas in the evening, the temperature varied between 30°C and 32°C. Throughout the study, the temperatures remained within the defined room temperature range.

### 3.2. Peel color changes

**Figure 3** shows the changes in the peel color of the bananas in each treatment. The results indicated that the treatments involving postharvest substances, including citric acid, sodium benzoate, and sodium hypochlorite, did not significantly affect color. On day 0, the peels of bananas from all the treatment groups were light blue (score level 2). From day 5 to day 20, the bananas presented a blue hue that was more prominent than a yellow hue (score level 3). On day 25, all the bananas from each treatment were predominantly yellow (score level 4). On the last day, only those in the treatment with sodium hypochlorite remained intact, whereas the others were all spoiled (Figure 4.3). On day 25, the plants in the T0, T1, and T2 treatments were completely spoiled, indicating that the use of citric acid, sodium benzoate, and sodium hypochlorite did not affect the color of the bananas. The storage method using polyethylene packaging effectively delayed the color change of the banana peel.


**Figure 3** Changes in colour of bananas during storage**.**

### 3.3. Parameter changes

**Figure 4a** shows the differences in weight loss among the various treatments during the storage period. Throughout the storage period, weight loss increased progressively. On day 25, the average percentage of weight loss for the banana groups was as follows: T0 = 2.83 ± 1.05%, T1 = 2.46 ± 0.46%, T2 = 2.89 ± 0.55%, and T3 = 2.83 ± 0.44%. One-way ANOVA revealed that the three types of postharvest treatments did not significantly affect the weight loss of bananas ($p > 0.05$). Pairwise comparisons between treatments revealed no significant differences between T0 and T1, T0 and T2, T0 and T3, T1 and T2, T1 and T3, or T2 and T3 at any confidence level ($p > 0.05$). By day 30, the plants in the T0, T1, and T2 treatments were completely spoiled, whereas those in the T3 treatment effectively preserved the bananas, resulting in a weight loss percentage of only 3.17 ± 0.38%. These findings indicated that the use of sodium hypochlorite (T3) successfully extended the shelf-life of bananas, maintaining their quality and minimizing weight loss for more than 25 days, whereas the other treatments failed.

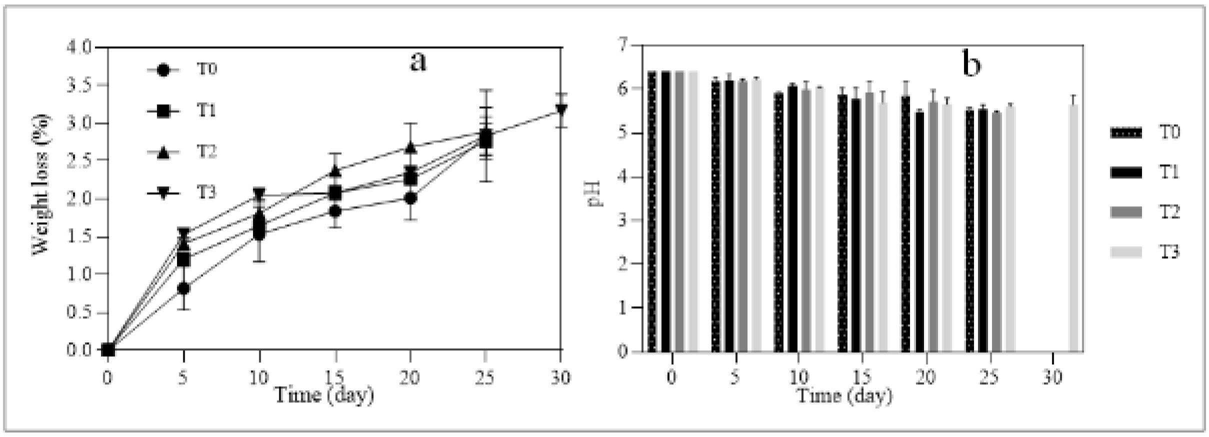


**Figure 4** Parameter changes during the storage experiment. (a) Percentage of weight loss. (b) Changes in pH.

Figure 4b shows the changes in the pH of the bananas in each treatment during the storage period. The pH of all the samples decreased over time, indicating an increase in acidity. By day 25, the average pH values were as follows: T0 = 5.52 ± 0.05, T1 = 5.55 ± 0.10, T2 = 5.47 ± 0.02, and T3 = 5.60 ± 0.06. One-way ANOVA revealed that the three types of postharvest treatments did not significantly affect the pH of the bananas ($p > 0.05$). Pairwise comparisons between treatments revealed no significant differences among T0 and T1, T0 and T2, T0 and T3, T1 and T2, T1 and T3, or T2 and T3 at any confidence level ($p > 0.05$). By day 30, the plants in the T0, T1, and T2 treatments were completely spoiled, whereas those in the T3 treatment effectively preserved the bananas, with a weight loss percentage of 5.64 ± 0.22%. These results demonstrated that the use of sodium hypochlorite (T3) successfully extended the shelf-life of bananas, maintaining pH levels beyond 25 days, whereas the other treatments failed.

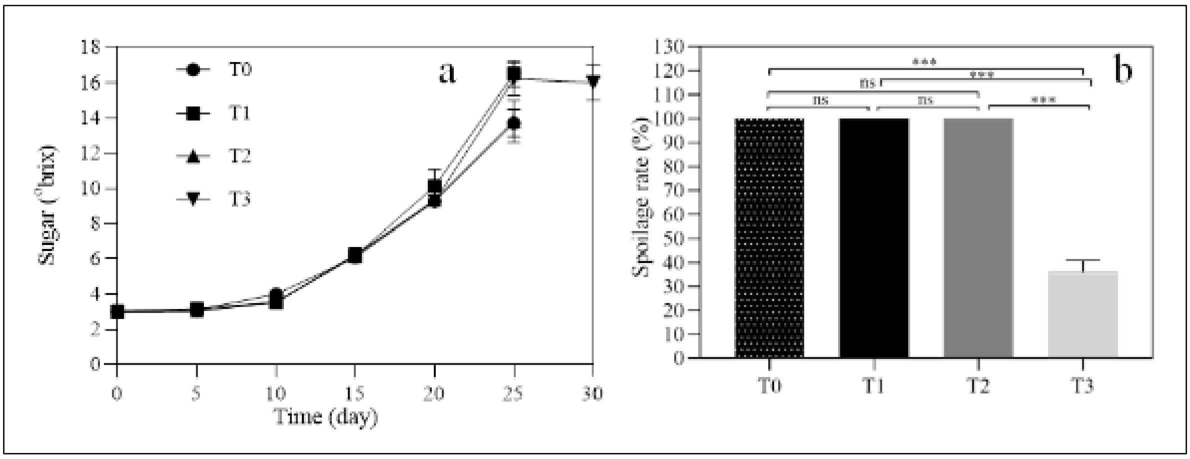


**Figure 5** Parameter changes during the storage experiment. (a) Changes in sugar content (°Brix). (b) Percentages of spoiled banana fruits.

*** Significant difference ($p < 0.01$); ns nonsignificant difference ($p > 0.05$)

**Figure 5a** shows the changes in the sugar contents of the bananas in each treatment during the storage period. The sugar content increased progressively across all the treatments over time. By day 25, the average sugar contents were as follows: T0 = 13.70 ± 1.35, T1 = 16.50 ± 1.31, T2 = 13.80 ± 2.08, and T3 = 16.20 ± 1.59. One-way ANOVA revealed that the three types of postharvest treatments did not significantly influence the sugar content of bananas ($p > 0.05$). Pairwise comparisons among the treatments (T0 and T1, T0 and T2, T0 and T3, T1 and T2, T1 and T3, and T2 and T3) revealed no significant differences at any confidence level ($p > 0.05$). By day 30, the plants in the T0, T1, and T2 treatments were completely spoiled, whereas those in the T3 treatment effectively preserved the bananas, with a sugar content of 16.00 ± 1.73. These findings demonstrated that the use of sodium hypochlorite (T3) successfully extended the shelf-life of bananas and maintained their sugar content above 25 days, whereas the other treatments failed.

**Figure 5b** shows the changes in the percentages of spoiled bananas for each treatment during the storage period. During storage, the number of spoiled bananas for each treatment increased progressively. Treatments T0, T1, and T2 increased the number of spoiled bananas after 1 week of storage, and by day 25, all bananas had spoiled. The T3 treatment group started showing spoilage on day 15, and the number of spoiled bananas increased slightly by the final day (day 30). The T3 treatment resulted in the lowest percentage of spoiled bananas (36.11% ± 4.81%), whereas all the other treatments resulted in 12 spoiled bananas by day 30. One-way ANOVA revealed that the three types of postharvest treatments significantly affected the number of spoiled bananas ($p < 0.01$). Pairwise comparisons between treatments revealed no significant differences between T0 and T1, T0 and T2, or T1 and T2 ($p > 0.05$). However, significant differences were observed between T1 and T3 and between T2 and T3 ($p < 0.01$). These results indicated that the use of sodium hypochlorite (T3) effectively preserved the shelf-life of bananas for more than 30 days, whereas the other treatments were effective for only 25 days.

## 4. Discussion

### 4.1. Changes in peel color

This study revealed that the use of postharvest treatments such as citric acid, sodium benzoate, and sodium hypochlorite, along with packaging in polyethylene bags, did not result in significant differences in the color changes of banana peels. These findings suggested that postharvest treatments had no effect on color change when the fruit was packaged in polyethylene bags. This study was consistent with the research of Batista-Silva et al. (2018), who reported that citric acid did not inhibit the activity of ethylene hormones and therefore could not delay the ripening of bananas. This result parallels those of Zhang et al. (2023) and Zhao et al. (2009), who reported that citric acid is not the most effective treatment for delaying postharvest. Similarly, a recent study by Moon et al. (2020) indicated that citric acid could be used to reduce pH levels but did not inhibit the ripening activity of fruits or vegetables. Additionally, Molnár et al. (2020) and Xiao et al. (2023) reported that sodium benzoate was commonly used to inhibit overripening activity but did not affect the ripening of fruits or vegetables. The use of sodium hypochlorite in this study was consistent with the findings of Arienzo et al. (2023) and Mishra et al. (2018), who reported that sodium hypochlorite was effective in cleaning the external surfaces of fruits and vegetables but was not effective in delaying color changes. Therefore, the use of polyethylene packaging remains an effective method for delaying color changes in banana peels. This finding was in agreement with the findings of Meir et al. (1995) and Schall (2020), who reported that polyethylene packaging reduced moisture loss, managed oxygen levels, and prevented browning, all of which contributed to reducing oxidation and delaying color changes in banana peels. Consequently, the use of postharvest treatments and polyethylene packaging successfully preserved the color changes of banana peels, with no significant difference from the use of polyethylene packaging alone.

### 4.2. Weight loss

This study revealed that the use of postharvest treatments, including citric acid, sodium benzoate, and sodium hypochlorite, along with polyethylene packaging, did not result in significant differences in pH. These findings confirmed that these treatments had no effect on pH changes when the fruit was packaged in polyethylene bags. Additionally, the study demonstrated that the use of these postharvest treatments did not lead to significant differences in weight loss when the fruit was packaged in polyethylene bags. These findings suggest that the treatments had no effect on weight loss. These results were consistent with the findings of Hailu et al. (2014) and Montesinos-Herrero et al. (2016), who reported that polyethylene packaging effectively preserved moisture and reduced weight loss in bananas, resulting in no significant difference in the effectiveness of various postharvest treatments. In contrast, the findings of this study differed from those of Alali et al. (2023), Macnish et al. (2010) and Shahmohammadi et al. (2016), who reported that citric acid, sodium benzoate, and sodium hypochlorite treatments could delay weight loss in fruits.

### 4.3. pH changes

The study revealed that the use of postharvest treatments, including citric acid, sodium benzoate, and sodium hypochlorite, along with polyethylene packaging, did not result in significant differences in pH. These findings confirmed that these treatments had no effect on pH changes when the fruit was packaged in polyethylene bags. This study was consistent with the findings of Jiang & Joyce (2000), who reported that postharvest treatments and polyethylene packaging effectively preserved fruit quality and pH levels, with no significant difference when only polyethylene packaging without treatments was used. Therefore, this study contrasts with the findings of Alali et al.

(2023), Kaur et al. (2019), and Mishra et al. (2018), who reported that postharvest treatments such as citric acid, sodium benzoate, and sodium hypochlorite had effects on the pH of fruits. Consequently, the use of postharvest treatments and polyethylene packaging effectively preserved the pH changes in banana peels, with no significant difference from the use of polyethylene packaging alone.

### 4.4. Sugar content

This study revealed that the use of postharvest treatments, including citric acid, sodium benzoate, and sodium hypochlorite, along with polyethylene packaging, did not result in significant differences in sugar content. These findings indicated that the three treatments had no effect on sugar content changes when the fruit was packaged in polyethylene bags. This study was consistent with the findings of Hailu et al. (2014) and Jiang & Joyce (2000), who reported that postharvest treatments and polyethylene packaging effectively preserved sugar content changes. However, this study contrasts with the findings of Yang et al. (2019), who reported that citric acid had an effect on sugar content changes. Similarly, Arienzo et al. (2023) and Kaur et al. (2019) reported that the use of sodium hypochlorite and sodium benzoate effectively altered the sugar content. Therefore, the use of postharvest treatments and polyethylene packaging effectively preserved sugar content changes in banana peels, with no significant difference from the use of polyethylene packaging alone.

### 4.5. Fruit spoilage

The study revealed that the use of postharvest treatments, including citric acid, sodium benzoate, and sodium hypochlorite, along with polyethylene packaging, resulted in differences in sugar content. These findings indicated that the three treatments affected the number of spoiled fruits. This study was consistent with the findings of Arienzo et al. (2023) and Dilmaçünal et al. (2014), who reported that sodium hypochlorite was highly effective in inhibiting the growth of spoilage microorganisms and preserving fruit quality. However, this study contrasts with the findings of Yang et al. (2019), who reported that citric acid effectively inhibited the growth of fungi and bacteria. Similarly, Kaur et al. (2019) reported that sodium benzoate was highly effective in preventing the growth of spoilage microorganisms on fruits and vegetables. Therefore, the use of postharvest treatments and polyethylene packaging effectively preserved sugar content changes in banana peels and differed from the use of a single postharvest treatment alone.

## 5. Conclusion

This study investigated the effects of different postharvest treatments, including citric acid, sodium benzoate, and sodium hypochlorite, on the shelf-life and quality preservation of bananas over a 30-day period. The results demonstrated that there were no significant differences in the effects of these treatments on color change, weight loss, pH, or sugar content. However, compared with the other treatments, sodium hypochlorite was found to be more effective at protecting bananas from microbial damage. The use of sodium hypochlorite in combination with polyethylene bag packaging proved to be the most effective method for preserving the quality of bananas, reducing weight loss, slowing pH decline, maintaining sugar content, and controlling microbial growth. In contrast, the other treatments, such as citric acid and sodium benzoate, did not result in significant improvements over the control when polyethylene bag packaging was used. These findings underscore the importance of postharvest treatments for extending the shelf-life and maintaining the quality of bananas.

For future research, additional postharvest treatments should be explored to evaluate their effectiveness, as well as the role of storage temperature, which was not considered in this study but is a critical factor for quality preservation. Further investigations into the combined effects of various treatments and environmental conditions could enhance the practical application of these findings for farmers and businesses, particularly in improving long-distance banana transportation and storage.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

Each author declares that he/she has no conflict of interest.

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