International Journal of Environmental & Agriculture Research (IJOEAR)
ISSN: [2454-1850]
[Vol-12, Issue-7, July- 2026]
Website: www.ijoear.com
Journal DOI: 10.25125/agriculture-journal

Evaluation of Natural Materials and Edible Coatings for Ripening Regulation and Shelf-Life Extension of Banana (*Musa* spp.) and Papaya (*Carica papaya* L.)

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Received:- 02 July 2026/ Revised:- 09 July 2026/ Accepted:- 16 July 2026/ Published: 31-07-2026

***Abstract*—** *Fruit ripening is a vital physiological process that enhances the color, flavor, texture, and nutritional quality of climacteric fruits such as banana (*Musa *spp.) and papaya (*Carica papaya *L.). However, uncontrolled ripening accelerates senescence, leading to substantial postharvest losses. The present study aimed to evaluate simple, safe, and economical methods for accelerating (forward ripening) and delaying (reverse ripening) fruit ripening under ambient storage conditions. Mature, uniform, and defect-free banana and papaya fruits were subjected to different forward ripening treatments, including paper wrapping, banana leaf covering, plastic cover storage, and storage with ripened fruits to promote natural ethylene accumulation. Reverse ripening treatments consisted of coatings containing calcium chloride and sodium alginate at different concentrations, while potassium permanganate was evaluated as an ethylene scavenger. Fruits were stored at room temperature and monitored for seven days. Quality attributes, including total soluble solids (TSS), physiological weight loss, color development, and texture, were assessed using standard analytical procedures.*

The results demonstrated that forward ripening treatments accelerated uniform ripening and improved market readiness through enhanced ethylene accumulation. In contrast, calcium chloride–sodium alginate coatings effectively delayed ripening; the 3% calcium chloride–sodium alginate coating extended ripening to 9 days while reducing physiological weight loss to 7 g, maintained firmness, and preserved fruit quality during storage. Potassium permanganate further contributed to extending shelf life by reducing ethylene concentration.

The study concludes that natural ripening techniques and edible coating treatments provide effective, low-cost, and safe alternatives for ripening management. These approaches have practical applications for farmers, retailers, and fruit industries by reducing postharvest losses, extending shelf life, and improving the marketability and quality of climacteric fruits.

Keywords*— *Banana, Papaya, Edible coating, Calcium chloride, Sodium alginate, Shelf life, Postharvest, Ripening regulation, Ethylene management, Climacteric fruits, Tropical fruits.

I. INTRODUCTION

Fruits are an essential component of a healthy diet because they provide vitamins, minerals, dietary fiber, antioxidants, and other bioactive compounds that contribute to human health and nutrition. Among tropical fruits, banana (*Musa* spp.) and papaya (*Carica papaya* L.) are widely cultivated and consumed due to their high nutritional value, year-round availability, affordability, and economic importance. Banana is an excellent source of carbohydrates, potassium, vitamin B6, and dietary fiber, whereas papaya is rich in vitamins A and C, folate, and the proteolytic enzyme papain, making both fruits valuable for improving nutritional security and supporting the fruit processing industry [1,2].

Banana and papaya are climacteric fruits that continue to ripen after harvest through a process characterized by increased respiration and ethylene production. Ripening enhances desirable quality attributes such as color, flavor, sweetness, aroma, and texture, thereby improving consumer acceptability. However, uncontrolled ripening accelerates senescence, resulting in excessive softening, moisture loss, microbial spoilage, and reduced marketability. Consequently, postharvest losses of climacteric fruits remain a significant challenge, particularly in developing countries where inadequate storage, transportation, and ripening management practices contribute to substantial economic losses [1,2].

Ethylene is the primary plant hormone regulating ripening in climacteric fruits. Even at low concentrations, it triggers biochemical and physiological changes that promote chlorophyll degradation, sugar accumulation, fruit softening, and aroma development. Proper management of ethylene is therefore essential to either accelerate ripening for immediate marketing or delay ripening during storage and transportation. Safe and economical techniques for controlling ethylene are particularly important for farmers, retailers, and exporters who require flexibility in fruit marketing and distribution [3,4].

Natural packaging materials are widely used as simple ripening methods because they create a semi-enclosed environment that promotes the accumulation of naturally produced ethylene around fruits. Traditional practices such as wrapping fruits in paper, covering them with banana leaves, storing them in plastic covers, or placing them with ripe fruits can accelerate uniform ripening without the use of hazardous chemicals. These methods are inexpensive, environmentally friendly, and suitable for small-scale farmers and local fruit markets [5].

Edible coatings have emerged as an effective postharvest technology for delaying ripening and extending shelf life. Coatings based on natural biopolymers act as semipermeable barriers that reduce moisture loss, respiration, and gas exchange while maintaining fruit firmness and overall quality. Sodium alginate is a biodegradable polysaccharide widely used for edible coating applications because of its excellent film-forming properties, whereas calcium chloride strengthens cell wall integrity and delays tissue softening. The combination of sodium alginate and calcium chloride forms a stable cross-linked coating that effectively preserves fruit quality during storage. In addition, potassium permanganate has been extensively used as an ethylene scavenger to reduce ethylene concentration and slow ripening [6,7,8].

Although numerous studies have investigated commercial ripening agents and individual edible coatings, limited information is available on the comparative effectiveness of low-cost natural packaging materials and calcium chloride–sodium alginate coatings for both accelerating and delaying ripening of banana and papaya under ambient storage conditions. Such information is particularly relevant for regions lacking cold-chain infrastructure and modern postharvest facilities [6,8].

Therefore, the present study was undertaken to evaluate simple and economical forward and reverse ripening techniques for banana and papaya under ambient conditions. The study aimed to compare natural packaging methods and edible coating treatments by assessing changes in total soluble solids, physiological weight loss, color, and texture. The findings are expected to contribute to the development of safe, sustainable, and affordable postharvest technologies for reducing fruit losses, maintaining quality, and improving the marketability of climacteric fruits.

II. MATERIALS AND METHODS

2.1 Experimental Location

The experiment was conducted under ambient laboratory conditions in the Department of Food Science and Technology. All treatments were carried out under hygienic conditions, and observations were recorded over a storage period of seven days.

2.2 Fruit Materials

Fresh, mature, and unripe banana (*Musa* spp.) and papaya (*Carica papaya* L.) fruits of uniform size, maturity, and color, free from physical damage and disease, were procured from a local market. The specific varieties used were [Please specify variety] for banana and [Please specify variety] for papaya. Fruits were washed with clean water, air-dried, and used immediately for the experiment.

2.3 Experimental Treatments

The study evaluated both forward and reverse ripening methods. The following treatments were evaluated:

Forward Ripening Treatments (to accelerate ripening):

1) Paper bag wrapping
2) Banana leaf covering
3) Plastic cover storage
4) Storage with naturally ripened fruits (apples) to promote ethylene accumulation
5) Storage with ripe bananas

Reverse Ripening Treatments (to delay ripening):

1) 1% calcium chloride + sodium alginate coating
2) 2% calcium chloride + sodium alginate coating
3) 3% calcium chloride + sodium alginate coating
4) Potassium permanganate (ethylene scavenger)
5) Untreated control

Additional treatment combinations tested:

- Banana leaf + Paper packaging
- Banana leaf + Plastic cover packaging
- Charcoal + Ash (as an ethylene adsorbent)

These treatments were applied to evaluate their effectiveness in regulating ripening and extending shelf life [9,10].

2.4 Experimental Design and Storage Conditions

The experiment was arranged in a Completely Randomized Design (CRD) with different ripening treatments applied to banana and papaya fruits. After treatment, fruits were stored separately in plastic trays under ambient conditions (27 ± 2°C) for seven days. Observations were recorded at regular intervals to evaluate ripening behavior and postharvest quality [11].

2.5 Quality Evaluation

The effectiveness of the different ripening treatments was assessed by monitoring ripening period, physiological weight loss, total soluble solids (TSS), fruit color, firmness, pH, titratable acidity, and sensory quality. Physiological weight loss, total soluble solids, pH, titratable acidity, and other quality parameters were determined according to the standard methods of the Association of Official Analytical Chemists (AOAC) where applicable [12]. Fruit color and firmness were evaluated visually and manually to monitor ripening progression.

2.6 Statistical Analysis

All experiments were conducted in triplicate, and the results were expressed as mean ± standard deviation. Data were analyzed using one-way analysis of variance (ANOVA), and significant differences among treatment means were determined at $p < 0.05$ according to the procedures described by Gomez and Gomez [11].

III. RESULTS AND DISCUSSION

The present study evaluated the influence of natural packaging materials and edible coating treatments on the ripening behavior and postharvest quality of banana and papaya stored under ambient conditions. Packaging materials significantly affected ripening rate, physiological weight loss, and fruit quality (Table 1). Paper packaging accelerated ripening, reducing the ripening period to six days while producing the highest physiological weight loss (132–147 g). The rapid ripening observed in paper-wrapped fruits is attributed to enhanced ethylene accumulation together with greater moisture loss and respiration. Similar observations have been reported by Paul et al. [13], who found that paper-based packaging promotes ethylene-mediated ripening but shortens storage life.

TABLE 1
EFFECT OF PACKAGING MATERIALS ON RIPENING PERIOD AND PHYSIOLOGICAL WEIGHT LOSS OF BANANA AND PAPAYA

Treatment	Fruit	Ripening period (days)	Weight loss (g)*	Remarks
Control	Banana/Papaya	8–13	44 ± 2.3	Normal ripening
Paper packaging	Papaya + Apple	6	132 ± 5.1	Rapid ripening, high moisture loss
Plastic cover packaging	Papaya + Apple	9	20 ± 1.8	Delayed ripening, fungal growth observed
Paper packaging	Papaya + Banana	6	147 ± 6.2	Rapid ripening
Plastic cover packaging	Papaya + Banana	11	95 ± 4.3	Delayed ripening
Banana leaf + Paper packaging	Papaya	7	8 ± 0.9	Moderate ripening
Banana leaf + Plastic cover	Papaya	9	42 ± 3.1	Delayed ripening, fungal growth

Mean ± standard deviation (n=3). Values with different superscripts within each column are significantly different ($p < 0.05$).
Note: "Papaya + Apple" and "Papaya + Banana" refer to storage of papaya with ripe apples or ripe bananas to promote ethylene accumulation.

Plastic cover packaging delayed ripening compared with paper packaging and considerably reduced physiological weight loss, indicating improved moisture retention. However, fungal growth developed during storage because of excessive humidity within the closed environment. Similar findings were reported by Dhall [7], who observed that high relative humidity in modified packaging suppresses moisture loss but may increase microbial spoilage if ventilation is inadequate.

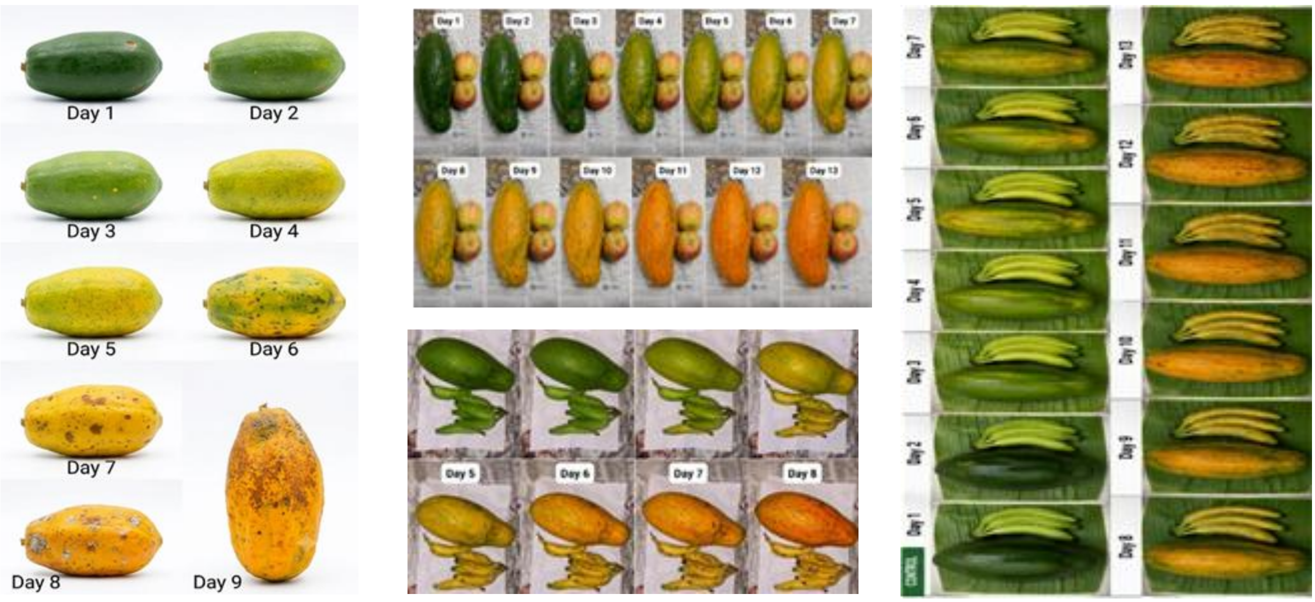

FIGURE 1: Effect of different packaging treatments (paper packaging, plastic cover packaging, banana leaf covering, and control) on the ripening of banana and papaya during seven days of ambient storage.

Banana leaf packaging moderately delayed ripening and reduced moisture loss compared with paper packaging. The semi-permeable nature of banana leaves likely maintained a favorable microenvironment around the fruit while permitting limited gas exchange. Similar observations have been reported for natural plant-based packaging materials used to improve postharvest quality and reduce environmental waste [14].

TABLE 2
EFFECT OF CALCIUM CHLORIDE–SODIUM ALGINATE COATINGS ON BANANA QUALITY

Treatment	TSS (°Brix)*	Weight loss (g)*	Ripening period (days)*	Quality response
Control	6.5 ± 0.4	10 ± 1.2	8 ± 0.5	Normal ripening
1% $CaCl_2$ + Sodium alginate	5.0 ± 0.3	17 ± 1.8	9 ± 0.6	Delayed ripening
2% $CaCl_2$ + Sodium alginate	7.0 ± 0.5	9 ± 0.8	7 ± 0.4	Moderate effect
3% $CaCl_2$ + Sodium alginate	4.5 ± 0.3	7 ± 0.6	9 ± 0.5	Best shelf-life extension

Mean ± standard deviation (n=3). Values with different superscripts within each column are significantly different ($p < 0.05$).

Note: The higher TSS value observed in the 2% $CaCl_2$ treatment may be attributed to variability in initial fruit maturity or measurement error and warrants further investigation.

Among the reverse ripening treatments, calcium chloride–sodium alginate coatings showed the greatest effectiveness in preserving fruit quality (Table 2). The 3% coating delayed ripening to nine days, recorded the lowest physiological weight loss (7 g), and maintained lower total soluble solids (4.5 °Brix), indicating reduced metabolic activity. Calcium chloride strengthens the cell wall through calcium–pectate interactions, whereas sodium alginate forms a semipermeable edible film that restricts respiration, transpiration, and ethylene diffusion. Comparable improvements in fruit firmness, moisture retention, and shelf-life extension have been reported for alginate-based edible coatings [15,16].

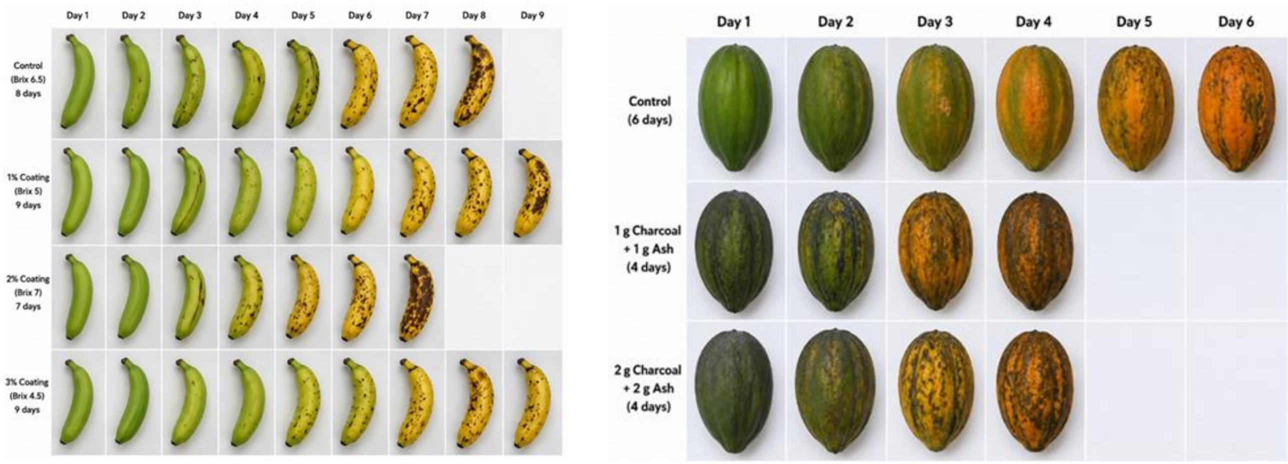

FIGURE 2: Effect of calcium chloride–sodium alginate coatings at different concentrations (1%, 2%, 3%) on the ripening period and shelf life of banana stored under ambient conditions.

Ethylene management plays a critical role in regulating ripening of climacteric fruits. Treatments that promoted natural ethylene accumulation, such as paper packaging and storage with ripe fruits, accelerated ripening and improved market readiness. In contrast, edible coatings and potassium permanganate reduced ethylene activity, slowed respiration, and delayed senescence. Similar responses have been reported in banana and papaya, where regulation of ethylene production effectively prolonged shelf life while maintaining acceptable fruit quality [13,17].

TABLE 3
OVERALL COMPARISON OF RIPENING TREATMENTS

Treatment	Ripening effect	Shelf-life	Moisture retention	Overall performance
Paper packaging	Accelerated	Low	Poor	Suitable for rapid marketing
Plastic cover packaging	Delayed	Moderate	Good	Risk of fungal growth
Banana leaf packaging	Moderate	Moderate	Good	Eco-friendly alternative
Charcoal + Ash	Accelerated	Low	Poor	Not recommended
3% Sodium alginate coating	Delayed	High	Excellent	Most effective treatment

Overall, the results indicate that the 3% calcium chloride–sodium alginate coating was the most effective treatment for extending shelf life and maintaining fruit quality under ambient conditions (Table 3). Although paper packaging is suitable where rapid ripening is required for immediate marketing, edible coatings provide a safer and more sustainable approach for postharvest preservation. These findings support the application of natural edible coatings as low-cost technologies for reducing postharvest losses and improving the storage quality of climacteric fruits, particularly in regions lacking cold-chain infrastructure [15–19].

IV. CONCLUSION

The present study demonstrated that natural packaging materials and edible coatings can effectively regulate the ripening and shelf life of banana (*Musa* spp.) and papaya (*Carica papaya* L.) under ambient storage conditions. Among the treatments evaluated, the 3% calcium chloride–sodium alginate coating was the most effective, significantly delaying ripening, minimizing physiological weight loss, and maintaining overall fruit quality compared with other treatments. In contrast, paper packaging accelerated ripening and is more suitable for situations requiring rapid market readiness.

These findings indicate that edible coatings offer a simple, safe, and cost-effective approach for postharvest management of climacteric fruits. The technology has considerable commercial potential for farmers, retailers, exporters, and the fruit processing industry by reducing postharvest losses, extending shelf life, and improving marketability without relying on expensive cold-chain infrastructure. Future research should focus on optimizing coating formulations, incorporating natural antimicrobial agents, evaluating consumer acceptance, and assessing large-scale commercial application under different storage and transportation conditions.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Food Science and Technology for providing laboratory facilities and support for this research.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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