Bioactive Edible Coatings: Enhancing fruit quality

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***Abstract*—This study investigates edible coatings as a sustainable alternative for food preservation, focusing on extending the shelf life of fresh produce. Biodegradable coatings were formulated using Aloe barbadense Miller (Aloe Vera) Gel, Cassava Starch, and Arabic Gum, with natural preservatives such as Citric Acid, Clove Oil, Apple Cider Vinegar, and Potato Peel Powder Extract to inhibit microbial growth. Coated produce was evaluated under different storage conditions refrigeration (1–4°C), room temperature (24 ± 2°C), and humid, dark environments. Titratable acidity and catalase activity assessments indicated maintained biochemical stability, reduced oxidative stress, and lower spoilage rates. Results demonstrate that these coatings offer a viable solution for extending food shelf life, with potential applications in agriculture, emergency food supply chains, and military rations where fresh produce preservation is critical.**

***Index Terms*—Edible Coatings, Food Preservation, Natural Preservatives, Shelf-Life Extension**

I. INTRODUCTION

In recent years, concerns regarding food sustainability, waste reduction, and environmental conservation have fueled interest in innovative preservation techniques. One such approach involves the use of edible coatings, which serve as a protective layer applied directly to food surfaces to extend shelf life while maintaining quality (Baldwin et al., 1995). Unlike conventional plastic packaging, edible coatings are composed of natural, biodegradable materials, making them a promising alternative in the pursuit of sustainable food preservation (Dhall, 2013). These coatings function by forming a semi-permeable barrier that regulates moisture exchange, gas diffusion, and microbial contamination, thereby reducing spoilage and enhancing the storability of fresh produce (Kester & Fennema, 1986).

The composition of edible coatings typically includes biopolymers such as polysaccharides, proteins, and lipids, which provide structural integrity and functional properties (Olivas & Barbosa-Cánovas, 2005). Among these, polysaccharide-based coatings, including starch, Aloe vera gel, and Arabic gum, have gained considerable attention due to their natural film-forming capabilities, biodegradability, and compatibility with food products (Khalid et al., 2022). These coatings can be further enhanced by incorporating natural preservatives such as citric acid, clove oil, apple cider vinegar, or plant extracts, which possess antimicrobial and antioxidant properties that help prevent microbial growth and enzymatic deterioration (Park, 1999). By integrating these bioactive compounds, edible coatings can not only serve as a physical barrier but also actively contribute to food safety and quality maintenance.

Beyond their functional benefits, edible coatings present an environmentally friendly alternative to synthetic plastic packaging, which contributes significantly to pollution and ecological degradation (Aayush et al., 2022). The widespread use of plastic packaging in the food industry has led to serious environmental concerns, with single-use plastics being a major contributor to global waste accumulation. By replacing plastic-based preservation methods with biodegradable edible coatings, the food industry can reduce its reliance on non-renewable resources and minimize plastic pollution. Moreover, consumer awareness and demand for sustainable packaging solutions are on the rise, highlighting the importance of developing eco- friendly alternatives that align with market expectations (Kumar et al., 2022).

This study aims to develop and evaluate edible coatings formulated with different natural preservatives to assess their effectiveness in prolonging the freshness of fresh produce. Specifically, it will explore the impact of Aloe vera gel, starch, and Arabic gum as base materials and investigate the role of Citric Acid, Clove oil, Apple Cider Vinegar, and Potato Peel Powder Extract as functional additives. By bridging scientific innovation with practical applications, this study seeks to contribute to the advancement of sustainable food preservation techniques that support both food security and environmental conservation.

II. RESEARCH OBJECTIVES

This study aims to formulate an edible coating for fruit preservation by incorporating natural preservatives, including Citric acid, Clove oil, Apple Cider Vinegar (ACV), and Potato Peel Powder Extract (PPPE). The objective is to extend the shelf life of fresh produce while maintaining quality and ensuring food safety.

- To integrate natural preservatives citric acid, clove oil, apple cider vinegar, and potato peel powder extract into edible coatings and assess their efficacy in inhibiting microbial growth and spoilage under various storage conditions, including refrigeration (1–4°C), room temperature (24 ± 2°C), and dark, humid environments.
- To evaluate the effectiveness of these edible coatings in preserving the freshness of fruits and vegetables across different storage conditions.
- To evaluate the effectiveness of edible coatings in enhancing food preservation, with potential applications in sectors requiring extended shelf life and reduced food wastage under challenging conditions.
- To explore the viability of edible coatings as an alternative to conventional packaging methods, focusing on improving food quality and reducing reliance on synthetic materials.

III. RESEARCH METHODOLOGY

The research developed formulations using natural ingredients like Aloe vera gel, starch, and Arabic gum, along with natural preservatives such as Citric acid, Apple cider vinegar, Potato Peel Powder Extract obtained through sequential cold maceration, and Clove oil obtained through distillation with a Clevenger apparatus. The qualitative analysis focused on visual appeal, preservation effects, and sustainability, using thematic and observational methods. The findings highlighted the potential of edible coatings to improve food quality and contribute to sustainability by reducing environmental impact.

Preparation of Edible Coating Formulation

1) Peel the leaves of Aloe vera, remove the gel, blend the gel, and strain it through a sieve.
2) In a beaker, add distilled water (250 ml), starch (7%), and Arabic gum (3%), stirring continuously until the solution boils and the Arabic gum dissolves.
3) Remove the beaker from the heat and allow it to cool for 10 minutes.
4) Measure the Aloe vera gel and add it to the beaker.
5) Repeat the process for each solution.
6) Add the respective preservative to each beaker according to the formulation table.
7) After a homogeneous mixture forms, autoclave it for 20 minutes.

Analysis Methods

The data collected were analyzed using several qualitative methods to assess the performance and sustainability of the edible coatings.

- Thematic analysis was used to identify recurring patterns and themes related to coating effectiveness, such as its impact on the visual appeal of produce, the preservation of freshness, and its ability to prevent spoilage.
- Comparative analysis was conducted to compare the performance of coated versus uncoated produce, focusing on preservation outcomes under different storage conditions like refrigeration and room temperature.
- Content analysis of relevant literature was used to contextualize the findings, particularly regarding the use of natural preservatives and the growing sustainability trends in food packaging.
- A DPPH assay (2,2-diphenyl-1- picrylhydrazyl) was included to measure the antioxidant activity of the natural preservatives in the coatings, providing insight into their potential to protect food from oxidation and spoilage.
- Titratable acidity: Monitored changes in acidity levels to evaluate spoilage and preservation over time, offering insights into the coatings' ability to maintain food freshness.

- Catalase activity: Analyzed to understand oxidative stress responses and the coatings' effectiveness in preventing oxidative damage.
- Finally, descriptive analysis was performed on data related to biodegradability, application uniformity, and visual changes in the coated produce to summarize the overall impact of the edible coatings on food preservation and environmental benefits.

The edible coatings were assessed for effectiveness and sustainability by analyzing their ability to preserve food quality, including visual appeal, texture, and shelf-life extension. The impact on microbial growth, spoilage, and freshness was observed under different storage conditions, such as refrigeration and room temperature.

The environmental benefits of edible coatings were compared with conventional plastic packaging, with a focus on biodegradability and waste reduction. A DPPH assay was conducted to measure the antioxidant potential, evaluating the coatings' ability to reduce oxidation and spoilage. The market and consumer evaluation examined aesthetic appeal, safety, and sustainability, highlighting their role in food preservation and the potential for eco-friendly packaging solutions.

IV. RESULT AND CONCLUSION

A. Shelf-Life

The shelf-life analysis, as demonstrated in the provided graph, shows the stability of the coated samples over time.

The graph (Figure 1) reflects the duration of preservation for both coated and uncoated samples, illustrating the potential extension of shelf-life due to the protective coating.

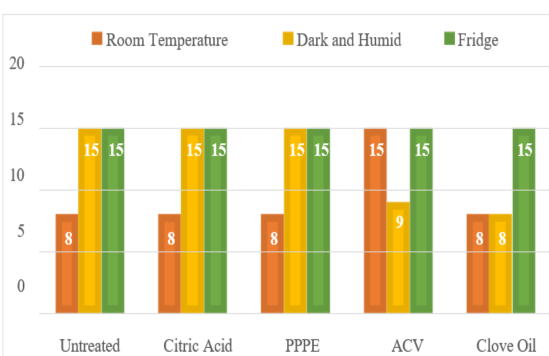


Figure 1.

Untreated: 8 (RT), 15 (DH), 15 (F)
Citric Acid: 8 (RT), 15 (DH), 15 (F)
PPPE: 8 (RT), 15 (DH), 15 (F)
ACV: 15 (RT), 9 (DH), 15 (F)
Clove Oil: 8 (RT), 8 (DH), 15 (F) (RT = Room Temperature, DH = Dark & Humid, F = Fridge)

B. Thickness of Coating

- The thickness of the coating containing clove oil was measured and found to be uniform, with a value of 118.47 GSM (100µm).
- The coating containing citric acid exhibited a thickness of 120 GSM (~ 100µm)., reflecting its uniform application and effective surface coverage.
- Similarly, the coatings prepared with apple cider vinegar and potato peel extract (PPPE) showed thicknesses of 118 GSM and 119 GSM (~100µm), respectively, ensuring consistent coverage and reliable protection.

C. Surface Colour Development

The surface colour development was observed to be uniform and visually appealing, indicating effective coating application. The coating contributed to an enhanced aesthetic quality and consistent surface appearance.

D. Sensory Evaluation

The sensory evaluation revealed that the coated samples were preferred over the uncoated samples in terms of appearance, texture, and overall acceptability. The coating enhanced the Visual appeal, improved the texture, and maintained a pleasant aroma.

E. pH Testing

- The pH testing results showed that the coating containing citric acid had a pH of 4.
- The coating with clove oil had a pH of 5.
- The coating formulated with Apple Cider Vinegar (ACV) had a pH of 6.
- The coating containing Potato peel powder extract (PPPE) had a pH of 6.

F. DPPH Analysis

1. Citric Acid (Figure 2)

- The antioxidant concentration is 60 µg/ml.

- The absorbance at 517nm is around 0.03.

2. Clove Oil (Figure 3)

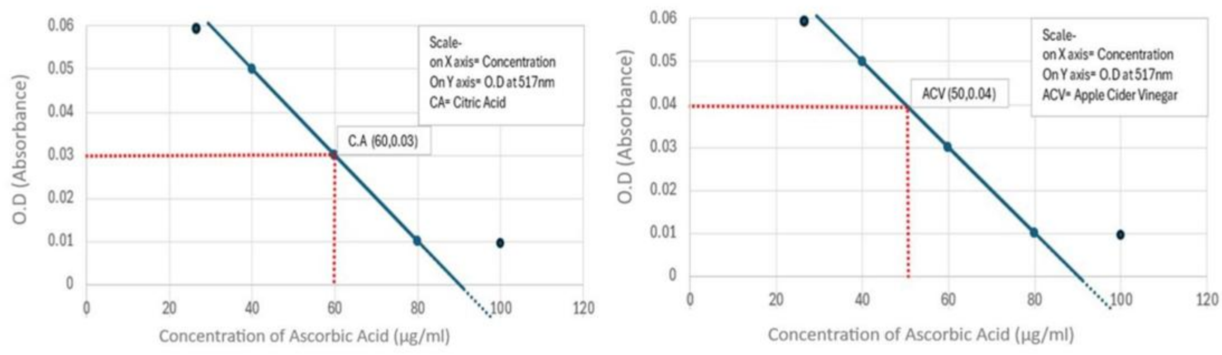
- The antioxidant concentration is 40µg/ml.
- The absorbance at 517nm is around 0.05.

3. Apple Cider Vinegar (Figure 2)

- The antioxidant concentration is 50 µg/ml.
- The absorbance at 517nm is around 0.04.

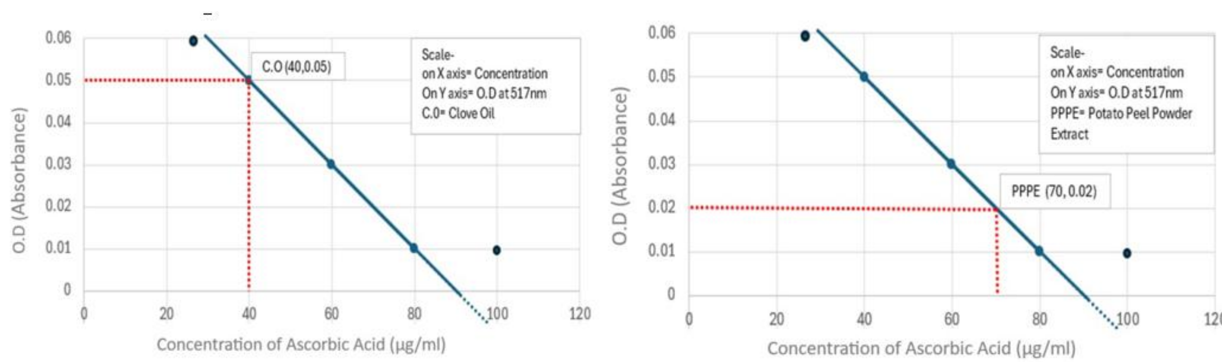
4. Potato Peel Powder Extract (PPPE) (Figure 3)

- The antioxidant concentration is 70 µg/ml.
- The absorbance at 517 nm is around 0.02



(A) (B)

Figure 2. Graph representing DPPH value of (A) Citric Acid (CA), (B) Apple cider vinegar (ACV) in coating solution.



(C) (D)

Figure 3. Graph representing DPPH value of (C) Clove Oil (C.O) and (D) Potato Peel Powder Extract (PPPE) in coating solution.

Table 1. Result of Catalase Test (A) and (B)

Catalase Analysis			Catalase Analysis		
Preservative	Conditions	Effervescence	Preservative	Conditions	Effervescence
Blank	Dark	No effervescence	C.O	Fridge	0.3cm
Blank	Fridge	0.3cm	ACV	Fridge	0.4cm
Blank	Fresh	0.2cm	ACV	R. T	0.4cm
C.A	Fridge	No effervescence	PPPE	Dark	No effervescence
C.A	Dark	No effervescence	PPPE	Fridge	0.4cm

G. Catalase Test

The catalase test results, as shown in the provided table (Table 1.), demonstrate the presence or absence of catalase activity in the tested samples. The results indicate whether the sample exhibited bubbling (indicating a positive catalase reaction) or no reaction (negative result).

H. Titratable Acidity

The titratable acidity results, as shown in the provided table (Table 2), indicate the concentration of acid present in the samples. The data reveals the acidity levels for both the coated and uncoated samples, offering a comparison of their pH stability and preservation effectiveness.

Table 2. Constant Burette reading and Titratable acidity % of the samples (calculated by including dilution factors)

Samples	rette Reading (CBR)	Titratable Acidity %
Blank (Dark)	0.3	0.00192
Blank (Fridge)	0.4	0.00256
Blank (Fresh)	0.3	0.00192
Blank (Dark)	0.3	0.00192
Citric Acid (Fridge)	0.4	0.00256
Citric Acid (Dark)	0.3	0.00192
Clove Oil (Fridge)	0.3	0.00192
ACV (Fridge)	0.3	0.00192
ACV (R.T)	0.3	0.00192
PPPE (Fridge)	0.2	0.00128
PPPE (Dark)	0.3	0.00192

This study developed an edible coating incorporating Citric Acid, Clove Oil, Apple Cider Vinegar, and Potato Peel Powder Extract (PPPE) to enhance fruit shelf-life while maintaining quality. The coatings effectively acted as a protective barrier, reducing microbial growth, oxidation, and moisture loss while ensuring biodegradability and sensory neutrality. Uniform application (118–120 GSM) provided consistent coverage, with Citric Acid and Clove Oil demonstrating slightly higher surface adherence. pH analysis confirmed Citric Acid (pH 4) as the most effective antimicrobial agent, while ACV, PPPE, and Clove Oil (pH 5–6) Contributed to preservation without compromising sensory attributes. Shelf-life studies showed that coated samples outperformed untreated fruits, particularly under room temperature and humid conditions, where Clove Oil, ACV, and PPPE demonstrated superior stability. Refrigerated storage preserved all samples, indicating that the coatings did not significantly impact preservation under low temperatures. Antioxidant analysis revealed PPPE (87.5%) as the most potent radical scavenger, followed by Citric Acid (81.25%), ACV (75.0%), and Clove Oil (68.75%), highlighting their role in delaying oxidative degradation. Enzymatic analysis confirmed reduced oxidation and browning in coated samples, while titratable acidity tests indicated stable pH levels, crucial for microbial inhibition. These findings support the use of plant-based antimicrobial agents in food preservation, offering an eco-friendly alternative to synthetic packaging. Future research should focus on scaling production, optimizing formulations, and assessing consumer acceptance to advance commercial viability.

V. CONCLUSION

This study developed an edible coating using Citric Acid, Clove Oil, Apple Cider Vinegar (ACV), and Potato Peel Powder Extract (PPPE) to enhance fruit shelf life. The coatings effectively inhibited microbial growth, reduced oxidative spoilage, and maintained sensory attributes. Uniform thickness (118–120 gsm) ensured optimal protection, with Citric Acid and Clove Oil forming slightly thicker layers due to viscosity. pH analysis confirmed antimicrobial activity, with Citric Acid (pH 4) creating the most inhospitable environment for microbes. Antioxidant tests showed PPPE exhibited the highest radical scavenging activity (87.5%), followed by Citric Acid (81.25%), ACV (75.0%), and Clove Oil (68.75%). The coatings preserved fruit appearance, texture, and aroma, ensuring consumer acceptability.

VI. DISCUSSION

The findings align with existing studies on edible coatings and natural preservatives. Tchinda et al. (2023) demonstrated that Aloe vera, starch, and Arabic gum coatings effectively delayed banana ripening and weight loss. This study builds upon their research by integrating multiple natural preservatives, enhancing microbial inhibition and oxidative protection. While Tchinda et al. (2023) emphasized polysaccharide-based structural integrity, this study highlights the synergistic effect of antimicrobial and antioxidant agents.

PPPE's high antioxidant activity is consistent with studies on plant-derived bioactive compounds in food preservation. Prior research has shown Aloe vera-based coatings delay oxidation, similar to PPPE's radical scavenging properties. However, this study broadens the scope by combining multiple preservatives, optimizing their functional benefits. Additionally, while Arabic gum has been studied for improving coating adherence, this research focuses on balancing antimicrobial, antioxidant, and structural properties for extended shelf life.

VII. LIMITATIONS OF THE STUDY

Despite promising results, several limitations exist. First, the study was conducted under controlled laboratory conditions, which may not fully replicate real-world storage variables such as fluctuating humidity, microbial diversity, and transportation stress. Further studies in commercial storage environments are needed.

Second, while sensory evaluations indicated positive consumer perception, large-scale market trials were not conducted. Consumer preferences in different cultural and economic contexts should be assessed for broader applicability. Additionally, while coating was tested on fruits, their effectiveness on vegetables and other perishable foods remains unexplored. Future research should examine a wider range of produce to determine broader applications.

Finally, mechanical properties, adhesion strength, and resistance to external stresses such as temperature fluctuations and handling were not extensively studied. Further research is needed to optimize durability and commercial viability. Edible coatings play a crucial role in reducing food waste by extending shelf life and minimizing spoilage, thereby supporting global food security (Nunes et al., 2023). Their integration with the circular bioeconomy promotes sustainability by utilizing natural antimicrobials derived from food waste valorization. Additionally, incorporating bioactive ingredients such as probiotics and vitamins can enhance coatings, aligning with consumer demand for healthier, minimally processed foods. Advances in nanotechnology further improve antimicrobial properties and bioactive compound delivery, extending the freshness of produce. Future research should focus on optimizing these coatings for various perishable foods to ensure widespread applicability and effectiveness (Nunes et al., 2023).

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