EVALUATION OF THE PHYSICAL AND CHEMICAL EFFECTS OF ALOE VERA GEL COATING ON CUCUMBER, BANANA AND PEPPER

BY

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DEPARTMENT OF CHEMISTRY

FACULTY OF PHYSICAL SCIENCES

UNIVERSITY OF BENIN

BENIN CITY, NIGERIA

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT O CHEMISTRY, IN PARTIAL FUFILLMENT OF THE REQUIREMENT FOR THE AARD OF BACHELOR OF SCIENCE (B.Sc.) HONOURS DEGREE IN CHEMSTRY

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CERIFICATION

This is to certify that **IGHALO ESEOHE PRECIOUS**, an undergraduate student in the Department of Chemistry, Faculty of Physical Sciences, University of Benin, Edo State, with Matriculation Number **PSC2105221**, under the supervision of **DR. (MRS) O.B. OVONRAMWEN** satisfactorily completed this project work on her own as partial fulfillment of the requirements for the award of a Bachelor of Science (B.Sc. Honours) Degree in Chemistry.

IGHALO ESEOHE PRECIOUS **DATE**

(PROJECT STUDENT)

DR. (MRS) O.B OVONRAMWEN **DATE**

(PROJECT SUPERVISOR)

PROF. EMMANUEL E.I. IRABOR **DATE**

(HEAD OF DEPARTMENT)

DEDICATION

This project research is dedicated to myself, for the resilience to keep moving forward, and to the pursuit of knowledge, which continues to inspire growth and progress.

ACKNOWLEDGEMENT

First and foremost, I sincerely thank Almighty God for His grace, strength, and guidance throughout the course of this project and my academic journey.

I am deeply grateful to my supervisor, Dr Mrs Ovonramwen, for her invaluable guidance, patience, and support, which made this work possible. My appreciation also goes to the Head of Department, Prof. E.I Irabor, as well as all my lecturers for their dedication and impact on my learning. I equally thank the Department of Chemistry and the entire institution for providing me with the knowledge, facilities, and opportunities to grow academically and personally.

To my family, friends and relatives, I owe heartfelt gratitude for their love, encouragement, and prayers. Especially my roommate (Phebe), thank you for the emotional support and understanding during challenging times.

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ABSTRACT

This study investigated the effectiveness of Aloe vera gel coatings in extending the shelf life and preserving the quality of cucumber, banana, and pepper during storage. The functional group of the experimental samples were carried out using Fourier Transform Infrared Spectroscopic (FTIR) analysis and the chemical composition of Aloe vera was determined using Gas Chromatography Mass Spectrometry (GC MS) whereas the physical parameters such as firmness, weight loss, odour, spoilage, and colour were evaluated, along with chemical parameters including pH, sugar content, and titratable acidity were carried out using standard methods. The results showed that fruits coated with Aloe vera gel exhibited reduced weight loss, slower firmness decline, delayed colour changes, and postponed spoilage compared to uncoated controls. Coated samples also retained higher sugar content and titratable acidity. In addition, while pH generally increased during storage, coated samples showed a lower rate of pH change compared to the controls, indicating delayed deterioration. The FTIR spectra of each fruit samples revealed similar compositions, with only slight variations in intensity. This indicates that while the Aloe vera gel preserved the fruits by forming an external protective barrier, it did not alter or interfere with their internal chemical composition.

Among the treatments, the 30-minutes and 60 minutes application generally produced the most effective preservation across the three fruits. These findings highlight the potential of Aloe vera gel as an eco-friendly, natural coating for prolonging the postharvest quality of perishable fruits, thereby reducing food loss and enhancing marketability.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The demand for fresh fruits and vegetables remains high due to their nutritional value, yet their short shelf life poses a major postharvest challenge. Postharvest deterioration remains a key challenge in preserving fruits and vegetables, especially in tropical regions where temperature and humidity accelerate spoilage. Rapid spoilage not only leads to economic losses but also contributes to food insecurity and waste. To mitigate these effects, researchers have explored various postharvest treatments, including chemical preservatives, refrigeration, and more recently, natural edible coatings that delay senescence and microbial spoilage (Kaur, 2024).

One natural substance that has gained attention is **Aloe vera gel**, which is rich in bioactive compounds such as polysaccharides, phenolics, and organic acids that possess antimicrobial and antioxidant properties. Aloe vera gel (AVG) creates thin, semi-permeable films that restrict oxygen penetration while also offering antioxidant and antimicrobial benefits (Gboyimde, 2019; Shala *et al.*, 2024). These coatings help to minimise moisture loss, oxygen uptake, respiration rate, and ethylene production, thereby maintaining fruit flavour (Esmaeili *et al.*, 2021). Being a water-soluble, polysaccharide-based coating, AVG spreads evenly across the fruit surface, shielding the tissues beneath from mechanical injury, reducing water evaporation, and regulating gas exchange through its effect on stomata and lenticels (Kocira *et al.*, 2021; Shiekh *et al.*, 2021). It further improves fruit gloss and can serve as a carrier for functional additives such as antifungal agents and vitamins (Fatemi *et al.*, 2024; Razavi, Maghsoudlou *et al.*, 2021). Moreover, AVG-based coatings slow down browning and oxidative changes while suppressing microbial activity, thanks to bioactive compounds like salicylic acid and saponins (Rasouli *et al.*, 2019; Shiekh *et al.*, 2021).

Studies have shown promising results with Aloe vera gel in preserving fruits like bananas, extending their shelf life and maintaining postharvest quality under different storage conditions and application techniques (QUOC, 2021). However, more investigation is needed to understand its effects on a wider range of produce, including its interaction with application methods, concentrations, and duration of exposure.

This project explores the preservation potential of Aloe vera gel on banana, cucumber, and pepper, using coating and dipping methods at different concentrations and time intervals, while monitoring both physical and chemical changes during storage.

1.1.1 Background of Study

Fruits and vegetables are important components of the human diet, valued not only for their flavour but also for their high content of vitamins, minerals, dietary fiber, and bioactive compounds that support health and immunity. However, despite their nutritional benefits, these commodities are highly perishable and susceptible to rapid deterioration after harvest.

According to the Food and Agriculture Organization of the United Nations (FAO, 2019), about 14% of the world's food is lost from post-harvest up to, but not including, the retail stage. Losses are not uniform across commodities, with roots, tubers, and oil-bearing crops experiencing the highest losses at 25.3%, followed by fruits and vegetables at 21.6%. While this is lower than earlier estimates suggesting that nearly one-third of global food production is lost or wasted annually, the scale of the problem remains significant, particularly in developing regions where postharvest infrastructure is limited. These losses are distributed, with 44 % occurring in developing countries and 40 % in developed countries (Gustavsson *et al.*, 2022). In tropical regions such as Nigeria, the problem is even more severe due to high ambient temperatures and humidity, which accelerate spoilage and lead to significant economic losses, food insecurity, and nutritional deficits.

To reduce these losses, various preservation techniques have been developed, ranging from refrigeration and chemical preservatives to more recent approaches like edible coatings and natural bio-preservatives (Kaur, 2024). While cold storage is effective, it is often expensive and inaccessible in rural areas. Chemical preservatives, though commonly used, are now being scrutinised for their potential health risks and environmental impact. As a result, there is growing interest in the use of natural and eco-friendly alternatives that are affordable, biodegradable, and safe for human consumption

One such promising alternative is the use of Aloe vera gel, a natural substance derived from the leaves of the Aloe vera plant (***Aloe barbadensis miller***). The gel contains bioactive compounds such as polysaccharides, phenolics, saponins, and organic acids, which exhibit antimicrobial, antioxidant, and anti-inflammatory properties (Suriati *et al.*, 2020).

Studies have demonstrated the effectiveness of Aloe vera gel in preserving fruits like apples, grapes (Chauan *et al.*, 2014), fig (Kaur *et al.*, 2024), mango (Ajeethan and Mikunthan, 2016), and bananas (QUOC, 2021; Al Rifat *et al.*, 2024) under room temperature conditions, showing improvements in firmness, colour retention, and delayed spoilage. However, there is still a need to explore its effectiveness across a broader range of produce, under varied application methods, concentrations, and storage durations.

In this study, three commonly consumed perishable fruits — banana, cucumber, and pepper are selected due to their high spoilage rates and widespread use in Nigerian households. The research investigates the preservation effects of Aloe vera gel applied using both coating (with cotton wool) and dipping methods at three concentrations (0%, 50%, and 100%) and time intervals (0, 30, and 60 minutes). The fruits will be monitored at room temperature while placed on plantain leaves, which also reflect traditional storage practices. Physical parameters such as colour change, firmness, and spoilage rate, along with chemical properties including pH, sugar content, and acidity, will be analysed.

This research aims to provide a sustainable and cost-effective solution for extending the shelf life of fruits and vegetables using locally available natural materials. By reducing postharvest losses, the study contributes to improving food security, reducing waste, and supporting local farmers and vendors who often lack access to modern preservation technology.

1.1.2 Statement of the Problem

According to Nto Philips Nto, Director of the Agribusiness Incubation Centre (ABIC) at Michael Okpara University, Nigeria loses up to ₦14 trillion annually due to poor postharvest management. Contributing factors include inadequate storage facilities, limited processing capacity, and inefficient distribution networks (Source; *business day newspaper*, 2025).

Similarly, Ibrahim Shaka, a Food and Nutrition Specialist at the Food and Agriculture Organization (FAO), noted that perishable goods are the most affected, with nearly 50% of fruits and vegetables produced annually lost to rotting and damage caused by poor storage and handling conditions (*punch newspaper*, 2024).

Perishable crops such as banana, cucumber, and pepper are especially vulnerable due to their high moisture content, susceptibility to microbial growth, and vulnerability to enzymatic reactions. Farmers and vendors in rural areas frequently rely on traditional, open-air storage methods, which offer little protection against microbial spoilage and physical damage.

The use of chemical preservatives and refrigeration, while effective, is either unaffordable or inaccessible for many smallholder producers. Moreover, synthetic preservatives are facing increased scrutiny due to concerns about food safety and environmental sustainability

Aloe vera gel (AVG) has emerged as a promising natural alternative, possessing active antifungal agent against postharvest diseases and significantly extends fruit shelf life by preserving firmness, colour, and moisture, and preventing bacterial growth, offering a safe, eco-friendly alternative to synthetic preservatives (Habeeb *et al.,* 2007; Parven *et al.,* 2020).

However, its effectiveness across various types of fruits and vegetables, especially under room-temperature storage conditions typical in Nigeria, remains underexplored.

This study seeks to address this gap by evaluating the use of Aloe vera gel as an affordable, eco-friendly preservation method for banana, cucumber, and pepper, using accessible techniques such as coating and dipping at varying concentrations and durations.

1.1.3 Justification of the Research

Fruits and vegetables play a vital role in ensuring food and nutritional security, especially in countries like Nigeria where they form a significant part of the diet. However, their high perishability leads to substantial postharvest losses, which undermine food availability, increase economic hardship for smallholder farmers, and contribute to food insecurity. Conventional preservation techniques such as refrigeration and chemical preservatives (Kaur, 2024) are often costly, environmentally unfriendly, or inaccessible in rural communities. This calls for the development of alternative, low-cost, and sustainable postharvest preservation strategies.

Aloe vera gel, a naturally occurring biopolymer, offers promising antimicrobial and antioxidant properties that can be harnessed to reduce spoilage and extend the shelf life of fresh produce. As a bio-based material, it aligns with the global shift toward safer, eco-friendly food preservation technologies. Its potential effectiveness under ambient temperature conditions, if validated, could provide a practical solution for local farmers and vendors in Nigeria who lack access to cold storage facilities.

By evaluating Aloe vera gel's application on banana, cucumber, and pepper, three widely consumed yet highly perishable crops, this study aims to contribute meaningful data to support its broader adoption. The research not only advances knowledge in natural postharvest technologies but also promotes sustainable agricultural practices, reduces food waste, and supports livelihoods at the grassroots level.

1.1.4 Scope of the Study

This study focuses on evaluating the effectiveness of Aloe vera gel as a natural postharvest treatment for three commonly consumed and highly perishable crops in Nigeria: banana (*Musa sapientum* Linn.), cucumber (*Cucumis sativus*), and pepper (*Capsicum annuum*).

The fruits and vegetables were first subjected to a preliminary physical assessment using two application methods, coating (with cotton wool) and dipping at 0%, 50%, and 100% Aloe vera gel concentrations, and exposure durations of 0, 30, and 60 minutes. They were observed over a period of 10 to 14 days, during which no notable difference was found between the two methods. Hence, the dipping method was selected for the main study. Also, the 50% coated fruits were observed to show faster spoilage than the 100% coated fruits. Therefore, 100% Aloe Vera gel was used for the main study.

In the main experimental phase, only the dipping method was employed, using 100% Aloe vera gel concentration durations: 0 minutes, 30 minutes, and 60 minutes. Treated fruits were stored under ambient room temperature conditions, placed on plantain leaves to reflect traditional local storage practices, and monitored for 14 days. The treated samples were observed and monitored throughout the storage period, and samples were taken at specific intervals for physical and chemical analyses while the bioactive compounds present in the gel was identified using Gas Chromatography Mass Spectrometric (GC MS) analysis.

1.1.5 Aim and Objectives

This study aims to evaluate the potential of Aloe vera gel as a natural postharvest preservative by assessing its effects on the physical and chemical properties of banana (*Musa acuminata*), cucumber (*Cucumis sativus*), and pepper (*Capsicum annuum*) during storage.

Objectives:

These following objectives were observed to:

1. conduct a preliminary assessment comparing the effectiveness of coating and dipping application methods across Aloe vera gel concentrations (0%, 50%, 100%) and exposure durations (0, 30, and 60 minutes) on banana, cucumber, and pepper.

2. assess the effects of 100% Aloe vera gel applied by dipping method only at 0, 30, and 60 minutes on physical parameters such as weight loss, colour, firmness, spoilage rate, odour and other visual qualities.

3. evaluate the impact of Aloe vera gel treatment on chemical properties including pH, acidity, sugar content using spectrophotometric, and functional groups.

4. identify the bioactive compounds present in Aloe vera gel using Gas Chromatography Mass Spectrometry (GC MS) analysis.

1.2 Literature Review

Postharvest preservation of fruits and vegetables has become a vital area of study due to rising concerns over food loss, food insecurity, and the environmental impacts of synthetic preservation techniques. In tropical and developing countries like Nigeria, where temperature and humidity levels are high, perishable produce such as banana, cucumber, and pepper are particularly prone to rapid deterioration. Traditional preservation practices often fall short in extending shelf life, while modern technologies like refrigeration remain largely inaccessible to rural farmers and vendors. Consequently, the use of natural, affordable, and environmentally friendly postharvest treatments, such as those derived from plant-based sources has drawn increasing scientific interest. This literature review presents an overview of postharvest losses, factors affecting produce spoilage, conventional and alternative preservation methods, and the emerging role of Aloe vera gel as a bio-based coating. It also discusses the physical and chemical parameters used to evaluate preservation effectiveness and identifies key research gaps addressed in this study.

1.2.1 Post-harvest Losses

Postharvest losses are classified as **quantitative**, involving reductions in weight (mass or volume), market value, where losses reduce the amount of produce available for consumption. and **qualitative**, referring to declines in nutritional quality, appearance, safety, and consumer acceptability. While quantitative losses are easier to measure, qualitative losses though harder to assess often have significant economic and nutritional implications, especially in regions lacking adequate postharvest infrastructure (Yahia *et al.*, 2019). Fruits and vegetables are highly vulnerable to spoilage because of their high moisture content and active metabolism, which makes them very perishable.

A Food and Nutrition Specialist at the Food and Agriculture Organisation (FAO), Ibrahim Shaka, stated that in Nigeria, postharvest losses are among the highest globally, with estimates indicating that up to 50% of agricultural produce—particularly fruits and vegetables—is wasted annually (*punchng,* 2024*)*

According to The Premium Times Nigeria, the African Centre for Supply Chain stated that a major driver of these losses is the lack of functional cold storage systems. For instance, about 50% of perishable export products are lost annually due to inadequate cold chain facilities at airports and weak logistics performance (Premium times, 2024).

The United States Agency for International Development (USAID) has stated that about 50% of fresh agricultural produce in Nigeria is lost at the post-harvest stage (Udi, 2024). These losses occur at various points in the supply chain from harvesting and handling to marketing, reducing the overall food available for consumption and income for smallholder farmers. Despite increasing food production, a significant portion is wasted before reaching consumers, posing a major challenge to food security and economic stability in the country (Adeyemi, 2024).

1.2.1.1 Classification of Postharvest Losses

Postharvest losses in fruits and vegetables can be classified based on the stage at which they occur during the handling and distribution chain. In Nigeria, the major classifications include:

1. Losses due to Poor Harvesting Methods:

Throwing stones or sticks to dislodge fruits from trees.

- Using crude tools (e.g., “go-to-hell” rods) that cause fruits to fall and bruise.
- Shaking trees such as orange or pawpaw to harvest ripe produce.

- Cutting branches (e.g., in *Chrysophyllum albidium* / agbalumo) instead of harvesting fruits individually.
- Detaching fruits incorrectly or at the wrong maturity stage.

2. Losses from Poor Handling Techniques:

- Tossing fruits and vegetables into baskets without regard for bruising.
- Rough loading and offloading that leads to internal injuries.
- Pressing or forcing produce into containers.
- Mixing healthy produce with damaged or diseased ones, accelerating spoilage.

3. Losses due to Lack of Storage Facilities:

Generally, for fruits and vegetables in Nigeria, there is no organised storage system. Even at the local level where the majority of the food is produced, farmers stand to lose all their products whenever there is a glut in the market. (Adebooye and Farinde, 2015).
These classifications highlight the critical control points in the postharvest chain where interventions can reduce losses significantly.

1.2.1.2 Causes of Post-harvest Loss

Fresh horticultural commodities are living organisms whose quality and postharvest life are affected by various factors, such as temperature; humidity; composition of the surrounding atmosphere; the level of damage that can be caused before, during, and after harvest; and the type and degree of infection with microorganisms, attacks by insects, etc., (Yahia *et al.*, 2019). These products are easily affected by less-than-optimal handling conditions and can be lost or wasted during the postharvest period due to many possible causes, such as the followings:

- Loss of moisture
- Loss of reverse materials such as carbohydrates
- Loss of other nutrients such as vitamins
- Physical loss due to different types of mechanical damage
- Losses and waste by pests and diseases
- Losses of quality due to physiological disorders
- Fiber development (toughness)
- Greening of some products (e.g., potatoes) when exposed to light
- Growth as in the case of carrots, potatoes, and onions
- Germination of seeds (Yahia *et al.,* 2019).

1.2.2 Postharvest Treatments and Technologies

Postharvest technologies encompass a range of treatments including physical methods such as heat application, irradiation, and the use of edible coatings, as well as chemical treatments involving antimicrobial agents, antioxidants and anti-browning agents. These diverse postharvest interventions are employed to improve the freshness and nutritional integrity of produce while ensuring compliance with safety regulations. These are often integrated with precise temperature management strategies during storage. Table 1 provides a summary of the major postharvest treatments, their benefits, limitations, and some of their commercial applications.

Table 1.1: Overview of the postharvest treatments of fresh produce.

Treatment	**Benefits**	**Limitations**	**Commercial applications**
Heat treatment	Reduction of chilling injury, delay of ripening, killing of critical insect contaminants, and controls decay.	High energy costs and added labour.	Potato, tomato, carrot, strawberry, asparagus, broccoli, beans, kiwi, celery, lettuce, melon, grape, plum, peach, spinach, rocket leaves (Schirra *et al.*, 2000; Maxin *et al.*, 2012)
Treatment	**Benefits**	**Limitations**	**Commercial applications**
Edible Coating.	Environmentally friendly, enhance sensory product attribute, improves functional and physiochemical properties being antimicrobial and antioxidative in nature (Perez-vazquez *et al.*, 2023)	edible coatings have poor barrier properties, and some of edible coatings impart undesirable flavour on produce (Duguma, 2021)	Banana (Rifat *et al.*, 2024), cucumber (Ajiboye and Gboyinde, 2020), fig (Kaur, 2024), Strawberry (Hassan *et al.*, 2022)
Irradiation	Inhibits sprouting of tubers, bulbs and roots, meets quarantine requirements for export trade and	Capital intensive, lack of harmonisation of regulations, slow consumer acceptance due to perceived association with radioactivity	Potato, onion, strawberry, mango (Mahto and Das 2013; Farkas 2014)

	recognised as a safe process.		
Anti-microbial and anti-browning agents	Retards browning, deterioration of texture, and microbial growth.	Inaccessible sites for treatments within fresh produce such as calyx and wax area.	Apple, strawberry, lettuce, melon, orange, prune, tomato, grapes, fresh-cut produce (Artes *et al.*, 2009; Carrasco *et al.*, 2010; Baskaran *et al.*, 2013)
Treatment	**Benefits**	**Limitations**	**Commercial applications**
Nitric oxide	Inhibits ethylene biosynthesis, reduces respiration rate, water loss, browning, and lower incidence of postharvest diseases.	Commercial application depends upon the development of a smart carrier/controlled release system for nitric oxide.	Apple, banana, kiwifruit, mango, peach, pear, plum, strawberry, tomato, papaya, loquat, jujube fruit and bayberry (Wendehenne *et al.*, 2004; Singh *et al.*, 2013)
Sulphur dioxide	Prevents postharvest decay.	Higher concentration may induce injuries and sulphite residues pose a health risk.	Grapes, litchi, fig, banana, lemon, apple, blueberries.
Ozone	Easily incorporated into existing cold storage, washing system, better efficacy than chlorine	Does not penetrate natural openings, further research is needed to improve application.	Apples, cherries, carrots, garlic, kiwi, onions, peaches, plums, potatoes, table grapes
Ethylene	Triggers ripening process thereby improves fruit color and quality	Need of optimum ethylene concentration, storage conditions for faster and more uniform ripening	Banana, avocado, persimmon, tomato, kiwifruit, mango, citrus fruits

Source: Adapted from Kaur, (2024).

1. **Physical Treatments**

❖ Heat Treatment: Hot water dips and vapour heat remain reliable techniques to reduce chilling injury, delay ripening, and control pathogens. For example, a hot water dip with carbonate salts reduced anthracnose incidence in papaya from 100% to 26.7%, while preserving key quality traits (Getnet *et al.*, 2023). These treatments also align with phytosanitary protocols for export, such as those developed for mango and bell pepper in African markets (Ndlela *et al.*, 2021).

- ❖ Irradiation: Involves exposing produce to gamma rays or electron beams to inhibit sprouting, delay senescence, and reduce microbial load. It is effective in crops like potato, onion, mango, and strawberry but may face limited acceptance due to public perception and regulatory issues (Kaur, 2024)
- ❖ Edible Coatings: Edible coatings have been intensively developed and studied because of their capacity to improve the quality, shelf life, safety, and functionality of the treated products. Edible coatings can be applied through different techniques, like dipping, spraying, or coating, in order to control moisture transfer, gas exchange, or oxidative processes (Miteluţ, 2022).

  Coatings like chitosan, alginate, and Aloe vera gel have been used successfully on apples, carrots, and strawberries. Despite their benefits, challenges exist in large-scale application, cost, and regulatory approvals (Petersen *et al.*, 1999; Diab *et al.*, 2001, Kaur, 2024).

2. Chemical Treatments

- ★ Antimicrobial and Anti-Browning Agents: Chemical dips and sprays such as hydrogen peroxide, citric acid, and chlorine-based solutions help prevent microbial spoilage and browning reactions in produce like melon, lettuce, apple, and tomato (Kaur, 2024).
- ★ Nitric Oxide (NO): A signaling molecule that delays ripening and senescence by suppressing ethylene biosynthesis and reducing respiration rate. Applied in fruits like banana, mango, pear, and strawberry (Kaur, 2024)
- ★ Sulphur Dioxide (SO_2): Used primarily for grapes and litchi to prevent postharvest decay. Though effective, its residues may pose health concerns at high concentrations (Kaur, 2024)

3. Gaseous Treatments

- Ozone: A strong natural oxidant used as a sanitizer in cold storage and washing systems. It effectively controls microbial growth on produce like kiwi, carrot, garlic, and grapes, offering an alternative to chlorine (Kaur, 2024).

- Ethylene Gas: Applied in controlled doses to accelerate ripening and enhance color development in fruits such as banana, tomato, and avocado. However, excessive exposure can hasten senescence and lead to spoilage, making control measures critical (Kaur, 2024)
- 1-Methylcyclopropene (1-MCP): Blocks ethylene receptors, thereby slowing ripening and senescence in climacteric fruits such as apple, tomato, mango, and avocado. (Kaur, 2024)

These technologies, when properly integrated with cold chain systems and good handling practices, can significantly reduce postharvest losses and improve the market value of fresh produce.

1.2.3 Factors Contributing to Deterioration

After harvest, fruits and vegetables remain living tissues and continue to undergo physiological and biochemical processes (Fig 1). These processes, if not properly managed, accelerate deterioration and lead to significant losses in quality, shelf life, and market value. The main factors contributing to deterioration are:

1. **Respiration Rate**

Respiration rate describes how quickly harvested produce absorbs oxygen or releases carbon dioxide. This rate reflects the metabolic processes occurring within the fruit or vegetable and helps determine how long the produce can be stored. Typically, fruits and vegetables exhibit their highest respiration rates when still immature, with a gradual decline as they mature, ripen, and eventually senesce. Respiration is usually measured in milligrams of carbon dioxide (mg CO_2) produced per kilogram per hour (mgCO_2/kg/hr). (Sangamesh and Karadiguddi, 2024). Table 2 presents the classification of fruits and vegetables based on their respiration rates at 5 °C, ranging from very low to extremely high.

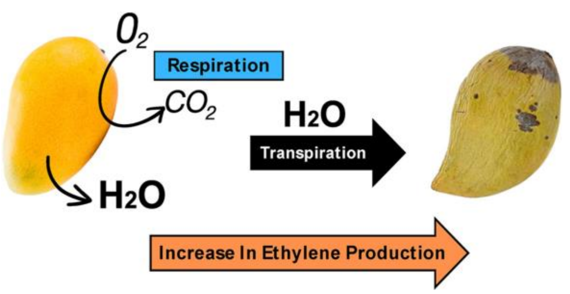


Fig. 1.1: Image illustrating respiration rate, transpiration and ethylene production in a mango fruit (Source; Gidado *et al.*, 2024)

Table 1.2: Classification of fruits and vegetables according to their respiration rates

Class	Range at 5ºC ($mgCO_2/kg/hr$)	Commodity
Very low	<5	Nuts, vegetables, dates, dry fruits
Low	5-10	Apples, sweet potato, citrus, garlic, grape, onion, potato
Moderated	10-20	Apricots, banana, tomato, cherry, peach, pear, fig, cabbage, carrot, lettuce, nectarine, pepper, mango
High	20-40	Avocado, strawberry, black berry, cauliflower, lima bean, raspberry
Very high	40-60	Artichoke, snapbean, Brussels sprouts, green onion
Extremely	high >60	sweet corn, broccoli, mushroom, spinach, pea, asparagus

(Sangamesh and Karadiguddi, 2024)

2. Water Loss and Transpiration in Postharvest Fruits

Postharvest water loss, mainly through transpiration, is a significant factor reducing fruit quality, shelf life, and market value. It's estimated that 45–55% of fruits are lost during postharvest stages, compared to 30% for cereals, 35% for seafood, and 20% for meats (FAO, 2011; Lipinski *et al.*, 2013; Xue *et al.*, 2021). Even a 3–10% water loss can compromise texture and render fruits unmarketable (Ben-Yehoshua and Rodov, 2003)

This water loss makes fruits more vulnerable to pathogens, flavour deterioration, and nutrient loss (Kays and Paull, 2004; Nunes and Emond, 2007; Hossain *et al.*, 2018). It is also referred to as weight loss (Lufu *et al.*, 2018; Maguire *et al.*, 2010) or moisture loss (Maw and Mullinix, 2005; Ngcobo *et al.*, 2012; Paniagua *et al.*, 2013), and occurs during handling, transportation, and storage (Pereira *et al.*, 2017). Effects include wilting, shrinkage, reduced firmness, significantly impact their market value and lower consumer acceptance (Shibairo *et al.*, 2002; Hertog *et al.*, 2015; Kader, 2022; Ayobami *et al.*, 2023; Chen *et al.*, 2024;)

3. Ethylene Production

Ethylene is a gaseous hormone in plants that significantly contributes to the ripening of many fruits, working alongside other hormones and signals. In unripe fruits, ethylene levels are typically low. However, as the fruit develops, ethylene production begins and triggers the ripening process. After harvest, ethylene levels continue to rise, which shortens shelf life, reduces storage potential, and increases the risk of pathogen infection. Therefore, controlling and regulating ethylene levels is essential to prevent fruits from overripening either before harvest or during storage, which can negatively affect marketability and reduce economic returns (Capino and Farcuh, 2024)

4. Microbial Contamination

Pathogens such as bacteria, yeasts, and molds can invade harvested produce, especially if there are wounds or bruises. Poor hygiene during handling, packaging, or transport worsens microbial spoilage, leading to visible rots, off-odours, and sliminess (Google, 2025)

5. Mechanical Damage

Mechanical damage (fatigue) occurs during transportation because of vibrations that occur while traveling what are typically long distances, usually over untarred roads. High temperatures and the build-up of gases that accelerate enzyme activity (and thus cause over-ripening or softening) and microbial activity are factors that contribute to the deterioration of fruit harvests (Das *et al.*, 2024)

6. Temperature Fluctuation

Temperature is usually the most important environmental factor limiting shelf life of fresh fruits.

Since fruits are alive after harvest, all physiological processes continue after harvest such as respiration and transpiration (water loss), and supply of nutrients and water is not possible since produce is no longer attached to the parent plant. Respiration results in deterioration, including loss of nutritional value, changes in texture and flavour, and loss of weight by transpiration. These processes cannot be stopped, but they can be reduced significantly by careful management of temperature and relative humidity during storage and transportation (Tiwari *et al.*, 2024). Other factors include: poor ventilation, delayed marketing or processing (Wikipedia, 2025) etc.

1.2.4 Edible Coating of Fruits and Vegetables.

Edible coatings help preserve the quality of fruits and vegetables, making them valuable in postharvest handling. Coatings made from lipids, polysaccharides, or proteins can minimise physical changes during storage. Their primary function is to act as a barrier to respiration and moisture loss. Additionally, they can carry functional agents like antioxidants and antimicrobials, thereby enhancing the quality and extending the shelf life of fresh and lightly processed produce (Sheetal *et al.,* 2023). Fig. 2, which demonstrates their effectiveness in reducing spoilage and maintaining quality during storage (Jamuna *et al.*, 2024).

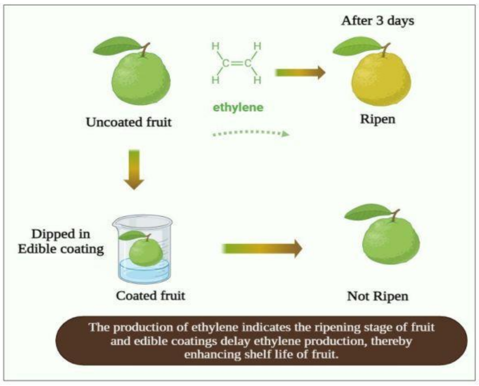


Fig. 1.2: *Impact of Edible Coatings on Fruit Shelf life* (Source; Jamuna *et al.*, 2024)

Natural biomolecules called edible coatings are employed to improve the beauty and preservation of fruits and vegetables. Their effectiveness can be increased by incorporating functional food-grade extracts such as flavours, pigments, antioxidants, and antimicrobials which help improve both the safety and nutritional quality of the produce when applied (Nawab *et al.*, 2017).

According to Miteluţ, 2022, edible coatings are thin layers composed of chemical or biological substances that are applied to the surface of produce to prevent gas exchange and thereby slow down the ripening process.

Edible coatings and films are primarily made from lipids, polysaccharides, and proteins. However, additional substances like resins, solvents, and plasticizers are often incorporated to enhance specific functional properties. Plasticisers improve flexibility and permeability, solvents contribute to tensile strength, while resins help reduce water vapour transmission (Ulusoy *et al.*, 2018; Galus, 2019)

Recent market analyses show a growing interest in the use of edible coatings, especially for extending the shelf life of fruits and vegetables. According to Mordor Intelligence (2025), the global edible coatings market is valued at approximately USD 3.57 billion in 2025 and is projected to reach USD 5.16 billion by 2030, growing at a compound annual growth rate

(CAGR) of 7.64%. Similarly, IMARC Group (2024) reports a strong upward trend in demand for natural, biodegradable packaging alternatives, with edible films and coatings gaining significant commercial traction across food supply chains.

1.2.4.1 Properties of Edible Coatings

The effectiveness of edible coatings is influenced by their molecular structure, size, and chemical composition. These coatings possess several key characteristics:

- They should not contain any toxic, allergic substance and should be digestible (Vaishali *et al.*, 2019)
- They serve as effective barriers against moisture, oxygen, carbon dioxide, and ethylene (Sheetal *et al.*, 2023).
- They should have good adhesion property (Vaishali *et al.*, 2019)
- Inertness of coating substances is required to assure it as non-reactive one with the food items which gets packed in (Priya *et al.*, 2023)
- They improve the visual appeal and handling strength of produce, helping to maintain shape and colour (Sheetal *et al.*, 2023)
- Enriched with active compounds like antioxidants and vitamins, they enhance the nutritional value of fruits and vegetables without compromising quality (Sheetal *et al.*, 2023)
- The appearance of coating and light barrier properties plays a vital role in obtaining the attention of consumers (Priya *et al.*, 2023)
- providing semi permeability to maintain internal equilibrium of gases which is involved during anaerobic and aerobic respiration, thus retarding senescence (Vaishali *et al.*, 2019)
- They should be easily manufactured and economically viable (Vaishali *et al.*, 2019)
- They should have antimicrobial and antibacterial properties (Vaishali *et al.*, 2019)
- By forming a protective film, edible coatings significantly contribute to extending the shelf life of fresh produce (Momin *et al.*, 2022).

1.2.4.2 Classifications of Edible Coating

Edible coatings derived from various sources are enlisted in Fig. 3

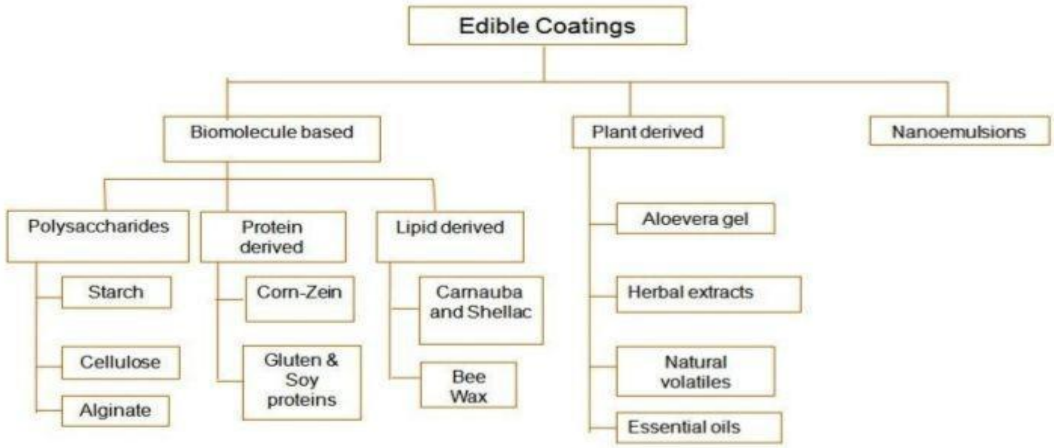


Fig. 1.3 Edible coatings derived from various sources (Source; Mahajan *et al.*, 2018)

PLANT BASED EDIBLE COATINGS

- **Aloe Vera Gel (AVG)**

Aloe vera gel (AVG) is recognised as a rich source of nutrients and bioactive phytochemicals, including phenols, flavonoids, terpenoids, lectins, and fatty acids (Al-Hilifi *et al.*, 2022). It also contains vitamins and polysaccharides, which contribute to its antioxidant potential (Rizwana *et al.*, 2022). Due to its diverse range of bioactive compounds, AVG exhibits several therapeutic properties, such as antiviral, antibacterial, antioxidant, anti-inflammatory, anticancer, antidiabetic, antiallergic, immunostimulatory, and UV-protective effects (Ray and Gupta, 2013).

Despite these benefits, pure AVG is highly hydrophilic, which limits its effectiveness and durability when used as a protective coating for fruits (Al-Hilifi *et al.*, 2022).

- **Herbal Extract**

Fruits are frequently exposed to a wide range of microorganisms, which may originate from the soil, air, or be transferred from the plant surface (Mahajan *et al.*, 2018). During postharvest storage, spoilage often results from microbial infections that enter the fruit through natural openings such as stomata, lenticels, as well as through cracks or surface injuries (Mahajan *et al.*, 2018). Numerous plant-derived products and extracts possess broad-spectrum antimicrobial activity and are considered bio-preservatives due to their non-toxic and human-safe nature (Mahajan *et al.*, 2018). Their simplicity of use, effectiveness under standard storage conditions, and safety make herbal extracts a promising solution for extending the shelf life of fruits (Mahajan *et al.*, 2018). Common examples of such natural preservatives include ginger, garlic, and turmeric (Mahajan *et al.*, 2018).

- **Natural Volatile Compound**

Natural volatile organic compounds (NVOCs) also referred to as biogenic volatile organic compounds are derived by living organisms, particularly plants, and have various functional properties (Kim *et al.,* 2021). In the context of edible coatings for fruits and vegetables, NVOCs include substances like essential oils and aldehydes, which contribute to preservation and antimicrobial effects (Sanahuja and García, 2021). Additional examples of these natural volatiles are methyl jasmonate, ethanol, tea tree oil, and garlic oil, all of which have been employed for their bioactive properties in extending shelf life and improving postharvest quality (Mahajan *et al.,* 2018).

- **Essential Oil based edible coating**

Essential oils (EOs) such as rosemary, thyme, cinnamon oil, and aldehydes like vanillin and cinnamaldehyde possess strong antimicrobial and antioxidant activities, contributing to improved food quality and prolonged shelf life (Sanahuja and García, 2021; Usman *et al.,* 2025).

Application of EOs such as ginger oil, lemongrass, clove bud oil, turmeric, neem extract, mint, and cinnamon oil has been shown to significantly extend the shelf life of fruits by reducing microbial spoilage and maintaining quality (Reddy and Singh, 2020; Yousuf *et al.*, 2021).

Nanoemulsions

Nanoemulsions are colloidal systems made up of two or more immiscible liquids, in which one phase is dispersed in the other in the form of nanometer-sized droplets (20–1000 nm). These are stabilised by emulsifiers such as surfactants and co-surfactants (Jhawat *et al.,* 2021; Jha *et al.,* 2022; Jamali *et al.,* 2023).

They serve as efficient delivery systems for bioactive compounds like antioxidants, antimicrobials, and vitamins, which can be incorporated into edible coatings. This encapsulation helps protect these compounds from degradation and enables controlled, sustained release over time (Thakur *et al.,* 2024).

Coatings based on Composite

Composite edible coatings are formulated by combining different biopolymers such as lipids, polysaccharides, and proteins to enhance preservation and quality (Jamuna *et al.,* 2024). These coatings are typically classified into two types: bilayer composites, consisting of two distinct layers made from combinations like lipid/polysaccharide or protein/protein (Rivero *et al.,* 2009), and conglomerates, which are homogeneous blends of multiple biopolymers, such as starch, chitosan, gelatin, and waxes (Jamuna *et al.*, 2024).

Each component contributes specific functionality, polysaccharides offer film-forming ability, proteins provide structural strength, and lipids enhance moisture resistance (Jamuna *et al.,* 2024). These biodegradable coatings extend shelf life by reducing moisture loss, limiting gas exchange, and protecting against decay, while also preserving the appearance and nutritional value of fruits (Jamuna *et al.,* 2024).

1.2.4.3. Methods of application of edible coating/films

Examples includes

- **Dipping Method**

The dipping method applies edible coatings to fresh fruits through three sequential steps:

1. Immersion: Fruits are submerged in a coating solution to ensure complete surface coverage (Oduro, 2021; Gouthami, 2023; Sheetal *et al.,* 2023).

2. Draining and Removal of Excess: After withdrawal, residual solution is drained, and excess coating is scraped or eliminated from the surface (Oduro, 2021; Gouthami, 2023; Sheetal *et al.,* 2023).

3. Drying: Fruits are dried to form a continuous, adherent film bonded to the surface (Oduro, 2021; Gouthami, 2023; Sheetal *et al.,* 2023).

Characteristics

-Versatility: Effective for viscous and adhesive coating solutions (Oduro, 2021; Gouthami, 2023).

- Historical Significance: The oldest commercial technique, yet remains practically relevant today (Oduro, 2021; Gouthami, 2023).

- **Vacuum Impregnation method**

Vacuum impregnation represents an advanced evolution of conventional dipping techniques (Oduro, 2021; Pandey *et al*., 2022; Gouthami, 2023). Its core innovation lies in employing a vacuum environment during submersion, distinguishing it from standard dipping protocols (Oduro, 2021; Gouthami, 2023). The process involves two critical phases:

1. **Vacuum Submersion**:

Fresh food items are placed in an airtight vacuum chamber containing coating solution, replacing conventional dip tanks ((Oduro, 2021; Gouthami, 2023; Sheetal *et al.,* 2023).

2. **Pressure Restoration**:

While maintaining submersion in the solution, the system is returned to atmospheric pressure (Oduro, 2021; Gouthami, 2023; Sheetal *et al.*, 2023).
This controlled pressure transition enhances coating penetration and adhesion efficiency compared to traditional methods (Pandey *et al.*, 2022).

- **Spraying Method**

The spraying technique is best suited for low-viscosity coating solutions that can be evenly applied under high pressure (Oduro, 2021; Gouthami, 2023). This method works by converting the coating solution into fine droplets, which are uniformly distributed over the surface of the fruit (Pandey *et al.*, 2022).
Moreover, the solution surface is increased because of the droplets' formation (Suhag *et al.*, 2020). The effectiveness of the coating depends significantly on the drying temperature and time, which influence the formation of a consistent polymeric layer (Oduro, 2021; Gouthami, 2023). An illustration of the spraying method, alongside dipping and vacuum impregnation, is shown in Fig. 4, which provides a schematic overview of common coating application techniques (Perez-Vazquez *et al.*, 2023).

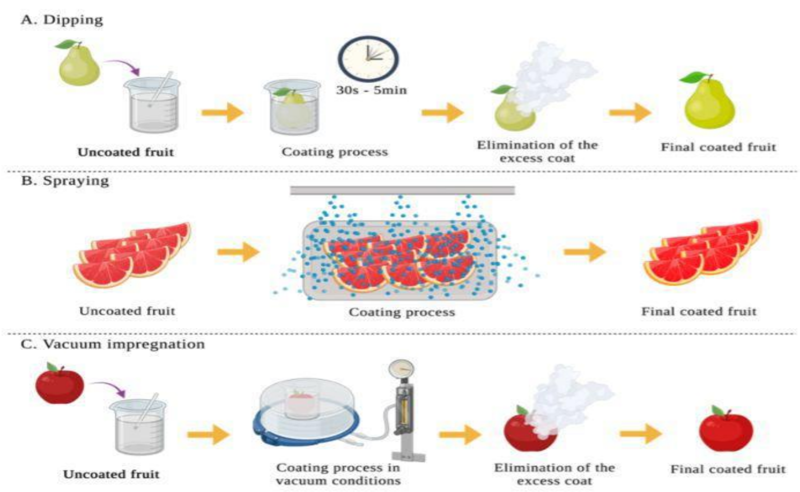


Fig. 1.4: *Schematic representation of the processes used for the coating application on fruits and vegetables. (A): dipping; (B): spraying; (C): vacuum impregnation.* (Source; Perez-Vazquez *et al.*, 2023)

- **Layer-by-layer method**

The layer-by-layer (LbL) technique builds edible coatings through sequential deposition of **oppositely charged polyelectrolytes** (Gouthami, 2023). This electrostatic assembly allows for precise tuning of coating functionality and physical properties (Gouthami, 2023; Sheetal *et al.*, 2023). Furthermore, the resulting multilayer films significantly enhance coating performance compared to single-layer alternatives (Gouthami, 2023; Sheetal *et al.*, 2023).

- **Foaming and dripping method**

The dripping and foaming methods are considered traditional techniques for applying edible coatings, though they are currently declining in popularity among researchers and industry professionals in the fruit sector (Oduro, 2021; Gouthami, 2023). In the dripping method, brushes are used to apply the coating directly onto the surface of the fruit (Oduro, 2021; Sheetal *et al.*, 2023).

The foaming method involves the addition of a foaming agent to the coating solution, after which compressed air is introduced into the applicator tank to generate foam (Oduro, 2021; Gouthami, 2023). A vigorous tumbling motion is then used to break the foam, allowing for even distribution across the fruit surface (Oduro, 2021; Gouthami, 2023)

- **Electro-spraying**

Electro-spraying is a modern technique used to apply bio-based edible coatings onto fruits and other food products (Jamuna *et al.*, 2024). In this method, an electric field is used to create a fine mist or aerosol, which is evenly distributed over the surface of the fruit (Jamuna *et al.*, 2024). It provides precise control over droplet size and coating distribution, making it especially suitable for covering irregularly shaped produce (Jamuna *et al.*, 2024). This technique ensures uniform application, minimises material waste, and enables accurate control of coating thickness and composition (Jamuna *et al.*, 2024). Studies have shown that electro-sprayed edible coatings enriched with bioactive compounds can effectively reduce microbial growth on fruits like peaches and plums, thereby enhancing their shelf life (Jamuna *et al.*, 2024).

- **Panning Method**

Pan coating (panning) applies bio-based coatings by tumbling fruits in a rotating drum while gradually adding coating material (Jamuna *et al.*, 2024). This mechanical agitation achieves uniform thickness through repeated surface contact (Jamuna *et al.*, 2024). Studies confirm its effectiveness for minimally processed fruits like sliced apples and packaged berries, where it significantly reduces moisture loss and microbial contamination (Jamuna *et al.*, 2024).

- **Brushing Method**

This manual technique uses brushes to spread coatings directly onto fruit surfaces. While offering precision for artisanal production, its labor requirements limit industrial scalability (Jamuna *et al.*, 2024).

1.2.5 ALOE VERA (AV)

Aloe vera plant

Aloe vera (botanical name; *Aloe barbadensis Miller*) is a well-known succulent plant belonging to the family *Asphodelaceae* (previously *Liliaceae*) and is widely cultivated in the arid and semi-arid regions of Africa, Asia, Europe, and the Americas due to its drought-tolerant (xerophytic) nature (Singh *et al.,* 2021; Rifat *et al*., 2024). It is a short-stemmed, perennial plant that stores water in its thick, fleshy green leaves, allowing it to survive in hot, dry climates (Mitra *et al.,* 2023). Aloe vera reserves water in leaves and it is widely used for the treatment of skin injuries (Mitra *et al.,* 2023). Among more than 500 species within the Aloe genus, *Aloe barbadensis Miller* is the most widely researched and commercially used due to its numerous medicinal, cosmetic, and postharvest applications (Maan *et al.,* 2018)

Botanically, the Aloe vera leaf is composed of three distinct layers:

1. **Inner Gel Layer:** Contains 99% water and the rest made up of amino acids, vitamins, lipids, sterols, and polysaccharides like glucomannan (Mitra *et al.,* 2023).
2. **Middle Latex Layer:** Rich in glycosides, latex and anthraquinones, which have laxative and antimicrobial properties (Mitra *et al.,* 2023).
3. **Outer Rind Layer:** The most-thick layer which serves a protective function and is responsible for carbohydrate and protein synthesis (Mitra *et al.,* 2023).

Aloe vera is also valued for its natural essential oils, which enhance the appearance of fruits and demonstrate antimicrobial activity against both Gram-positive and Gram-negative bacteria, as well as fungi responsible for postharvest diseases (Rifat *et al.*, 2024).

Its ability to reduce respiration rate, delay spoilage, and maintain fruit firmness has made it a promising agent in the development of bio-based edible coatings for postharvest fruit preservation (Rifat *et al.*, 2024)

1.2.5.1 Aloe vera gel (AVG)

Aloe vera gel (AVG), extracted from the inner portion of the leaf, is a transparent, gelatinous substance which is odourless and edible, used to produce natural edible coating that does not affect the quality of the fruit and vegetables, moreover, it is safe for human health and it is eco-friendly, which is why it is been widely used in medicine, cosmetics, and more recently, food/fruit preservation (Hasan *et al.,* 2021; Al-Hilifi *et al.,* 2022).

Its application as an edible coating for fruits has gained attention due to its natural origin, safety, and effectiveness in extending shelf life without compromising fruit quality (Hasan *et al.*, 2021; Maan *et al.*, 2021; Kaur *et al.*, 2024).

Historically, Aloe vera gel (AVG) has been known to have many therapeutic benefits and is used to treat several diseases (Embark and Abdalla, 2019; George *et al.*, 2023).

Research has shown that Aloe vera gel acts as a semi-permeable barrier, helping to reduce moisture loss, regulate gas exchange, and inhibit microbial growth. These properties collectively slow down the ripening process and minimise spoilage in various horticultural commodities (Adhikary *et al.*, 2023; Farooq *et al.*, 2023; Kaur *et al.*, 2024).

1.2.5.2 Phytochemical Composition and Bioactive Properties

Aloe vera gel contains approximately 99% water, while the remaining 1% comprises a rich array of bioactive compounds such as amino acids, vitamins, polysaccharides (like glucomannan), sterols, lipids, phenols, flavonoids, terpenoids, lectins, and fatty acids (Rizwana *et al.*, 2022; Mitra *et al.*, 2023).

AV gel mainly composed of polysaccharides, the mucilage plays as a normal barrier to oxygen and moisture, which can increase the rate of food spoilage (Ali and Abdel-Aziz, 2021). Also, it could improve the safety of fruit and vegetables preservation (Ali and Abdel-Aziz, 2021).

AV gel still contains various antibiotic and antifungal components, like quinones and phenolic components (flavonoids) that may be responsible for delaying or inhibition of the growth of microorganisms for food-borne diseases in humans or food spoilage (Ali and Abdel-Aziz, 2021)

These compounds contribute to its numerous pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, antiviral, antitumour, antidiabetic, preservation of horticulture and skin-protective effects (Guenther *et al.*, 2012; Komatsu *et al.*, 2017; García *et al.*, 2019).

(i) **Carbohydrates**

The carbohydrate fraction includes:

- Monosaccharides (mannose, fructose and galactose),
- Polysaccharides (main constituent of AVG), namely long-chain linear gluco-mannans, β(1,4)-linked acetyl-mannan presenting glucose and mannose subunits, galactan, galactogalacturan, free sugars (glucose), fibres, cellulose and xylan (Ni *et al.*, 2004)

Although not fully understood, the structure of carbohydrates in AV gel has been demonstrated by linkage and optical rotation analysis, (Darzi *et al.*, 2024).

- Acetylated mannan or acemannan is the primary carbohydrate fraction present in AV gel with beneficial medicinal properties (Alvarado-Morales *et al.*, 2019).

FTIR analysis of AV gel shows strong bands within the range of 1078–1036 cm^{-1} indicating the presence of mannose and glucose sugars, the primary monomers. The transmittance spectrum around 1740 and 1248 cm^{-1} may be attributed to the presence of C=O and C−O−C stretches in acetyl groups corresponding to the bioactive acetylated acemannan (Alvarado-Morales *et al.*, 2019).

(ii) **Phenolic Compounds and Flavonoids**

Aloe vera gel contains quinones, flavonoids, anthraquinones, and phenolic acids, which provide antioxidant and antimicrobial activities. These components inhibit microbial growth, including food-borne pathogens, and help reduce fruit spoilage (Ali and Abdel-Aziz, 2021).

(iii) **Vitamins, Enzymes, and Minerals**

AVG is also a rich source of antioxidant vitamins, including:

★ Vitamin C (ascorbic acid)
★ Vitamin E (tocopherol)
★ Carotenoids
★ B-complex vitamins – thiamine (Vitamin B1), riboflavin (Vitamin B2), niacin (Vitamin B3), Vitamin B6, and folic acid.

AV gel contains at least six enzymes;

reportedly cellulose, carboxypeptidase, amylase, bradykinase, oxidase and catalase, that help digestion and nutrient absorption out of food decomposition (fats, sugars) (Surjushe *et al.*, 2008; Javed and Atta-ur, 2014)

Essential minerals and trace elements found in AVG include:

- Macronutrients: Potassium (K), Calcium (Ca), Magnesium (Mg), Phosphorus (P)
- Micronutrients: Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Chlorine (Cl), Chromium (Cr), and Nickel (Ni) (Surjushe *et al.*, 2008; Javed and Atta-ur, 2014)

The presence of trace elements such as Mg contributes to the anti-allergic properties of AV gel (Ali *et al.*, 2014). The essential minerals such as Fe, P, Cu, Mn and Ni are crucial for good health (Darzi *et al.*, 2021).

These contribute to various metabolic functions, antioxidant defenses, and the overall health benefits of AVG (Darzi *et al.*, 2021).

1.2.5.3 Functional Role of AVG in fruits and vegetables preservation.

The preservation effectiveness of AVG coatings has been attributed to its ability to (i) reduce phenolic oxidation, (ii) inhibit peroxidase and polyphenol oxidase enzyme activity, and (iii) reduce the browning of fruits while preserving their quality from the detrimental effects of weight loss, enzymatic browning, electrolytic leakage, respiration rate degradation, and chlorophyll degradation (Ali *et al.*, 2019), (iv) AVG has shown in vitro antioxidant and antimicrobial effects, (v) decreases respiration rate and ripening process and (vi) delays firmness loss, weight loss and preserves phenolic content (Nicolau-Lapeña *et al.*, 2021).

1.2.5.4 Key Research Findings on Aloe Vera Gel (AVG) in Fruits and vegetables

Preservation

A growing body of research supports the use of Aloe vera gel (AVG) as an effective edible coating for preserving various fruits by delaying ripening, reducing spoilage, and maintaining quality parameters: Ali and Abdel-Aziz (2021) studied the application of AVG on *Physalis peruviana* L. (golden berries) for 30 days at 5°C and observed that AVG coating significantly reduced weight loss, delayed browning and decreased fungal decay compared to uncoated controls. These results indicate AVG’s potential for producing edible films with shelf-life extension capabilities while maintaining the fruit's physicochemical quality.

Rifat *et al.* (2024) investigated AVG coating on bananas and found that coated fruits underwent slower colour change and ripening compared to controls, which showed faster pigment transformation due to chlorophyll degradation. AVG coating created a modified internal atmosphere by increasing CO_2 levels and reducing O_2 permeability, thus slowing ethylene biosynthesis and delaying the conversion of chlorophyll into anthocyanins and carotenoids (Parven *et al.*, 2020). This contributed to delayed ripening and discolouration.

Aloe vera gel is a natural, edible, and active biopolymer with significant potential for use in fruits and vegetables preservation. Its antioxidant and antimicrobial properties contribute to the extension of shelf life and quality maintenance of perishable fruits (Mann et al., 2021). Aloe vera coatings are simple to prepare, easy to apply, and safe for consumers (Mann et al., 2021). Beyond physical protection, Aloe vera offers nutritional and therapeutic benefits, making it a valuable material for edible film/coating applications in modern postharvest technology (Mann et al., 2021).

1.2.6 Physical and Chemical Assessment of Coated Fruits

1.2.6.1 Physical Assessments

- Weight Loss

Edible coatings reduce moisture loss in fruits, thereby limiting weight loss. The cumulative weight loss is expressed as a percentage of the original fresh weight using the formula:

Weight loss (%) = $(F_0 - F_1) / F_0 \times 100$,

where F_0 is the initial fresh weight and F_1 is the weight measured on each sampling day (Hassan *et al.*, 2022).

- Fruit Firmness

Firmness is commonly measured using a texture analyser such as the FT011 Fruit Firmness Tester. The device uses a 1 mm diameter penetrating cylinder to penetrate the pulp up to 5 mm at a speed of 2 mm/s (Hassan *et al.*, 2022).

- Colour Change

Edible coatings delay pigment breakdown and chlorophyll degradation. Colour changes can be quantified using a colourimeter, which measures surface colour in L*, a*, b* values.

- Shrinkage

Shrinkage due to moisture loss alters fruit volume (Rifat *et al.*, 2024). It can be measured using water displacement: the ratio of initial to final volume reflects the extent of shrinkage (Rifat *et al.*, 2024). A measuring cylinder is used with known water volume and the fruit sample added incrementally (Rifat et al., 2024).

- Decay percentage (%)

Decay is visually assessed, and the decay rate is calculated using the formula:

Decay (%) = (Number of decayed fruits / Total number of fruits) × 100 (Shehata *et al.*, 2020).

- Fruit texture

Textural analysis can be conducted using a CTX USB Texture Analyzer (Brookfield, USA) to evaluate changes in structural integrity during storage (Ahmed *et al.*, 2022).

- Sensory Evaluation

Sensory attributes such as appearance, flavour, texture, and overall acceptability are evaluated by trained panelists using structured scoring methods.

- Viscosity

The viscosity of Aloe vera-based edible coating solutions is measured in centipoise (cP) using an Ametek Viscometer (Brookfield, WI, USA) (Kaur *et al.*, 2024).

1.2.6.2 Chemical Parameters

- pH

The pH of coated and uncoated fruit is measured using a digital pH meter.

- Titratable Acidity (TA%)

TA is determined by titrating a known volume of fruit juice with a standard base and calculating the percentage of acid content.

- Total Soluble Solids (TSS)

This is measured using a refractometer, which measures the refractive index of a solution and relates it to the concentration of dissolved solids. This measurement is often expressed in degrees Brix (°Brix), where 1° Brix is equivalent to 1 gram of sucrose in 100 grams of solution at 20 °C.
(Source; Google)

1.2.6.3 CHARACTERISATION

Coatings can also be characterised using techniques such as FTIR (Functional Group Analysis), SEM (Surface Morphology), EDX (Elemental Analysis), and XRD (Crystallinity and Structure).

1.2.7 Nutritional and Economic Importance of Selected Fruits

1.2.7.1 Banana (*Musa spp*.)

Bananas are climacteric fruits belonging to the genus Musa within the family *Musaceae* (Choudhury *et al.,* 2023). The two main species are *Musa acuminata* and *Musa balbisiana*, with most cultivated varieties being hybrids, commonly referred to as *Musa* × *paradisiaca.*
As the second most produced fruit globally, bananas are cultivated in over 150 countries, with an annual production of approximately 105 million tonnes (Choudhury *et al.,* 2023; Banana Link, 2025). They are widely consumed due to their pleasant taste, high energy content, and rich nutritional value, whether in their ripe or culinary forms (Choudhury *et al.,* 2023; Banana Link, 2025).
Nutritionally, bananas are an excellent source of carbohydrates, dietary fiber, and essential minerals such as potassium, iron, magnesium, sodium, calcium, and copper. They also provide vitamins like vitamin C, thiamine, niacin, and folic acid (Choudhury *et al.,* 2023). They are rich in calories and nutrients, providing five times more vitamin A and iron, four times more

protein, three times more phosphorus, and twice the carbohydrates of apples, along with other essential vitamins and minerals (Rifat *et al.*, 2024)

Bananas also contain various bioactive compounds that contribute to their health benefits. During ripening, several physiological changes occur, including increased sugar concentration due to starch breakdown, enhanced respiration rate, softening of the pulp, loss of firmness, colour transition, and membrane permeability changes, all of which influence shelf life and consumer acceptability (Putri *et al.,* 2020).

Economically, bananas play a vital role in food security, income generation, and export potential for many tropical and subtropical countries. Locally consumed bananas are mostly cultivated under traditional extensive farming systems, which support the livelihoods of millions of smallholder farmers.

1.2.7.2 Pepper (Capsicum spp.)

Peppers, encompassing both sweet varieties (such as bell peppers) and spicy ones (such as chili peppers), are members of the Capsicum genus and are widely appreciated for their flavour, colour, and nutritional profile. They are nutrient-dense vegetables that contribute significantly to a healthy diet (Google, 2025)

Nutritionally, peppers are an excellent source of vitamin C, vitamin A (as beta-carotene), vitamin B6, vitamin K, vitamin E, folate, potassium, and dietary fiber (Gzraryan and Arakelyan, 2020). Red bell peppers, in particular, are rich in antioxidants such as beta-carotene, lutein, quercetin, and capsaicin, which exhibit anti-inflammatory and disease-preventing properties.

Peppers are also known for their phytochemical content, which plays a role in preventing chronic illnesses, supporting immune function, and promoting overall well-being. Their antioxidant activity contributes to reducing oxidative stress and cellular damage (Google, 2025)

Economically, pepper cultivation plays a crucial role in many agricultural systems, particularly in tropical and subtropical regions. In 2024, Nigeria produced an estimated 770,000 metric tons of pepper, making it the leading producer of chili pepper in Africa. However, despite this substantial output, domestic and export demands are not fully met. In 2024 alone, Nigeria imported 20,000 metric tons of bell peppers while exporting 8,000 metric tons, reflecting both market opportunities and production challenges (Google, 2025)

1.2.7.3 Cucumber (*Cucumis sativus*)

Cucumber (*Cucumis sativus*) is a member of the *Cucurbitaceae* family, which also includes squashes and melons. It is well known for its high-water content, making it an excellent fruit for hydration (Ware, 2025). While cucumbers are low in calories, fat, cholesterol, and sodium, they provide a good range of essential nutrients such as vitamin K, vitamin C, potassium, magnesium, and manganese (Ware, 2025).

Cucumbers have long been appreciated not just for their refreshing taste but also for their potential health benefits. Regular consumption of cucumbers has been linked to improved skin health, better digestion, weight management, and balanced hydration (Chakraborty and Rayalu, 2021). They are also thought to contribute to lower blood sugar levels and provide antioxidant support due to the presence of various phytonutrients, including carotenoids and flavonoids found in the seeds (Chakraborty and Rayalu, 2021).

Additionally, cucumbers are known for their mild detoxifying and antimicrobial properties and may offer protection against certain types of cancer and bone-related conditions (Mallick, 2022). Their ease of cultivation and wide acceptance make them economically important, especially in local markets. Due to their combination of nutritional, medicinal, and health-supporting properties, cucumbers hold a significant place both nutritionally and commercially (Mallick, 2022).

CHAPTER TWO

MATERIALS AND METHODS

2.1 Materials

The materials used in this study were grouped into three categories: raw materials, reagents/chemicals, and instruments/apparatus. The raw materials were sourced fresh from local suppliers, while the reagents and chemicals were of analytical grade. The instruments and apparatus used were standard laboratory equipment suitable for sample preparation and analysis.

Samples

Fig. 2.1: Samples: Banana (*Musa sapientum* Linn.), B) Pepper (*Capsicum spp*.), (C) Cucumber (*Cucumis sativus*) and (D) Aloe vera plants (*Aloe vera* (L.) Burm.f.

2.1.1 Reagents / Chemicals

- Distilled water
- Buffer solutions (pH 7 and pH 4)
- R_3 and R_4 sugar reagents (See Appendix A and B for details of the sugar composition)
- Sodium Hydroxide (NaOH)
- Phenolphthalein

2.1.2 Instruments / Apparatus

- Knife
- Spoon
- Blender
- Filter paper
- White mesh cloth
- Beaker
- Bowl (for dipping)
- Sample bottles
- pH meter
- Weighing balance
- Test tubes
- Centrifuge
- Vortex mixer
- Spectrophotometer
- Retort stand
- Burette
- Conical flask
- Stove
- Volumetric flask

2.2 Methodology

2.2.1 Extraction of Gel and Sourcing

The Aloe vera plants were sourced from Ovbiogie Community, Ovia North East, Benin City, by uprooting mature plants and cutting off the roots, while the cucumber, banana and pepper was purchased from New Benin Market. The cucumber, peppers, bananas, and Aloe vera were identified by Prof. Prof. Akinnibosun Henry Adewale at the Plant Biology and Biotechnology Laboratory, with voucher numbers assigned for each UBH-A528 (Aloe Vera plant), UBH-M416 (banana), UBH-C232 (Cucumber), and UBH-C229 (pepper). Voucher images of the fruit samples are presented in Appendix C, D, E and F respectively.

After identification, all materials were washed thoroughly with clean water. The Aloe vera leaves were cut open, and the gel was scooped out. The gel was then blended and filtered using

Whatman filter paper to obtain a clear extract as illustrated in Fig. 2.2. The clear extract obtained after filtration was pasteurised using a water bath method. The gel was placed in a heat-resistant container, which was then set in a pot of water and gently heated on a stove for 5 minutes to reduce microbial load without altering the active components.

Fig. 2.2: Extraction of Aloe vera gel and filtration to a clear liquid

2.2.2 Application Method

For the pre-test, Aloe vera gel was prepared in three concentrations:

- 0% (control, no gel),
- 50% (1:1 dilution of Aloe vera gel and distilled water), and
- 100% (undiluted gel).

The fruits were treated using two application methods: direct dipping into the gel solution and coating with cotton wool soaked in the gel for different time duration; 0 minutes (removed immediately), 30 minutes and 60 minutes. The treated fruits were then stored at room temperature on banana leaves and monitored for 14 days.

For the main test, fruits were immersed in 100% Aloe vera gel for three different durations: 0 minutes (removed immediately), 30 minutes, and 60 minutes. After treatment, the fruits were placed on banana leaves.

The treated samples were observed and monitored throughout the storage period, and samples were taken at specific intervals– Day 1, 3, 5, 8 10, and 13 (with variations depending on the type of analysis), for chemical analyses and other assessments while the bioactive compounds present in the gel was identified using Gas Chromatography Mass Spectrometric(GC MS) analysis

2.2.3 Physical Assessment

Physical parameters of the treated and untreated fruits were evaluated at regular intervals during the storage period (Day 1, 3, 5, 10, and 14).

Assessments included:

- **Weight Loss (%)**: Determined by recording the initial and subsequent weights of the samples using a digital weighing balance and calculating the percentage loss.
- **Colour**: Assessed visually through direct observation and recorded based on noticeable changes during storage.
- **Firmness:** Evaluated manually by applying gentle pressure to the fruit surface and noting changes in texture.
- **Odour:** Assessed by perceiving the smell emitted from fruit samples.

2.2.4 Chemical Assessment

2.2.4.1 Determination of pH

The pH of the fruit samples was determined following standard procedures. Each fruit sample was blended with a small quantity of distilled water. For bananas, the blended pulp was filtered using a clean white mesh cloth to obtain a uniform extract.

The pH meter was first calibrated before measurements. Calibration involved turning on the meter, rinsing the electrode in distilled water, and gently shaking off excess water. The electrode was then placed in a pH 7.00 buffer solution, and the CAL function was activated until the reading stabilized. The electrode was rinsed again and placed in a pH 4.00 buffer solution, repeating the calibration step.

For pH measurement, the electrode was immersed in the prepared sample extract, and the reading was recorded once stable. Measurements were taken in triplicate for accuracy.

2.2.4.2 Determination of Sugar Content

Determination of Total Sugar

The total sugar content of the samples was determined following the method of Somogyi (1952).

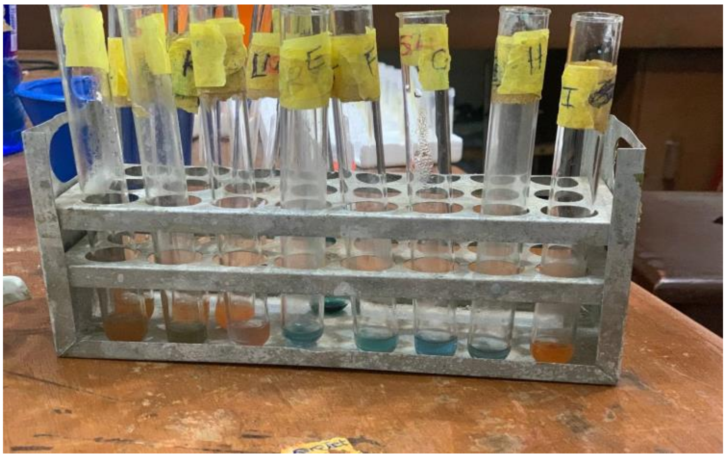


Fig. 2.3: Test tubes containing fruit samples with sugar reagent for sugar content analysis

Sample Analysis

A 0.2 g portion of each fruit sample was pounded and homogenised with 5 mL of distilled water. The mixture was centrifuged for 10 minutes, and the supernatant (clear liquid) was carefully separated from the solid particles.

A 0.5 mL (500 µL) aliquot of the supernatant was transferred into clean glass test tubes. One milliliter of R_4 was added, which produced a blue colouration in cucumber and banana samples and a green colouration in pepper samples.

The tubes were boiled for 20 minutes, after which 1 mL of R_3 was added, followed by 10 mL of distilled water. The mixture was then placed in a vortex mixer for thorough mixing. The spectrophotometer was calibrated according to the manufacturer's instructions, and absorbance readings were recorded. The calibration curve was then used to determine the total sugar content of the samples.

2.2.4.3 Determination of Titratable Acidity (TA)

The titratable acidity was determined using the following procedure. The fruit pulp or juice was first homogenized and diluted with a known volume of distilled water. A 10 mL aliquot of this diluted juice was then transferred into a conical flask, and 2–3 drops of phenolphthalein indicator were added. This mixture was titrated against a standardized 0.1 M sodium hydroxide (NaOH) solution. The titration endpoint was identified as the appearance of a faint pink color that persisted for at least 30 seconds. A blank titration using distilled water was performed to correct for any inherent acidity in the reagents. To ensure accuracy and reproducibility, each sample was analysed in duplicate, and the mean value was calculated and recorded.

2.2.5. CHARACTERISATION

2.2.5.1. GC MS ANALYSIS OF ALOE VERA GEL

The gel was extracted from fresh Aloe vera plants and carefully transferred into sterilised injection vials under clean conditions. The vials were then sealed, frozen, and sent to the laboratory to identify the bioactive components present in the gel using Agilent Technologies 7890B GC System and Agilent Technologies 5977A MS System.

2.2.5.2 FTIR ANALYSIS

The Fourier Transform Infrared (FTIR) spectroscopy analysis was conducted to identify the characteristic functional groups and chemical bonds present in the fruit samples, enabling a comparative analysis of their biochemical compositions using the FTIR model M530 Buck scientific company.

CHAPTER THREE

RESULTS AND DISCUSSION

This chapter presents the results obtained from the preliminary (pre-test) and main experiments on the use of Aloe vera gel as a postharvest treatment for banana, cucumber, and pepper. The pre-test was conducted using both coating and dipping methods at different concentrations (0% (controlled), 50% and 100%) and exposure times (0, 30, and 60 minutes). The aim of the pre-test was to compare the two methods and determine the most suitable treatment approach for the main study. The results showed that there was no significant difference between coating and dipping, as both methods produced the same trends. Consequently, the dipping method was selected for the main experiment.

3.1.1 PHYSICAL ASSESSMENT (PRE-TEST FOR CUCUMBER ON FIRMNESS, ODOUR, COLOUR AND SPOILAGE (DECAY)

At the start of storage (day 1), all cucumber samples, including the control, were firm (score 5) and had no detectable odour, indicating initial freshness. The results from this pre-test, summarized in Table 3.1, confirmed the preservative potential of the Aloe vera gel coating and informed the selection of parameters for the main study.

Overall, the results indicate that Aloe vera gel was effective in preserving cucumber firmness and freshness, with the 100% concentration performing better than the 50%.

Table 3.1: Cucumber Pre-Test on Firmness and Odour

	FIRMNESS						ODOUR					
Cucumber	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**		**5**	**8**	**10**	**14**
control	5	4.5	4	3			Fresh, odour	No	slight	sour	offensive	Very offensive
0 mins, 50%	5	5	5	4	3.5	–	Fresh, odour	No	No	Slight	Mildly sour	Offensive
0 mins, 100%	5	5	5	5	5	4.5	Fresh, odour	No	No	No	No	slight
30 mins, 50%	5	5	5	4.5	4	–	Fresh, odour	No	No	Slight	Mildly sour	Offensive
30 mins, 100%	5	5	5	5	5	5	Fresh, odour	No	No	No	No	No
60 mins, 50%	5	5	5	5	4.5	3.5	Fresh, odour	No	No	Slight	Mildly sour	Offensive
60 mins,100%	5	5	5	5	5	4.5	Fresh, odour	No	no	no	no	no

Note: Firmness was assessed on a 5-point scale, where 5 = firmest and 1 = least firm.

At the beginning of storage (day 1), all cucumber samples, including the control, exhibited a fresh green colour with no signs of spoilage. The progression of colour change and spoilage for all treatments throughout the storage period is detailed in Table 3.2.

Overall, the results demonstrate that Aloe vera gel effectively delayed both colour changes and microbial spoilage in cucumbers, with the 100% concentration performing markedly better than the 50%. This indicates that Aloe vera gel functioned as a protective barrier, slowing down physiological deterioration and extending the storage life compared to the untreated control.

Table 3.2: Colour and spoilage of cucumber during pre-test storage

	COLOUR						SPOILAGE					
Cucumber.	**Day 1**	**3**	**5**	**8**	**10**	**14**	**1**	**3**	**5**	**8**	**10**	**14**
control	Green	Green	Light green	yellow	_	_	No	No	slight	yes	yes	yes
0 min, 50%	Green	Green	Green	Greenish yellow	Yellow	–	No	No	No	Slight	Yes	Yes
0 min, 100%	Green	Green	Green	Light green	Yellow spotting	Brown spoiling	No	No	No	No	No	No
30 min,50%	Green	Green	Green	Greenish yellow + spots	Yellow	–	No	No	No	Slight	Yes	Yes
30 min, 100%	Green	Green	Green	Light green	Yellow spotting	Brown sotting	No	No	No	No	No	No
60 min, 50%	Green	Green	Green	Green	Light green	Yellow spotting	No	No	No	Slight	Yes	Yes
60 mins,100%	Green	Green	Green	Light green	Light yellow	Yellow sotting	No	No	No	No	No	No

Firmness was assessed using a 5-point scale, where 5 = firmest and 1 = least firm.

At the start of storage (day 1), all banana samples, including the control, were firm (score 5) and had no detectable odour, confirming freshness.

By day 5, firmness had begun to decline in the control (score 4), while Aloe vera–treated bananas maintained higher firmness across all treatments, with 100% concentrations generally retaining full firmness (score 5), except for the 0-minute treatment, which slightly declined to 4.5.

By day 8, control fruits softened more sharply, dropping to 2, whereas Aloe vera–treated samples retained greater firmness. At 50% concentration, firmness ranged from 3 (0 min) to 3.8 (30 min) and 4 (60 min). At 100% concentration, firmness was 3 (0 min), 4 (30 min), and 4 (60 min). The 60-minute dipping treatments at both concentrations maintained the highest firmness, showing the strongest delay in softening compared to the control.

Odour changes followed a similar trend to firmness loss. Control bananas began showing spoilage odours earlier, with clear detection ("yes") from day 5 through day 10, progressing rapidly to offensive levels before day 14. In the 50% Aloe vera treatments, all dipping durations (0, 30, and 60 min) developed slight odours by day 5, which intensified to spoilage odours ("yes") by days 8–10. At 100% concentration, the 0 min treatment followed a similar pattern to the 50% group, showing slight odour at day 5 and spoilage by days 8–10. However, the 30 and 60 min treatments at 100% concentration delayed this change, remaining fresh with no detectable odour up to day 5, and only developing spoilage odours by days 8–10. Importantly, all banana samples, whether treated or untreated, had completely decayed before day 14.

Firmness was assessed using a 5-point scale, where 5 = firmest and 1 = least firm.

Overall, Aloe vera gel preserved banana firmness and freshness better than the untreated control, with the 100% concentration (particularly at 30 and 60 minutes) providing the most effective delay in softening and odour development.

Table 3.3: Physical changes in banana (Firmness and odour) during pre-test storage

	FIRMNESS						ODOUR						
Banana	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**		**3**	**5**	**8**	**10**	**14**
control	5	5	4	2	--	–	Fresh, odour	No	No	Yes	Yes	Yes	–
0 min, 50%	5	5	4	3	2	–	Fresh, odour	No	No	Slight	Yes	Yes	–
0 min, 100%	5	5	4.5	3	2	–	Fresh, odour	No	No	slight	Yes	Yes	–
30 min, 50%	5	5	4.5	3.5	2.5	–	Fresh, odour	No	No	Slight	Yes	Yes	–
30 min, 100%	5	5	5	4	3	–	Fresh, odour	No	No	No	Yes	Yes	–
60 min, 50%	5	5	4.5	4	3	–	Fresh, odour	No	No	Slight	Yes	Yes	–
60 min,100 %	5	5	5	4	3	–	Fresh, odour	No	No	No	Yes	Yes	–

Firmness was assessed using a 5-point scale, where 5 = firmest and 1 = least firm.

At the start of storage (day 1), all banana samples were green and firm, indicating uniform initial freshness. The progression of colour change and the onset of spoilage across all treatments during the storage period are detailed in Table 3.4. The pre-test results indicated that while the Aloe vera gel coating delayed ripening and spoilage compared to the control, it could not prevent eventual deterioration, helping to inform the parameters for the main experiment.

Table 3.4: Physical changes in banana (Colour and spoilage) during pre-test storage

	COLOUR						SPOILAGE					
Banana	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**	**3**	**5**	**8**	**10**	**14**
control	Green	Green	yellow	Yellow + black patches	Black	–	No	No	yes	Yes	Yes	–
0 min, 50%	Green	Green	Greenish yellow	Yellow	Yellow + black patches	–	No	No	Slight	Yes	Yes	–
0 min, 100%	Green	Green	Greenish yellow	Yellow	Yellow + black patches	–	No	No	slight	Yes	Yes	–
30 min, 50%	Green	Green	Greenish yellow	Yellow	Yellow + black patches	–	No	No	Slight	Yes	Yes	–
30 min, 100%	Green	Green	Green	Yellow	Yellow + black patches	–	No	No	No	Yes	Yes	–
60 min, 50%	Green	Green	Greenish yellow	Yellow	Yellow + black patches	–	No	No	Slight	Yes	Yes	–
60 min,100%	Green	Green	Greenish yellow	yellow	Yellow + black patches	–	No	No	No	Yes	Yes	–

At the beginning of storage (day 1), all pepper samples, including the control, were firm (score 5) and fresh, with no detectable odour. However, as storage progressed, differences became more pronounced between Aloe vera–treated and untreated fruits.

Odour changes followed a similar pattern. Control peppers began to show spoilage odours by day 5 (yes), while the Aloe vera–treated samples delayed this. The 100% treatments (0, 30, and 60 minutes) remained fresh up to day 5, with only slight odour changes by day 8, progressing to spoilage odours by day 10. Overall, Aloe vera gel treatments were effective in delaying softening and odour development in peppers, with the 100% concentration (across all dipping durations) showing the best results. However, the protective effect diminished toward the end of storage, as all fruits eventually lost firmness and developed spoilage odours.

Table 3.5: Physical changes in pepper (firmness and odour) during pre-test storage

	FIRMNESS						ODOUR						
Pepper	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**		**3**	**5**	**8**	**10**	**14**
control	5	4	3	2	-	–	Fresh, odour	No	No	Yes	Yes	Yes	–
0 min, 50%	5	5	4	3.5	3	–	Fresh, odour	No	No	Yes	Yes	Yes	–
0 min, 100%	5	4.5	4.5	4	3	–	Fresh, odour	No	No	Slight	Yes	Yes	–
30 min, 50%	5	5	4	3	2	–	Fresh, odour	No	No	Yes	Yes	Yes	–
30 min, 100%	5	5	4.5	4	3	—	Fresh, odour	No	No	Slight	Yes	Yes	–
60 min, 50%	5	5	4	3	2	–	Fresh, odour	No	No	Yes	Yes	Yes	–
60 min,100%	5	5	4.5	4	3	–	Fresh, odour	No	No	slight	Yes	Yes	–

Firmness was assessed using a 5-point scale, where 5 = firmest and 1 = least firm.

At the beginning of storage (day 1), all pepper samples, including the control, were bright red and showed no signs of spoilage.

The 100% Aloe vera treatments also developed spotting, but deterioration was less severe than in the control and 50% treatments, indicating a delayed progression of decay.

By day 14, all peppers had deteriorated. The control had turned completely black, while the 50% treatments showed strong blackening and advanced spoilage. The 100% Aloe vera–treated samples (0, 30, and 60 min) retained some red tones but were also marked by extensive spotting and clear spoilage.

Overall, Aloe vera gel at 100% concentration slowed down colour deterioration and spoilage in peppers compared to the control and 50% treatments. However, by day 14, all samples were spoiled, indicating that while Aloe vera extended shelf life and delayed deterioration, it could not prevent spoilage completely.

Table 3.6: Physical changes in Pepper (colour and spoilage) during pre-test storage

	COLOUR						**SPOILAGE**					
Pepper	**Day 1**	**3**	**5**	**8**	**10**	**14**	**1**	**3**	**5**	**8**	**10**	**14**
control	Red	Red	Dark Red	Brownish red + black spot	black	–	No	slight	yes	Yes	Yes	–
0 min, 50%	Red	Red	Dark Red	Brownish red + black spot	More blackening	–	No	No	Yes	Yes	Yes	–
0 min, 100%	Red	Red	DarkRed	Red + black spot	More spotting	–	No	No	Slight	Yes	Yes	–
30 min, 50%	Red	Red	DarkRed	Brownish red+ black spot	More blackening	–	No	No	Yes	Yes	Yes	–
30 min, 100%	Red	Red	DarkRed	Red + black spot	More spotting	–	No	No	Slight	Yes	Yes	–
60 min, 50%	Red	Red	DarkRed	Brownish red + black spot	More blackening	–	No	No	Yes	Yes	Yes	–
60 mins,100%	Red	Red	DarkRed	Red+ black spots	More spotting	–	No	No	Slight	Yes	Yes	–

3.1.2 Main Test: Physical Analysis

The main test was conducted to evaluate the effectiveness of Aloe vera gel as a postharvest treatment for banana, cucumber, and pepper under ambient storage conditions, using the dipping method at 100% concentration with exposure times of 0, 30, and 60 minutes.

Physical parameters assessed during storage included firmness, weight loss (%), odour development, spoilage incidence, and colour changes. These indices were selected as key indicators of postharvest quality and shelf-life extension in fresh produce.

The firmness of cucumber fruits showed a progressive decline during storage, with clear differences between treated and untreated samples (Table 3.7). On day 1, all fruits, including the control, maintained maximum firmness (score 5). However, by day 8 the control had already softened to 3, and by day 14 it had completely decayed, making it the only sample to lose full structural integrity. In contrast, Aloe vera–treated fruits maintained higher firmness throughout storage. The 60-minute dipping treatment at 100% concentration was the most effective, retaining firmness at 4.5 on day 14, while other Aloe vera–treated samples ranged between 3.0–4.0. These results agree with Ochiki *et al.*, (2015), who reported that Aloe vera coatings significantly reduced firmness loss in mango during storage.

Weight loss (%) increased steadily across all treatments, reflecting normal postharvest moisture loss (Table 8; Figure 5). By day 10, the control fruits had lost 9% of their weight, whereas Aloe vera–treated cucumbers exhibited significantly lower losses: 6.04% (0 min), 4.5% (30 min), and only 4.27% (60 min). The reduced weight loss in treated samples can be attributed to the semi-permeable barrier provided by Aloe vera gel, which minimises water evaporation and slows down respiration (Rifat *et al.*, 2024. Similar observations were reported by Rifa*t et al.*, (2024), who explained that biopolymer coatings act as barriers to O_2, CO_2, and moisture exchange, thereby reducing dehydration. Likewise, Ali and Abdel-Aziz (2024) demonstrated that Aloe vera coatings lowered weight loss in *Physalis Peruviana* L. fruits compared to untreated controls. The observed net weight gain (negative values) in some coated cucumbers, particularly at Day 3, is attributed to the hygroscopic Aloe vera coating. This gel layer absorbed atmospheric moisture within the packaging, temporarily increasing the fruit's mass more than water was lost through transpiration.

Overall, the results confirm that Aloe vera gel effectively delayed firmness loss and reduced weight loss in cucumbers. The effect was concentration- and time-dependent, with the 100% Aloe vera gel at 60 minutes dipping showing the greatest preservation potential. Importantly, while the control fruits had completely decayed by day 14, all Aloe vera–treated cucumbers remained intact, further highlighting the protective role of the coating.

Table 3.7: Firmness and Weight Loss (%) for cucumber

Cucumber	Day 1	3	5	8	10	14	Day 3	5	10
A (Control)	5	5	4	3	2	–	0 ± 0.00	4.00 ± 0.01	9.00 ± 0.88
B (0 min AVG)	5	5	5	4.5	4	3	-0.20 ± 0.70	2.51 ± 0.01	6.04 ± 0.03
C (30 min AVG)	5	5	5	5	4.5	4	-0.43 ± 0.74	1.80 ± 0.00	4.50 ± 0.00
D (60 min AVG)	5	5	5	5	5	4.5	0.00 ± 0.00	1.51 ± 0.02	4.27 ± 0.57

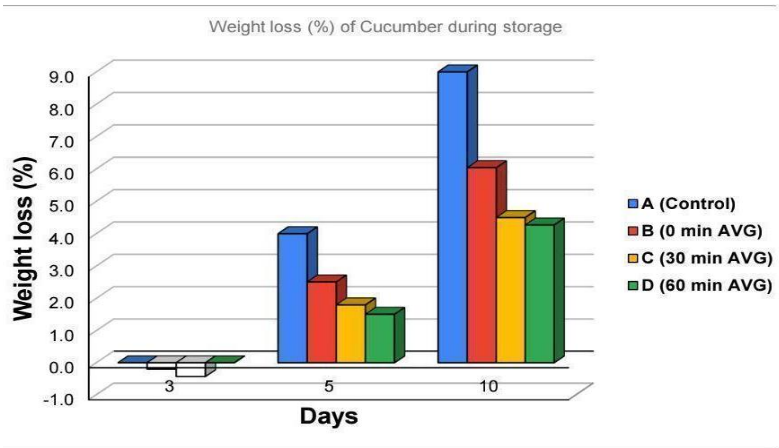


Fig. 3.1: Effect of Aloe vera gel treatments on weight loss (%) of cucumber during storage.

Table 3.8 presents the effect of Aloe vera gel treatments on odour development and spoilage in cucumbers during storage. The untreated control samples began to deteriorate rapidly: by day 5, slight off-odours were noticeable, progressing to sour and offensive odours by day 10, and becoming very offensive by day 14. Visible spoilage followed a similar pattern, with slight decay noted by day 5 and complete spoilage by day 14.

These findings align with the results of Ali and Abdel-Aziz, who reported that Aloe vera–coated Physalis fruits maintained their sensory quality and resisted decay significantly longer than untreated fruits. Their study also highlighted that Aloe vera coatings delayed the onset of off-odours and extended shelf life by preserving texture, colour, and freshness (Ali and Abdel-Aziz, 2021).

Overall, Aloe vera gel proved highly effective in suppressing both microbial spoilage and odour development in cucumbers, with higher concentrations (100%) and longer dipping durations (30–60 min) providing the strongest protection.

Table 3.8: Odour and Spoilage Decay Cucumber

Cucumber	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**	**3**	**5**	**8**	**10**	**14**
A (Uncoated)	Fresh	No	Slight	Sour	Offensive	Very offensive	No	No	Slight	Yes	Yes	Yes
B (0 mins)	Fresh	No	No	No	No	Slight	No	No	No	No	No	Slight
C (30 mins)	Fresh	No	No	No	No	No	No	No	No	No	No	No
D (60 min)	Fresh	No	No	No	No	No	No	No	No	No	No	No

Colour change is one of the most visible indicators of fruit ripening and senescence. In this study, cucumbers across all treatments remained green during the early storage period (days 1–3). By day 5, the uncoated sample (A) began to lose its bright green colour, turning light green, whereas Aloe vera–treated cucumbers (B, C, and D) retained their green appearance.

These findings suggest that Aloe vera gel coating slowed the rate of colour degradation in cucumbers, with the 60 min treatment showing the strongest effect. This aligns with Umut Ates *et al.*, 2022, who observed that Aloe vera treatment helped maintain higher lightness and hue values in blueberries during storage by reducing chlorophyll breakdown. Similar to their findings, the present study confirms that Aloe vera coating extends visual quality and delays senescence in cucumbers compared to uncoated fruits.

Table 3.9: Colour change of cucumber during storage

Cucumber	Day 1	Day 3	Day 5	Day 10	Day 14
A (Uncoated)	Green	Green	Light green	Extreme Brown patches	–
B (0 min)	Green	Green	Green	Yellow spot	More yellow spots
C (30 min)	Green	Green	Green	Yellow spot	More Yellow spot
D (60 mins)	Green	Green	Green	Light green	Yellow spot

Table 3.10: Physical appearance of cucumber samples during storage.

Cucumber	**Time (min)**			
	Uncontrol	**0**	**30**	**60**
Day 1				
Day 3				
Day 5				
Day 10				
Day 14				

Table 3.11 and Fig 3.2 present the changes in firmness and weight loss of bananas treated with Aloe vera gel compared to uncoated fruits during storage.

Firmness decreased progressively in all samples as storage advanced, but Aloe vera treatments slowed the rate of softening. The control (uncoated) bananas showed a sharp decline, dropping from a firmness score of 5 at day 1 to 3 by day 5 and as low as 1 by day 8, and totally decayed by day 10. In contrast, Aloe vera–treated bananas maintained higher firmness values throughout storage. At day 8, the 30 and 60 min treatments retained firmness scores of 4, while the 0 min treatment had declined to 3.

All the fruit were totally decayed by day 14. This trend agrees with Quoc (2021), who reported that Aloe vera gel coatings consistently preserved firmness in bananas compared to untreated controls, delaying senescence and ripening.

Weight loss followed a similar pattern. Control bananas exhibited the highest cumulative weight loss, reaching 8.15% by day 10. In comparison, Aloe vera–treated fruits experienced significantly less weight loss, with values of 5.98%, 4.86%, and 3.35% for 0, 30 and 60 min treatments, respectively. The lowest weight loss observed in the 60 min treatment highlights the effectiveness of longer dipping durations in reducing moisture loss. This result aligns with the findings of Nowrozi and Zakavatiasal (2024), they noted that Aloe vera gel reduces water evaporation which slows respiration and water vapor loss, thereby maintaining fruit freshness for longer periods. The initial weight gain in certain Aloe vera-coated banana samples indicates the coating's effectiveness. Its hygroscopic properties likely caused it to absorb moisture from the storage environment, leading to a temporary net increase in mass before respiration-driven weight loss resumed.

Table 3.11: Firmness and Weight Loss (%) For Banana

Banana	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 3**	**5**	**10**
E (uncoated)	5	4	3	1	–	-	0 ± 0.00	3.49 ± 1.38	8.15 ± 1.31
F (0 min)	5	5	4	3	2	-	0.51 ± 0.88	2.54 ± 0.74	5.98 ± 0.83
G (30 min)	5	5	5	4	3	-	-0.44 ± 0.77	2.30 ± 0.67	4.86 ± 1.49
H (60 min)	5	5	5	4	3	-	-0.44 ± 0.77	0.77 ± 0.78	3.35 ± 0.64

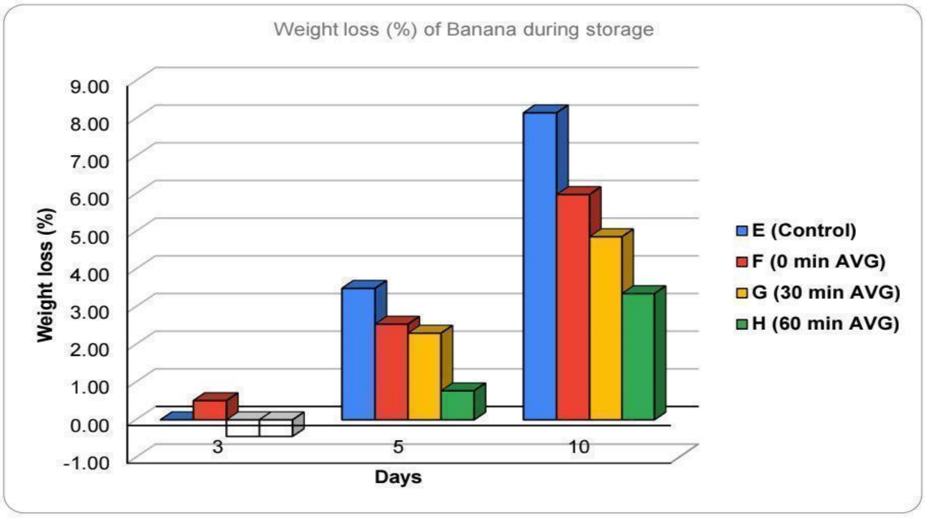


Fig. 3.2: Effect of Aloe vera gel treatments on weight loss (%) of Banana during storage.

The development of odour and spoilage symptoms in bananas is summarised in Table 3.12. At the start of storage (day 1), all samples were fresh and odourless.

Overall, the results indicate that Aloe vera gel treatment delayed the development of odour and visible spoilage, with longer dipping durations (30 and 60 minutes) providing the best effect. However, the protective action was limited, as spoilage was only postponed and not entirely prevented.

Table 3.12: Odour and Spoilage of Banana

Banana	**Day 1**	**3**	**5**	**8**	**10**	**14**	**Day 1**	**3**	**5**	**8**	**10**	**14**
E (uncoated)	Fresh	No	Fruity	Mildly fermented	Fermented	–	No	No	Slight	Yes	Yes	–
F (0 min)	Fresh	No	No	Fruity	Mildly fermented	–	No	No	No	Slight	Yes	–
G (30 min)	Fresh	No	No	Fruity	Mildly fermented	–	No	No	No	No	Yes	–
H (60 min)	Fresh	No	No	Fruity	Mildly fermented	–	No	No	No	No	Yes	–

Colour change in bananas is a key indicator of ripening and senescence, driven largely by chlorophyll degradation and the synthesis of carotenoids. In this study, all samples were initially green at the start of storage. By day 5, both the uncoated control (E) and the 0 min treated sample (F) had already transitioned to light green, whereas the 30 min (G) and 60 min (H) Aloe vera treatments still retained their green colour.

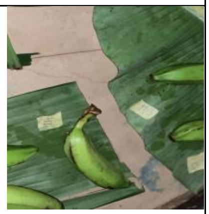
This agrees with the findings of Rifat *et al.*, 2024, who reported that Aloe vera–treated bananas showed delayed colour change compared to untreated controls, which transitioned more quickly to yellow and dark patches. Coatings applied to fruits act as barriers that alter gas permeability, increasing internal CO_2 levels. This modified atmosphere slowed ethylene production, delaying ripening and color change by inhibiting chlorophyll degradation, anthocyanin accumulation, and carotenoid synthesis (Parven *et al.*, 2020). Coated carambola fruits have reported Similar color retention effects (Gol *et al.*, 2015).

Overall, Aloe vera application significantly slowed down peel colour changes, extending the visual quality of bananas compared to uncoated fruits.

Table 3.13: Colour change in bananas during storage.

Banana	Day 1	Day 3	Day 5	Day 10	Day 14
E (Uncoated)	Green	Green	Light Green	Yellow+ black patches	Yellow+more black patches
F (0 min	Green	Green	Light Green	Yellow+ black patches	Yellow+more black patches
G (30 min)	Green	Green	Green	Green	Green
H (60 min)	Green	Green	Green	Green	Yellow+ black patches

Table 3.14: Physical appearance of banana samples during storage.

Banana	**Time (min)**			
	Uncoated	**0**	**30**	**60**
Day 1				
Day 3				
Day 5				
Day 10				
Day 14				

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Firmness and weight loss are important indicators of postharvest quality (Nasrin *et al.*, 2018). Fruit weight loss is primarily linked to respiration and moisture evaporation through the skin, while firmness is closely tied to texture, a critical factor in consumer acceptability (Nasrin *et al.*, 2018). The application of Aloe vera gel coating helps reduce these changes by forming a protective barrier that restricts water transfer, protects the skin from mechanical injuries, and delays dehydration (Nasrin *et al.*, 2018).

Weight loss followed a similar trend. The uncoated peppers showed the highest losses, reaching 12.58% by day 10. Coated samples exhibited significantly lower weight loss, with values of 5.04%, 6.03%, and 8.01% for the 0, 30, and 60 min treatments, respectively. This confirms the role of Aloe vera coating in reducing moisture loss and slowing the decline in texture. The transient weight gain seen in coated peppers is a result of the Aloe vera film's affinity for water. The coating absorbed moisture from the surrounding humid air, which initially outweighed the minimal water loss from the fruit, demonstrating its role in modifying the fruit's micro-environment

Overall, the results suggest that Aloe vera gel coating effectively delayed softening and minimised weight loss in peppers, with the 60 min treatment providing the greatest protective effect.

Table 3.15: Firmness and Weight Loss (%) of Pepper

Pepper	Day 1	3	5	8	10	14	Day 3	5	10
I (uncoated)	5	4	2	1	–	–	0.64 ± 2.04	5.59 ± 2.75	12.58 ± 1.95
J (0 mins)	5	5	4	3	3	–	0.74 ± 3.55	1.93 ± 3.52	5.04 ± 2.27
K (30 mins)	5	5	4	3	3	–	-1.16 ± 2.58	2.52 ± 0.07	6.03 ± 0.04
L (60 mins)	5	4	3	2	–	–	-0.08 ± 4.63	2.92 ± 2.56	8.01 ± 2.56

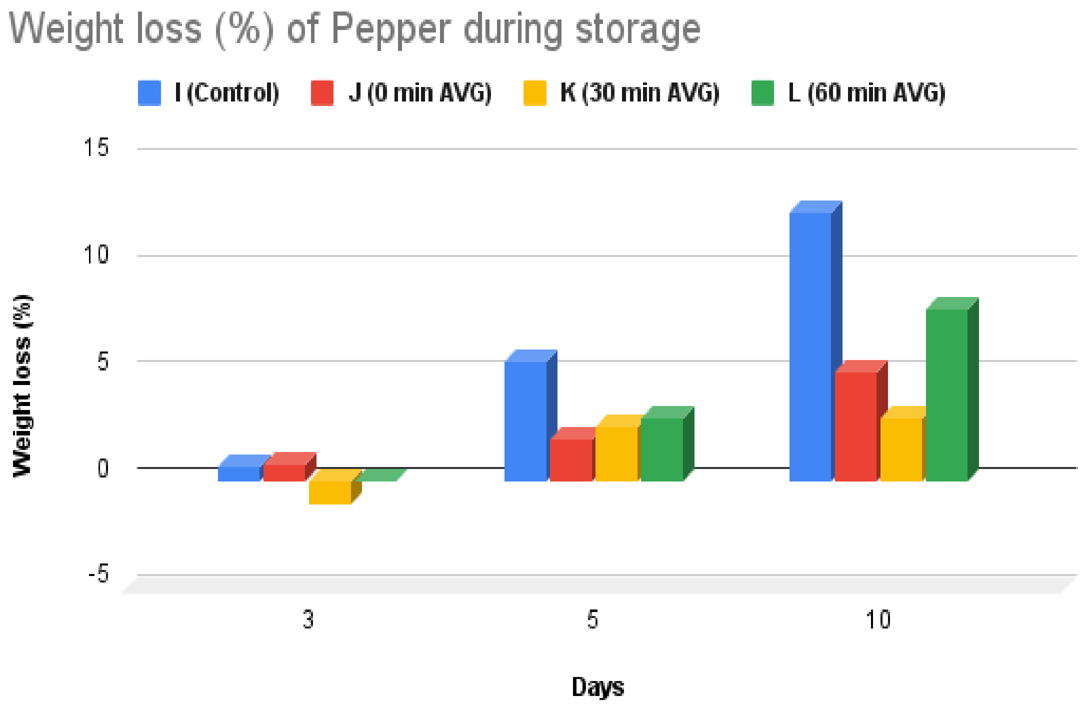


Fig 3.3: Effect of Aloe vera gel treatments on weight loss (%) of pepper during storage.

Odour and spoilage progression in peppers during storage are presented in Table 3.16. The uncoated sample (I) showed faster deterioration, with slight odour and spoilage already detectable by day 5 and progressing to advanced spoilage by day 8–10.

Overall, Aloe vera gel coating delayed spoilage in peppers compared to the uncoated control. However, unlike in cucumbers and bananas, the 60 min treatment did not provide the best preservation effect. Instead, the 0 and 30 min Aloe vera treatments showed greater effectiveness in delaying odour development and spoilage up to day 8–10. This indicates that prolonged dipping did not necessarily enhance preservation in peppers. Nevertheless, all peppers eventually decayed by day 14, indicating that Aloe vera could only slow but not prevent deterioration.

Table 3.16: odour and spoilage of pepper

Pepper	Day 1	3	5	8	10	14	Day 1	3	5	8	10	14
I (uncoated)	Fresh	No	Slight	Yes	Yes	–	No	No	Slight	Yes	Yes	–
J (0 min)	Fresh	No	No	Slight	Yes	–	No	No	No	Slight	Yes	–
K (30 min)	Fresh	No	No	Slight	Yes	–	No	No	No	Slight	Yes	–
L (60 min)	Fresh	No	Slight	Slight	Yes	–	No	No	Slight	Slight	Yes	–

Colour retention in peppers is a critical postharvest quality attribute, as consumers often associate bright red colour with freshness and marketability. In this study, peppers showed noticeable differences between coated and uncoated samples over the storage period.

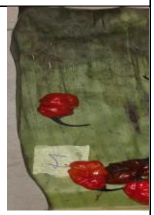
These findings agree with Sheetal *et al.*, 2023, who reported that edible coatings enhance the visual appeal of fruits and vegetables by reducing moisture loss, delaying pigment breakdown, and preserving external appearance. The ability of Aloe vera to act as a semi-permeable barrier likely slowed respiration and moisture loss, which contributed to better retention of the red colour in peppers.

Overall, Aloe vera coatings helped maintain the colour quality of pepper fruits, with the 30 min treatment being the most effective in sustaining bright red colour over time.

Table 3.17: Colour Change of pepper during storage

Pepper	Day 1	Day 3	Day 5	Day 10	Day 14
I (uncoated)	Red	Dark red	Dark red	Light brownish red (due to loss moisture)	,–
J (0 min.)	Red	Red	Dark red	Dark red	Brownish red
K (30 min.)	Red	Red	Red	Red	Red
L (60 min.)	Red	Dark red	Dark red	Brownish red	–

Table 3.18: Physical appearance of pepper samples on day 14 of storage

Banana	Time (min)			
	Uncoated (I)	0 (J)	30 (K)	60 (L)
Day 1				
Day 3				
Day 5				
Day 10				
Day 14	——			——

N.B: Samples I and L were excluded from the table due to deterioration.

3.2 CHEMICAL ANALYSIS

Chemical analysis was carried out to evaluate the compositional and biochemical changes in fruits during storage under Aloe vera treatment. The parameters measured included total soluble solids (TSS or sugar content), pH, titratable acidity (TA), Fourier Transform Infrared Spectroscopy (FTIR), and Gas Chromatography–Mass Spectrometry (GC-MS). These analyses provided insights into fruit quality, ripening behaviour, and the effect of Aloe vera gel in extending shelf life.

Total Soluble Solids / Sugar Content of Cucumber

Uncoated samples (A) exhibited the lowest °Brix values, indicating higher sugar loss during storage (López-Córdoba and Aldana-Usme, 2019; Toscano Ávila *et al.*, 2020).

According to Hassani *et al.*, 2025, in their investigation on the effect of aloe vera gel coating combined with free and encapsulated savory essential oil on strawberry shelf life, Aloe vera coating acts as a physical barrier that modulates respiration and slows down physiological processes such as sugar conversion and degradation. This barrier helps maintain the stability of soluble solids (including sugars, organic acids, and other soluble compounds), thereby reducing variation over storage. Additionally, the antimicrobial activity of savory essential oil restricts microbial growth, limiting sugar decomposition and fermentation (Shiekh *et al.*, 2021; Romanazzi and Moumni, 2022).

Table 3.19: Total Soluble Solids (TSS / Sugar Content) for Cucumber Samples

Cucumber Samples	Day one	Day ten
A (Uncoated)	1.694 ± 0.004	1.063 ± 0.005
B (0 min)	1.352 ± 0.003	1.206 ± 0.005
C (30 min)	1.758 ± 0.003	1.275 ± 0.018
D (60 min)	1.832 ± 0.003	1.428 ± 0.007

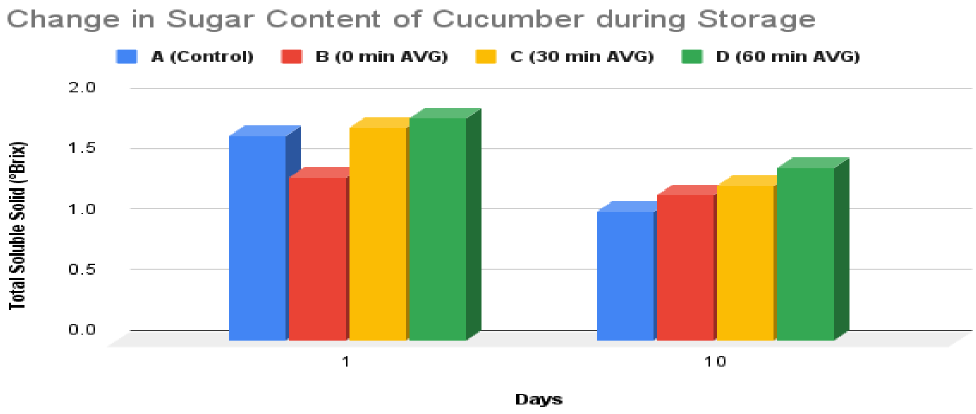


Fig. 3.4; Changes in Total Soluble Solids (TSS) of Cucumber

The sugar content (measured as Total Soluble Solids, TSS) of bananas during storage is presented in Table 3.20. Across all treatments, TSS values increased from day 1 to day 10, reflecting the normal ripening process of bananas. According to Rifat *et al.*, 2024, in their experiment on the effectiveness of aloe vera gel coating and optimised packaging materials on postharvest quality and shelf life of banana (*Musa acuminata*), total soluble solids (TSS) levels were found to increase gradually in all fruits during storage, as ripening typically enhances TSS in bananas and other fruits. This increase can be linked to the enzymatic breakdown of starch into soluble sugars, as well as moisture loss due to respiration and transpiration (Thakur *et al.*, 2019). Aloe vera gel coating influenced the rate of sugar accumulation in bananas. The 30 min treatment (G) best delayed ripening, maintaining the lowest TSS increase, while the 0 min treatment (F) allowed the fastest sugar buildup. The uncoated fruit ripened quickly, whereas 60 min (H) provided a moderate delay.

Table 3.20: Total Soluble Solids (TSS / Sugar Content) for Banana Samples

Banana	**Day one**	**Day ten**
E (uncoated)	0.755 ± 0.001	1.450 ± 0.003
F (0 min)	1.055 ± 0.001	1.490 ± 0.003
G (30 min)	0.697 ± 0.001	1.424 ± 0.005
H (60 min)	0.971 ± 0.001	1.436 ± 0.014

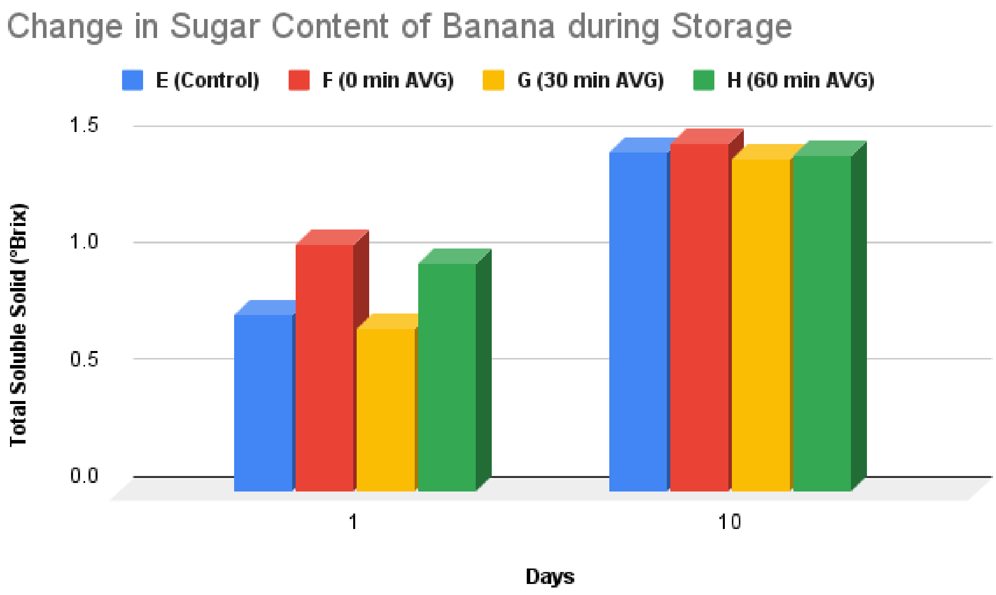


Fig. 3.5: Changes in Total Soluble Solids (TSS) of Banana

The sugar content, measured as Total Soluble Solids (TSS), was observed in pepper samples over a 10-day storage period, as summarised in Table 3.22. A clear decrease in TSS was seen across all samples from day 1 to day 10. This kind of drop is normal in peppers, a non-climacteric produce, since they continue to respire after harvesting, using up their sugars as an energy source during storage, The same phenomena have been published by many scientific reports, like that of (Lawal *et al.*, 2019) who recorded higher soluble solid while in storage using wood by-product to extend shelf life of tomato. Another possible reason could be that complex carbohydrates break down into sugars more slowly than the rate at which those sugars are used up in metabolism (Tigist *et al.*, 2013). Unlike bananas, which tend to sweeten with ripening, the peppers lose sugar over time. A quick dip in aloe vera (0 min) showed a slight preservative effect, but longer dipping times, especially 60 minutes, seemed to reduce the coating's benefits, perhaps due to tissue damage. This suggests that dipping time plays a key role in how well the aloe vera coating can slow respiration and protect quality in peppers.

Table 3.21: Total Soluble Solids (TSS / Sugar Content) for Pepper Samples

Pepper Sample	Day One	Day Ten
I (Uncoated)	1.788 ± 0.003	1.428 ± 0.004
J (0 min)	1.785 ± 0.000	1.435 ± 0.008
K (30 min)	1.787 ± 0.003	1.432 ± 0.002
L (60 min)	1.785 ± 0.000	1.412 ± 0.005

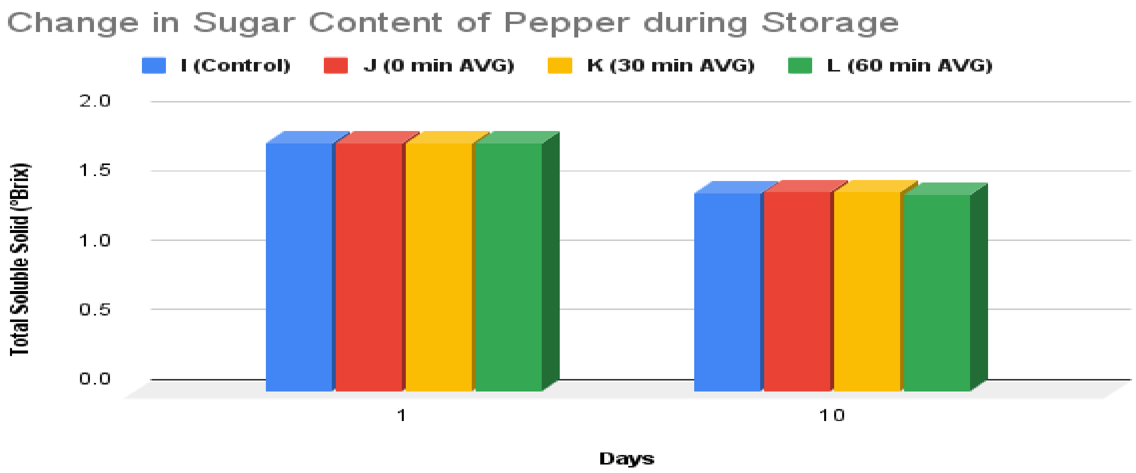


Fig. 3.6: Changes in Total Soluble Solids (TSS) of Pepper

The pH values of cucumber samples treated with Aloe vera gel coating were monitored over a 10-day storage period, as summarised in Table 3.22. A general decrease in pH was observed across all treatments over time. This decline is favourable, as a lower pH environment can inhibit the growth of spoilage microorganisms, thereby extending the shelf life of fresh produce (Onyegbula *et al.*, 2023). A key finding was that the Aloe vera coating itself influenced the initial pH readings. The coated samples (B, C, D) consistently exhibited a higher, more basic pH at the start of the experiment compared to the uncoated control (A). This effect was most pronounced in sample D (60-min dip), which began with the most basic pH of 6.17. This suggests that the Aloe vera gel film itself imparts a slight buffering effect or alters the surface chemistry of the cucumber.

Despite starting at a higher pH, all coated samples demonstrated a slower rate of acidification compared to the uncoated control. This supports the literature suggesting that Aloe vera gel coating reduces respiration rates and limits microbial activity, which are processes that cause the rapid breakdown of organic acids and a sharp drop in pH (Source: Google, 2025). The Aloe vera gel coating had a measurable impact on the cucumbers' surface pH, initially creating a more basic environment, with the effect strengthening as dipping time increased. Crucially, sample D (60-min dip), which started with the highest pH, also best maintained its pH over time. This demonstrates that the coating successfully formed a barrier that slowed respiration and spoilage, effectively retarding the natural acidification process seen in the uncoated control. The 60-minute Aloe vera coating proved to be the most effective treatment for preserving the cucumber's quality and extending its shelf life.

Table 3.22: pH of the Cucumber Samples.

Cucumber Samples	Day one	Day three	Day five	Day ten
A (Uncoated)	5.87 ± 0.06	5.80 ± 0.00	5.73 ± 0.06	5.33 ± 0.06
B (0 min)	6.07 ± 0.06	6.03 ± 0.06	6.03 ± 0.06	5.93 ± 0.49
C (30 min)	6.07 ± 0.06	6.07 ± 0.06	6.03 ± 0.06	6.00 ± 0.00
D (60 min)	6.17 ± 0.06	6.17 ± 0.06	6.13 ± 0.06	6.03 ± 0.06

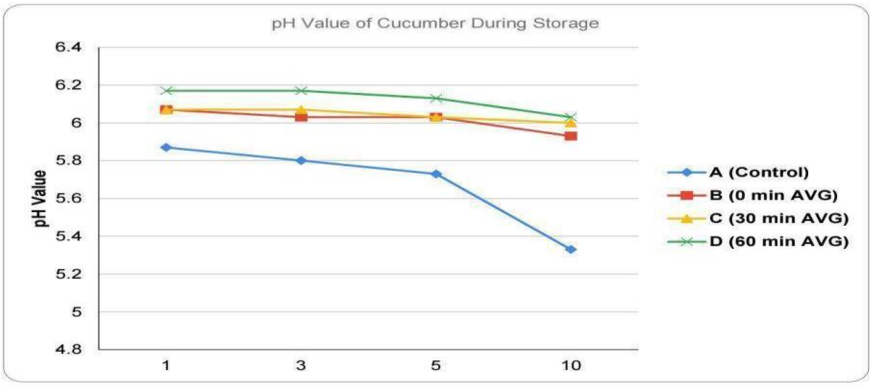


Fig. 3.7: Effect of Aloe Vera Gel Coating and Dipping Time on the pH of Cucumber During Storage.

The pH values of banana samples treated with Aloe vera gel coating were monitored over a 10-day storage period. pH is a critical indicator of fruit acidity and biochemical stability, reflecting underlying metabolic and microbial changes (Huang *et al.*, 2017; Asiamah *et al.*, 2023). As anticipated, a general decrease in pH was observed across all samples over time, indicating progressive acidification of fruit tissue due to organic acid accumulation, microbial activity, and respiratory metabolism (Nasrin *et al.*, 2018; TAA *et al.*, 2018).

Table 3.23: pH of Banana Samples

Banana Samples	Day one	Day three	Day five	Day ten
E (Uncoated)	5.73 ± 0.06	5.57 ± 0.06	5.43 ± 0.06	5.07 ± 0.06
F (0 min)	5.73 ± 0.06	5.70 ± 0.00	5.53 ± 0.06	5.17 ± 0.06
G (30 min)	5.73 ± 0.06	5.73 ± 0.06	5.67 ± 0.06	5.40 ± 0.00
H (60 min)	5.73 ± 0.06	5.73 ± 0.06	5.67 ± 0.06	5.37 ± 0.06

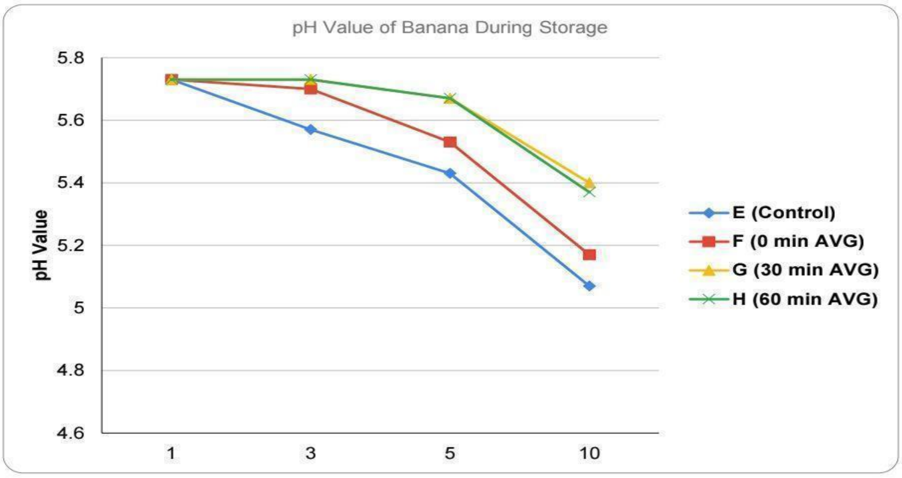


Fig. 3.8: Effect of Aloe Vera Gel Coating and Dipping Time on the pH of Banana

The pH values of pepper samples treated with Aloe vera gel coating were evaluated over a 10-day storage period**.** Similar to other fresh produce, pH serves as an important indicator of biochemical stability and quality in peppers. A general decrease in pH was observed over time across all samples, reflecting progressive acidification likely associated with microbial activity and metabolic changes.

Notably, Aloe vera coating contributed to pH stabilisation by reducing respiration rates and limiting moisture loss, thereby decreasing the overall metabolic activity of the fruit (Salehi, 2020). The better retention of pH in coated samples suggests maintained levels of natural organic acids, such as citric and malic acid, which are essential for flavour and quality preservation (Zhang *et al.*, 2023; Qin *et al.*, 2025).

The application of Aloe vera coating helped mitigate pH reduction in pepper samples, with the 30-minute treatment proving most effective in maintaining biochemical stability. This aligns with the role of Aloe vera in reducing metabolic activity and preserving organic acids essential for sensory quality. However, extended dipping (60 minutes) may compromise the protective effect, indicating that optimal coating duration is essential for maximising shelf life and quality retention in peppers.

Table 3.24: pH of Pepper Samples

Pepper Samples	Day one	Day three	Day five	Day ten
I (Uncoated)	5.23 ± 0.06	5.13 ± 0.06	4.87 ± 0.06	4.73 ± 0.06
J (0 min.)	5.27 ± 0.06	5.20 ± 0.00	5.17 ± 0.06	5.03 ± 0.06
K (30 min.)	5.33 ± 0.06	5.27 ± 0.06	5.27 ± 0.06	5.17 ± 0.06
L (60 min.)	5.43 ± 0.06	5.00 ± 0.00	4.80 ± 0.00	4.70 ± 0.00

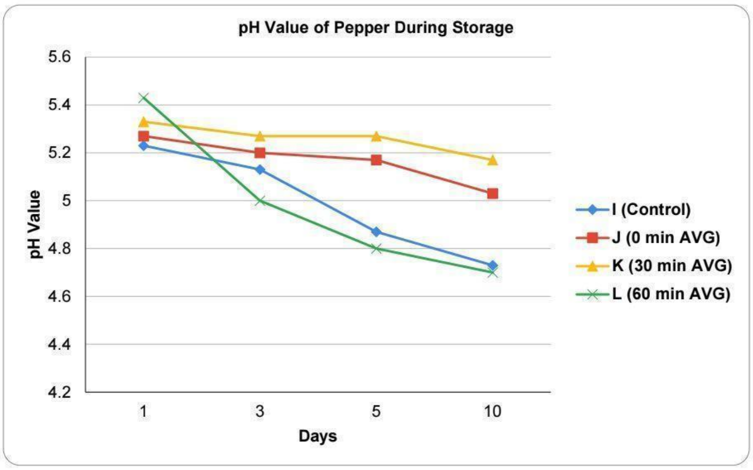


Fig. 3.9: Effect of Aloe Vera Gel Coating and Dipping Time on the pH of Pepper During Storage.

Titratable acidity (TA) serves as a key chemical indicator of fruit quality, reflecting the degradation of organic acids during storage (Low and Chong, 2022). The changes in the TA of cucumber samples, expressed as % citric acid, are presented in Table 3.25; Fig. 3.10.

A general decreasing trend in TA was observed from day one to day ten across all treatments. This decline is expected and is attributed to the consumption of organic acids as substrates for the fruit's ongoing respiration process.

In conclusion, the Aloe vera gel coating was highly effective in slowing the postharvest degradation of organic acids in cucumber. The coating's ability to modify the internal atmosphere of the fruit likely reduced respiratory activity, inhibiting ethylene action, thereby preserving citric acid levels (Low and Chong, 2022). The positive correlation between dipping time (from 0 to 60 min) and TA retention demonstrates that the duration of coating application is a critical factor in maximizing its preservative effect and extending the shelf-life of cucumber.

Table 3.25: Titratable Acidity (TA) of Cucumber during storage

Cucumber Samples	Day one TA (% Citric acid)	Day five TA (% Citric acid)	Day ten TA (% Citric acid)
A (Control)	0.68 ± 0.01	0.54 ± 0.01	0.40 ± 0.03
B (0 min AVG)	0.68 ± 0.01	0.59 ± 0.01	0.54 ± 0.00
C (30 min AVG)	0.68 ± 0.01	0.62 ± 0.00	0.54 ± 0.01
D (60 min AVG)	0.68 ± 0.01	0.65 ± 0.03	0.56 ± 0.01

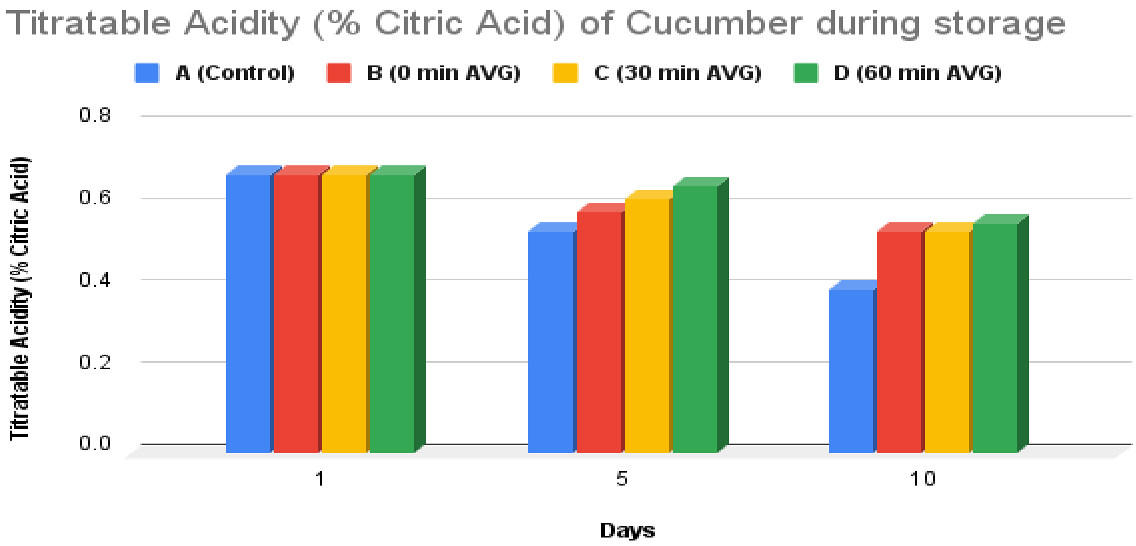


Fig. 3.10: *Titratable Acidity (% Citric Acid) of Cucumber Samples During Storage*

Titratable acidity (TA) is a critical quality parameter that decreases in banana fruit during storage due to the metabolic consumption of organic acids as energy substrates (Thakur *et al.*, 2019). The changes in TA of banana samples, expressed as % citric acid, are presented in Table 3.26 and illustrated in Fig. 3.11.

Consistent with previous findings by Passafiume *et al.*, (2020) on coated kiwifruits, a notable decreasing trend in TA was observed in all samples by day 10. However, the application of an Aloe vera gel (AVG) coating significantly mitigated this decline.

In conclusion, the Aloe vera gel coating was effective in slowing the postharvest degradation of organic acids in banana, a climacteric fruit. The coating's efficacy was directly proportional to the dipping duration, with the 60-minute treatment providing the best barrier against quality loss. This preservative effect is likely due to the coating's ability to suppress respiration and reduce metabolic activity, thereby conserving citric and malic acids essential for flavor and quality.

Table 3.26: Titratable Acidity (TA) of Banana during storage

Banana Samples	Day one TA (% Citric acid)	Day five TA (% Citric acid)	Day ten TA (% Citric acid)
E (Control)	0.34 ± 0.03	0.57 ± 0.03	0.19 ± 0.01
F (0 min AVG)	0.34 ± 0.03	0.55 ± 0.01	0.20 ± 0.01
G (30 min AVG)	0.34 ± 0.01	0.53 ± 0.01	0.28 ± 0.01
H (60 min AVG)	0.34 ± 0.00	0.53 ± 0.00	0.29 ± 0.01

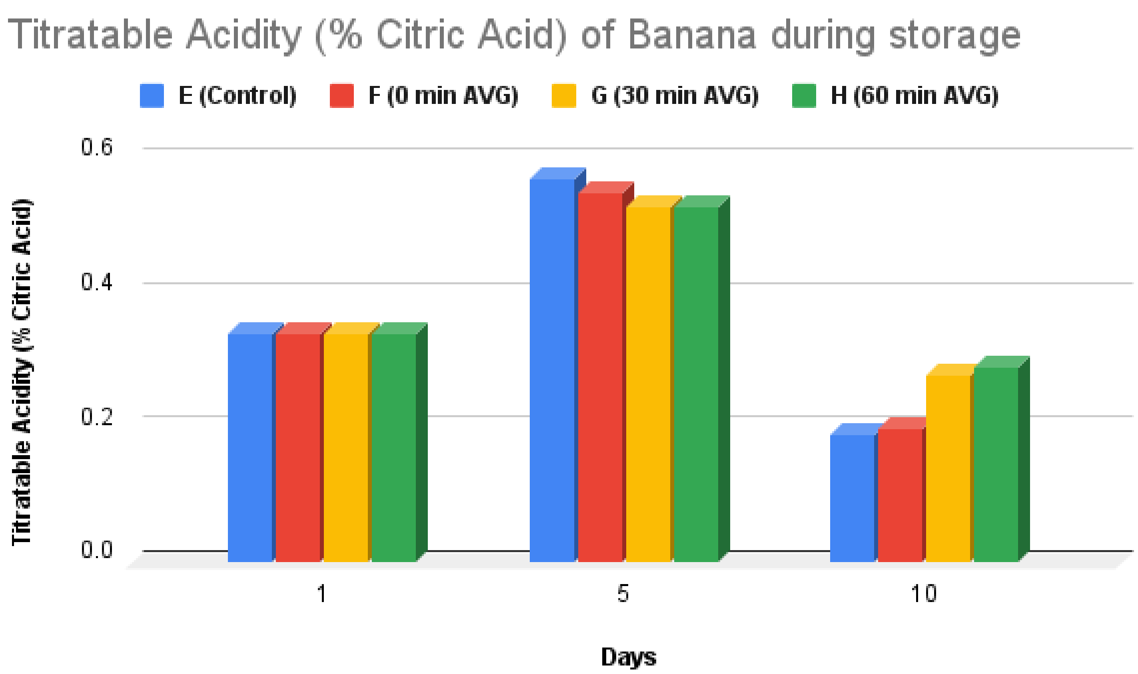


Fig. 3.11: Titratable Acidity (% Citric Acid) of Banana Samples During Storage

Titratable acidity (TA) is an important quality parameter in peppers, reflecting the content of organic acids that contribute to flavour and shelf life. As observed in studies on coated fruits like *Physalis peruviana* L., TA typically peaks initially and gradually declines during storage as acids are metabolized through respiration (Ali and Abdel-Aziz, 2021). The changes in TA of pepper samples, expressed as % citric acid, are presented in Table 3.28 and illustrated in Fig 3.12.

The Aloe vera gel coating helped preserve titratable acidity in peppers, with shorter dipping times (0 min and 30 min) proving most effective. The decline in TA in the 60-min treatment highlights the need for optimized coating application to avoid adverse effects on fruit metabolism.

Table 3.27: Titratable Acidity (TA) of Pepper during storage

Pepper Samples	Day one TA (% Citric acid)	Day three TA (% Citric acid)	Day ten TA (% Citric acid)
I (Control)	0.26 ± 0.03	0.22 ± 0.03	0.15 ± 0.01
J (0 min AVG)	0.26 ± 0.01	0.24 ± 0.01	0.20 ± 0.01
K (30 min AVG)	0.26 ± 0.00	0.23 ± 0.00	0.20 ±0.01
L (60 min AVG)	0.26 ± 0.03	0.22 ± 0.03	0.16 ± 0.01

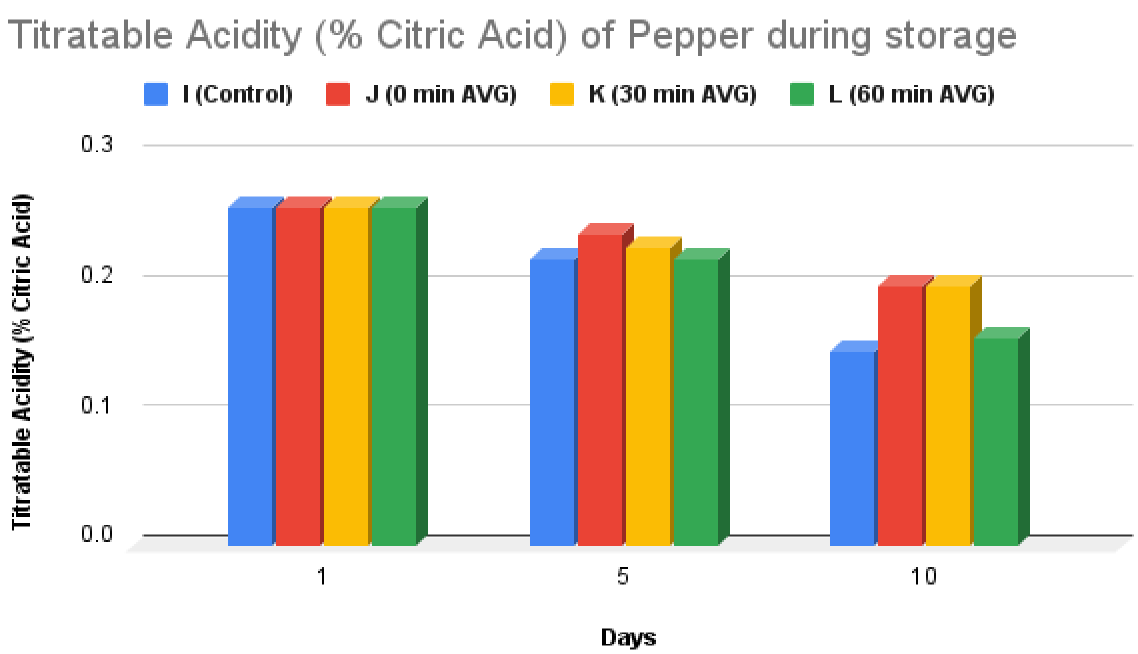
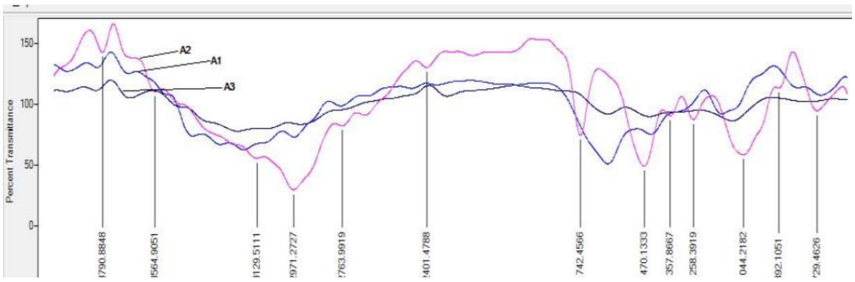


Fig. 3.12: Titratable Acidity (% Citric Acid) of Pepper Samples During Storage

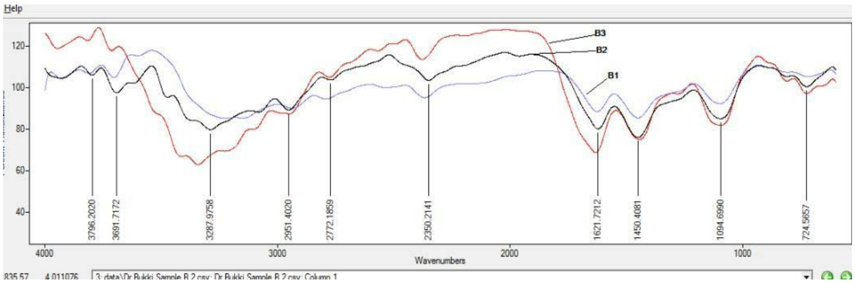
Cucumber

Uncoated



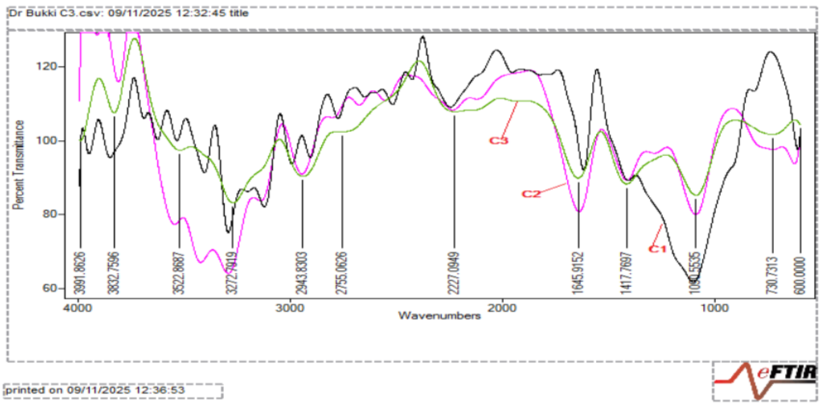
A3;day1 A2;day3 A1;day10

Coated (0 min)



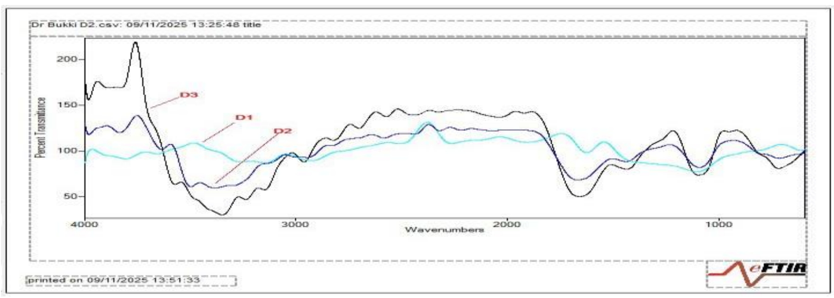
B3;day1 B2;day3 B1;day10

Coated (30 min)



C3;day1 C2;day3 C1;dyay10

Coated (60 min)

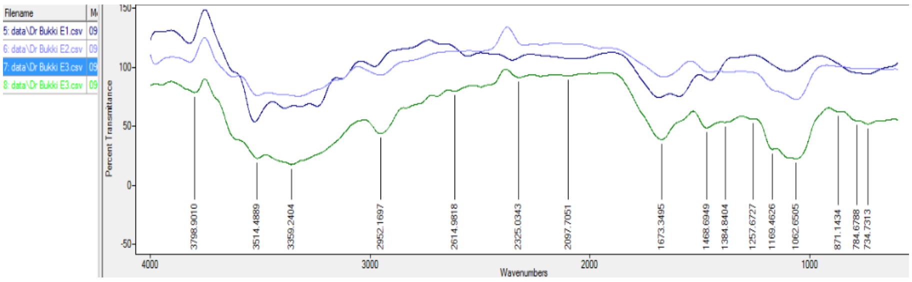


D3;day1 D2;day3 D1;day10

Fig 3.13: Overlaid FTIR Graph of Cucumber Samples

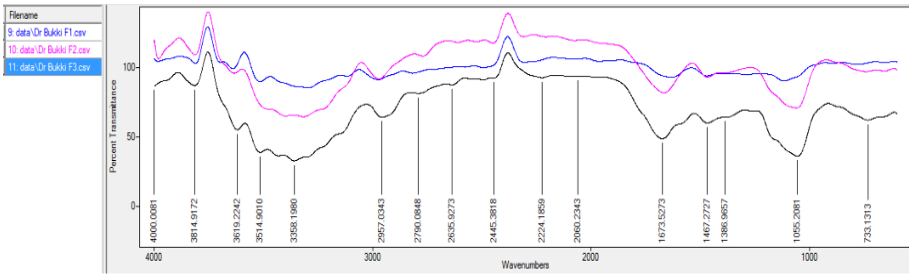
Banana

Uncoated



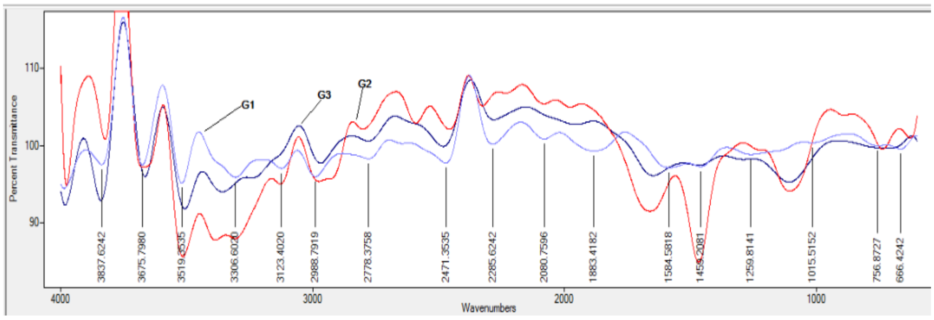
E3;day1 E2;day3 E1;day10

Coated (0 min)



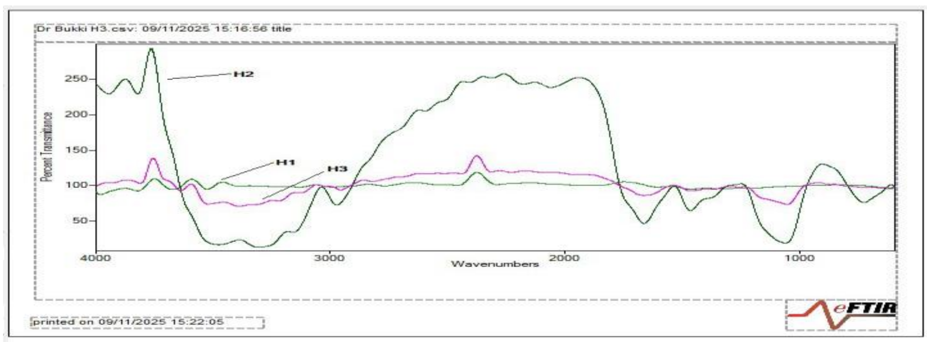
F3;day1 F2;day3 F1;day10

Coated (30 min)



G3;day1 G2;day3 G1;day10

Coated (60 min)

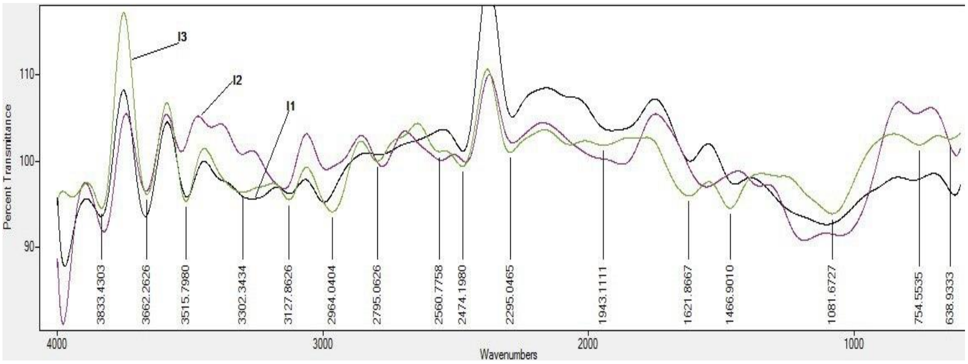


H3;day1 H2;day3 H1;day10

Fig 3.14: Overlaid FTIR Graph of Banana Samples

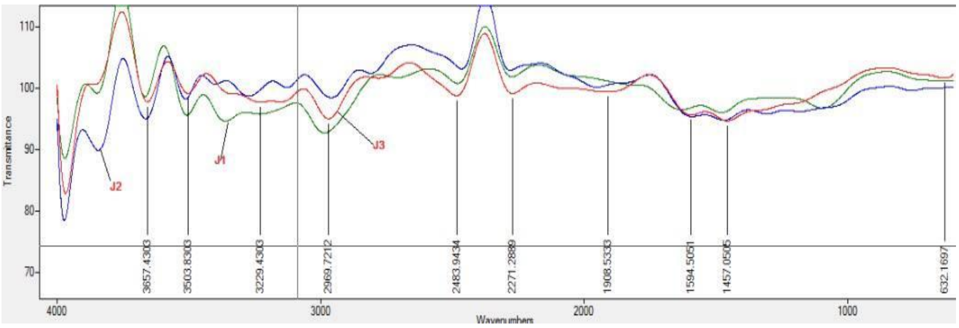
Pepper

Uncoated



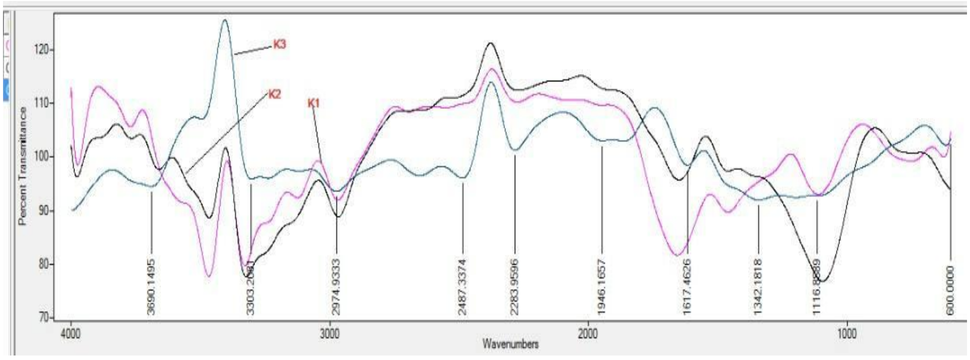
I3;day1 I2;day3 I1;day10

Coated (0 min)



J3;day1 J2;day3 J1;day10

Coated (30 min)



K3;day1 K2;day3 K1;day10

Coated (60 min)

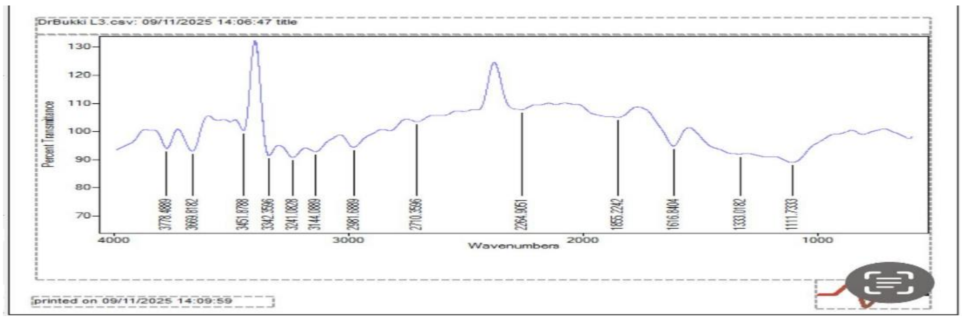


Fig 3.15: Overlaid FTIR Graph of Pepper Samples

The FTIR results from the 12 samples, four each for cucumber, banana, and pepper, showed similar peak positions across all treatments (uncoated and coated with Aloe vera for 0, 30, and 60 minutes), showed consistent peak positions across all treatments but the intensity of certain peaks increased slightly in the coated samples.This indicates that the Aloe vera coating did not alter the fundamental chemical composition of the fruits. The main functional groups identified were O–H stretching (3500–3200 cm^{-1}) from moisture and sugars, C–H bonds (2950–2850 cm^{-1}) from lipids, C=O stretching (1740–1700 cm^{-1}) from organic acids and esters, and C–O/C–O–C bonds (1300–1000 cm^{-1}) from carbohydrates and alcohols. These correspond to inherent fruit components like pectin, cellulose, and organic acids. The coating therefore functioned primarily as a physical barrier to preserve quality by retaining moisture and reducing oxidation, with only minor intensity changes reflecting this enhanced surface protection rather than any chemical modification.

GC MS RESULTS

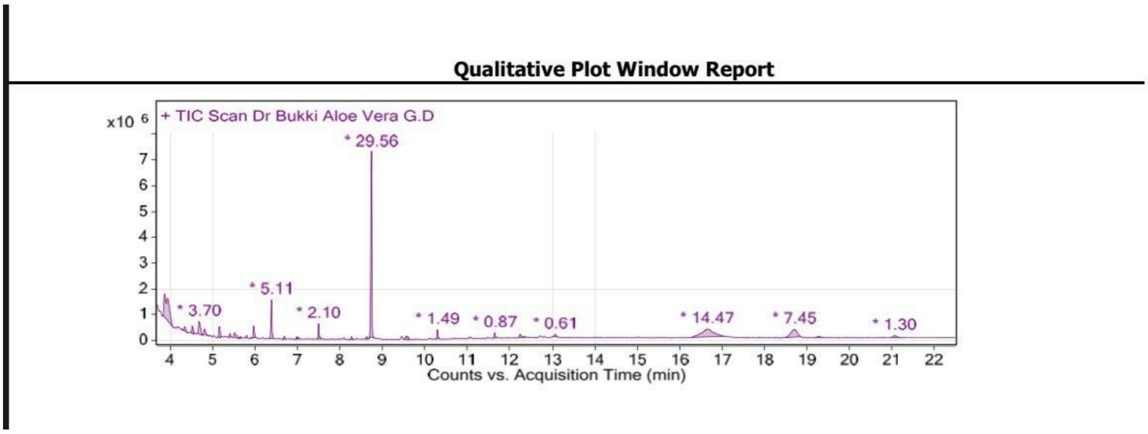


Fig 3.16: GC MS Chromatogram of Aloe Vera Gel

The Gas Chromatography-Mass Spectrometry (GC-MS) analysis identified key bioactive compounds in the Aloe vera gel responsible for its preservative effects. These compounds function synergistically through three primary mechanisms:

1. Barrier Formation: Fatty acid esters (e.g., Ethyl Palmitate, Ethyl Laurate) and hydrocarbons (e.g., Tetradecane) form a hydrophobic, semi-permeable film on the fruit surface. This barrier reduces transpiration (explaining lower weight loss) and gas exchange (slowing respiration and preserving TSS and TA).

2. Antioxidant Activity: Compounds like Vitamin E (Tocopherol) and Eugenol act as potent antioxidants, preventing oxidative browning and degradation, which helps maintain the fruit's color and nutritional quality.

3. Antimicrobial Properties: Several identified compounds contribute to inhibiting microbial growth, extending shelf life.

The analysis also detected non-native compounds (e.g., siloxanes, phthalates), which are common laboratory contaminants and do not contribute to the preservative effect. The presence of authentic bioactive compounds confirms that the Aloe vera gel acts as a multi-functional, natural coating. (Yoruk *et al.,* 2024)

Table 3.28: Identified Compounds in Aloe Vera Gel

Peak	Retention Time (min)	Compound Name	Primary Mechanism / Category
1	3.9	Benzaldehyde, 4-(1-methylethyl)-	Antimicrobial Properties
2	4.4	1-Octanol, 2-butyl-	Antimicrobial Properties
3	4.5	Tetradecane	Barrier Formation (Hydrocarbon)
4	4.7	Naphthalene, 1-methyl-	Antimicrobial Properties
5	4.8	Naphthalene, 1-methyl-	Antimicrobial Properties
6	5.2	Decanoic acid, ethyl ester	Barrier Formation (Fatty acid ester)
7	5.4	Naphthalene, 2,6-dimethyl-	Antimicrobial Properties
8	5.5	Naphthalene, 2,6-dimethyl-	Antimicrobial Properties
9	6.0	Phenol, 2,4-bis(1,1-dimethylethyl)-	Antioxidant Activity (Substituted Phenol)
10	6.4	Dodecanoic acid, ethyl ester (Ethyl Laurate)	Barrier Formation (Fatty acid ester)
11	6.7	Pentadecanoic acid, 3-methylbutyl ester	Barrier Formation (Fatty acid ester)
12	7.0	Heptadecane	Barrier Formation (Hydrocarbon)

13	7.5	1-Nonadecene	Barrier Formation (Hydrocarbon)
14	8.3	Hexadecanoic acid, methyl ester	Barrier Formation (Fatty acid ester)
15	8.6	Dibutyl phthalate	Non-Native/Contaminant (Phthalate)
16	8.7	Hexadecanoic acid, ethyl ester (Ethyl Palmitate)	Barrier Formation (Fatty acid ester)
17	9.6	9-Octadecenoic acid (Z)-, methyl ester	Barrier Formation (Fatty acid ester)
18	10.3	1-Docosene	Barrier Formation (Hydrocarbon)
19	11.6	2-Nonadecanol	Antimicrobial Properties
20	12.2	1,1,1,3,5,5,5-Heptamethyltrisiloxane	Non-native/Contaminant
21	13.1	1,1,1,3,5,5,5-Heptamethyltrisiloxane	Non-native/Contaminant
22	16.6	Phosphine, tris(penfluorophenyl)-	Contaminant
23	18.7	Pentasiloxane, dodecamethyl-	Contaminant
24	19.3	Beta-Tocopherol	Antioxidant(Vitmin E)
25	21.1	α-Tocopheryl acetate (Vitamin E)	Antioxidant Activity (Vitamin E/Tocopherol)

CONCLUSION

This study demonstrated that Aloe vera gel is an effective natural preservative for extending the shelf life and maintaining the postharvest quality of cucumber, pepper, and banana. The results showed that coated fruits generally experienced lower weight loss, delayed firmness decline, slower colour changes, and reduced spoilage compared to uncoated controls.

Chemically, coated samples retained higher sugar content and titratable acidity. The pH generally increased for coated samples likely due to the alkalinity of the aloe Vera gel and there was a lower rate of pH change compared to the controls, indicating delayed deterioration. The FTIR spectra of each fruit samples revealed similar compositions, with only slight variations in intensity. This indicates that while the Aloe vera gel preserved the fruits by forming an external protective barrier, but did not alter or interfere with their internal chemical composition.

Further analysis using Gas Chromatography Mass Spectrometry (GC MS) revealed the presence of compounds like tocopherol and eugenol, which enhance the antioxidant properties of the gel along with hydrocarbons and fatty acid estesr that aid in forming a protective barrier on the fruit surface.

Among the fruits tested, cucumber responded best to Aloe vera treatment, particularly with 60-minute coating, likely due to direct absorption of the gel on its skin. Pepper performed optimally at 30 minutes, while longer exposure appeared less effective, possibly due to over-absorption on its smaller surface area. Banana, though showing some benefit, responded least to Aloe vera coating, which may be attributed to its thick peel acting as a barrier to penetration.

Overall, the findings suggest that Aloe vera gel can serve as a simple, affordable, and eco-friendly coating to slow deterioration and extend market life of perishable fruits. For practical use by farmers and vendors, these results imply simple, low-cost postharvest treatment options: adopt Aloe vera gel coatings tailored to fruit type (e.g., 60-minute treatment for cucumber and banana; 30-minute treatment for pepper) to reduce weight loss, help retain sugars and acidity (important for taste and marketability), and slow pH changes associated with spoilage.

Future work may explore the combination of Aloe vera gel with other edible coatings and natural preservatives to further enhance its protective effect across a wider range of produce.

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APPENDICES

Appendix A: Composition of R3 (Reagent III)

R3 (Reagent III) A

- 25 g Ammonium molybdate dissolved in 400 ml distilled water
- 21 ml concentrated H_2SO_4 added

R3 (Reagent III) B

- 30 g Sodium arsenate dissolved in 25 ml distilled water
- Solutions A and B were mixed and made up to 500 ml with distilled water.

Appendix B: Composition of R4 (Reagent IV)

R2 (Reagent II)

- 30 g $CuSO_4$ dissolved in 200 ml distilled water
- Four drops of concentrated H_2SO_4 added

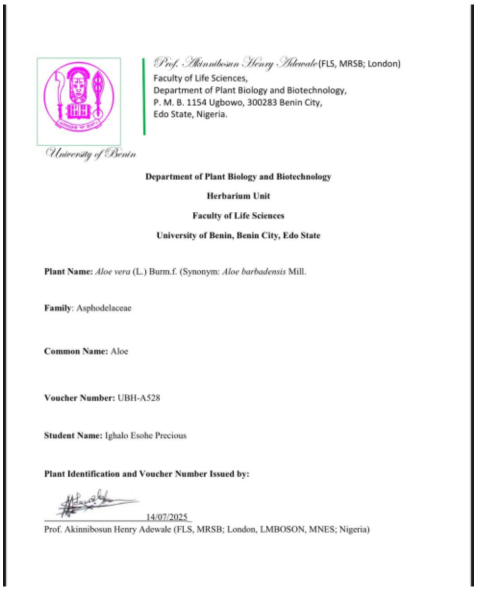
R1 (Reagent I)

- 25 g Sodium carbonate
- 25 g Potassium tartrate
- 20 g Sodium hydrogen carbonate
- 20 g Sodium sulphate
- All dissolved in 500 ml distilled water and made up to 1 litre.

Reagent R4

• Prepared from 400 ml of Reagent I + 16 ml of Reagent II

APPENDIX C; Voucher Image of Aloe Vera


Prof. Akinnibosun Henry Adewale (FLS, MRSB; London)
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Edo State, Nigeria.

University of Benin

Department of Plant Biology and Biotechnology

Herbarium Unit

Faculty of Life Sciences

University of Benin, Benin City, Edo State

Plant Name: *Aloe vera* (L.) Burm.f. (Synonym: *Aloe barbadensis* Mill.

Family: Asphodelaceae

Common Name: Aloe

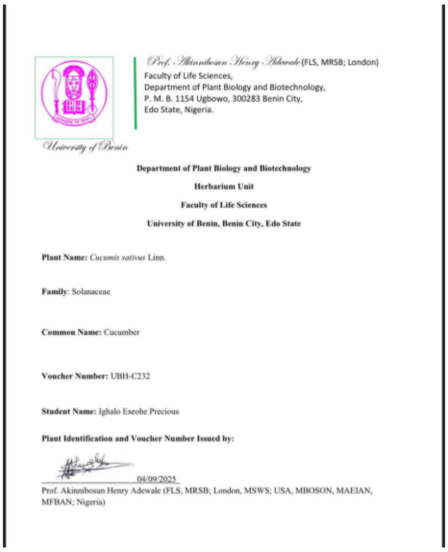
Voucher Number: UBH-A528

Student Name: Ighalo Esohe Precious

Plant Identification and Voucher Number Issued by:

14/07/2025
Prof. Akinnibosun Henry Adewale (FLS, MRSB; London, LMBOSON, MNES; Nigeria)

APPENDIX D; Voucher Image of Cucumber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University of Benin

Department of Plant Biology and Biotechnology

Herbarium Unit

Faculty of Life Sciences

University of Benin, Benin City, Edo State

Plant Name: *Cucumis sativus* Linn.

Family: Solanaceae

Common Name: Cucumber

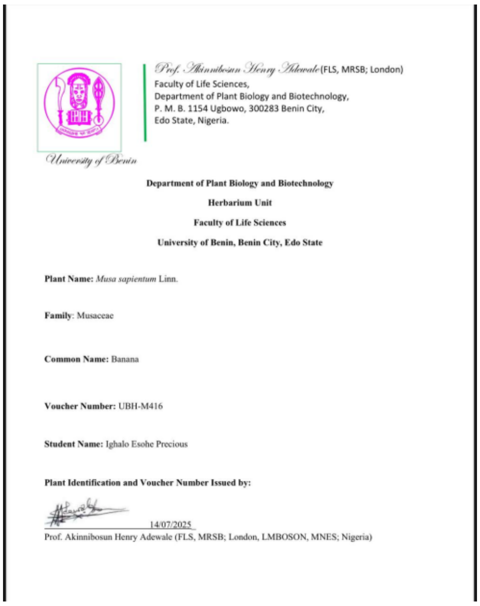
Voucher Number: UBH-C232

Student Name: Ighalo Eseohe Precious

Plant Identification and Voucher Number Issued by:

04/09/2025
Prof. Akinnibosun Henry Adewale (FLS, MRSB; London, MSWS; USA, MBOSON, MAEIAN, MFBAN; Nigeria)

APPENDIX E; Voucher Image of Banana



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Plant Name: *Musa sapientum* Linn.

Family: Musaceae

Common Name: Banana

Voucher Number: UBH-M416

Student Name: Ighalo Esohe Precious

Plant Identification and Voucher Number Issued by:

14/07/2025
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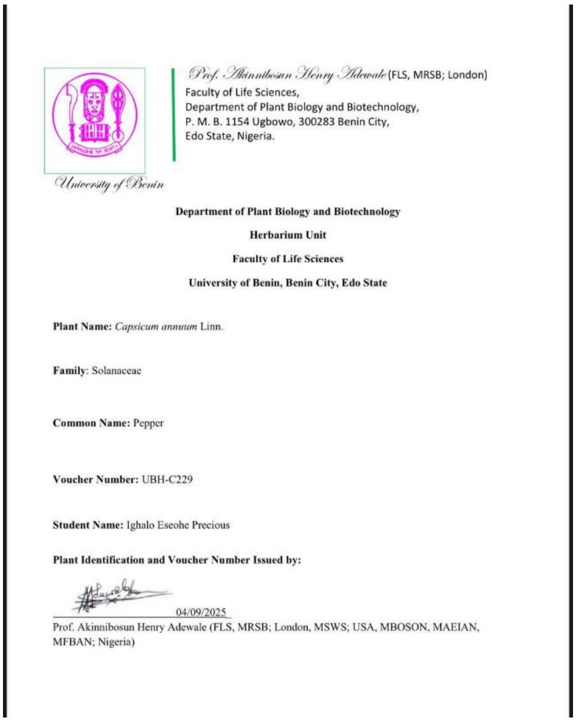
APPENDIX F; Voucher Image of Pepper



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Plant Name: *Capsicum annuum* Linn.

Family: Solanaceae

Common Name: Pepper

Voucher Number: UBH-C229

Student Name: Ighalo Eseohe Precious

Plant Identification and Voucher Number Issued by:

04/09/2025
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APPENDIX G; pH readings of fruit samples with three replicates, average and Standard deviations

	Rep1	**Rep2**	**Rep3**	**Avg**	**SD**	**Rep1**	**Rep2**	**Rep3**	**Avg**	**SD**
SAMPLES	**DAY1**					**3**				
A	5.9	5.8	5.9	5.87	0.06	5.8	5.8	5.8	5.8	0
B	6	6.1	6.1	6.07	0.06	6	6.1	6	6.03	0.06
C	6.1	6	6.1	6.07	0.06	6.1	6.1	6	6.07	0.06
D	6.1	6.2	6.2	6.17	0.06	6.2	6.1	6.2	6.17	0.06
E	5.7	5.8	5.7	5.73	0.06	5.6	5.5	5.6	5.57	0.06
F	5.7	5.8	5.7	5.73	0.06	5.7	5.7	5.7	5.7	0.06
G	5.7	5.8	5.7	5.73	0.06	5.8	5.7	5.7	5.73	0.06
H	5.8	5.7	5.7	5.73	0.06	5.7	5.8	5.7	5.73	0.06
I	5.2	5.2	5.3	5.23	0.06	5.1	5.2	5.1	5.13	0.06
J	5.3	5.3	5.2	5.27	0.06	5.2	5.2	5.2	5.2	0
K	5.3	5.4	5.3	5.33	0.06	5.3	5.3	5.2	5.27	0.06
L	5.4	5.5	5.4	5.43	0.06	5	5	5	5	0.06

SAMPLE	Rep1	Rep2	Rep3	Avg	SD	Rep1	Rep2	Rep3	Avg	SD
	5					**10**				
A	5.8	5.7	5.7	5.73	0.06	5.3	5.4	5.3	5.33	0.06
B	6	6.1	6	6.03	0.06	5.9	5	5.9	5.93	0.49
C	6.1	6	6	6.03	0.06	6	6	6	6	0
D	6.1	6.1	6.2	6.13	0.06	6.1	6	6	6.03	0.06
E	5.4	5.4	5.5	5.43	0.06	5.1	5	5.1	5.07	0.06
F	5.5	5.6	5.5	5.53	0.06	5.1	5.2	5.2	5.17	0.06
G	5.7	5.7	5.6	5.67	0.06	5.4	5.4	5.4	5.4	0.06
H	5.7	5.6	5.7	5.67	0.06	5.3	5.4	5.4	5.37	0.06
I	4.9	4.9	4.8	4.87	0.06	4.7	4.7	4.8	4.73	0.06
J	5.2	5.1	5.2	5.17	0.06	5	5	5.1	5.03	0.06
K	5.3	5.2	5.3	5.27	0.06	5.2	5.1	5.2	5.17	0.06
L	4.8	4.8	4.8	4.8	0.06	4.7	4.7	4.7	4.7	0

APPENDIX H; Total Sugar Content with three replicates, average and Standard deviation

SUGAR CONTENT

DAY1

SAMPLES	Rep1	Rep 2	Rep 3	Mean	SD
A	1.695	1.689	1.697	1.694	0.004
B	1.349	1.352	1.354	1.352	0.003
C	1.76	1.755	1.76	1.758	0.003
D	1.835	1.831	1.829	1.832	0.003
E	0.754	0.755	0.755	0.755	0.001
F	1.055	1.054	1.056	1.055	0.001
G	0.697	0.698	0.696	0.697	0.001
H	0.971	0.972	0.971	0.971	0.001
I	1.79	1.79	1.785	1.788	0.003
J	1.785	1.785	1.785	1.785	0
K	1.785	1.785	1.79	1.787	0.003
L	1.785	1.785	1.785	1.785	0

DAY10

SAMPLES	Rep1	Rep 2	Rep 3	Mean	SD
A	1.064	1.068	1.058	1.063	0.005
B	1.204	1.211	1.202	1.206	0.005
C	1.255	1.281	1.288	1.275	0.018
D	1.431	1.42	1.434	1.428	0.007
E	1.447	1.452	1.451	1.45	0.003
F	1.491	1.492	1.486	1.49	0.003
G	1.428	1.419	1.424	1.424	0.005
H	1.432	1.452	1.425	1.436	0.014
I	1.425	1.432	1.428	1.428	0.004
J	1.427	1.437	1.442	1.435	0.008
K	1.43	1.433	1.434	1.432	0.002
L	1.407	1.411	1.417	1.412	0.005

APPENDIX I; Titratable Acidity of fruit samples including two titre volume, average titre, calculated TA% and Standard deviation

sample	DAY TA %	Vol of NaOH	Titre1	Titre 2	SD	DAY5 TA %	Vol of NaOH	Titre1	Titre2	SD	DAY10 TA %	Vol of NaOH	Titre1	Titre2	SD
A	0.68	10.6	10.5	10.7	0.01	0.54	8.4	8.3	8.5	0.01	0.4	6.25	6.3	6.3	0.03
B	0.68	10.65	10.6	10.7	0.01	0.59	9.25	9.2	9.3	0.01	0.54	8.5	8.5	8.5	0.00
C	0.68	10.65	10.7	10.6	0.01	0.62	9.7	9.7	9.7	0.00	0.54	8.45	8.4	8.5	0.01
D	0.68	10.55	10.6	10.5	0.01	0.65	10.15	10	10.3	0.03	0.56	8.75	8.8	8.7	0.01
E	0.34	5.3	5.6	5	0.03	0.57	8.85	9	8.7	0.03	0.19	3	3.1	2.9	0.01
F	0.34	5.25	5.4	5.1	0.03	0.55	8.6	8.7	8.5	0.01	0.2	3.15	3.2	3.1	0.01
G	0.34	5.25	5.3	5.2	0.01	0.53	8.25	8.3	8.2	0.01	0.28	4.3	4.2	4.4	0.01
H	0.34	5.3	5.3	5.3	0.00	0.53	8.3	8.3	8.3	0.00	0.29	4.55	4.5	4.6	0.01
I	0.26	4.0	3.9	4.2	0.03	0.22	3.4	3.6	3.2	0.03	0.15	2.35	2.4	2.3	0.01
J	0.26	4.05	4.0	4.1	0.01	0.24	3.75	3.8	3.7	0.01	0.2	3.15	3.1	3.2	0.01
K	0.26	4.0	4.0	4.0	0.00	0.23	3.6	3.6	3.6	0.00	0.2	3.15	3.2	3.1	0.01
L	0.26	4.0	3.8	4.2	0.03	0.22	3.5	3.4	3.6	0.03	0.16	2.5	2.6	2.4	0.01

NOTE; Average (Avg), Standard Deviation (SD) and TA% Values were calculated using the following formulas;

Average (Avg);

Avg=$\frac{\sum x}{n}$

Where x=individual measurements

n= number of replicates

Standard deviation (SD);

SD=$\frac{\sqrt{\sum(x-A)^2}}{n-1}$

Where x=individual measurements

A= Average

n= number of replicates

Titratable Acidity(% citric acid)

$$\text{TA (\% citric acid)} = \frac{(V_{NaOH} \times M_{NaOH} \times E_{qwt}\,(\text{citric acid}) \times 100)}{(\text{Volume of sample (mL)} \times 1000)}$$

Where:

= Volume of NaOH used (mL)

= Molarity of NaOH (mol/L)

Equivalent weight of citric acid = 64.04 g

Appendix J; Preparation of 0.1M of NaOH

Preparation of 0.1 M NaOH Solution (250 mL)

Calculation

Mass= Conc × V × Molar Mass

Conc=0.1M

Volume=250ml

250ml/1000=0.25L

Molar mass of NaOH = 40 g/mol

Mass = 0.1 × 0.25 × 40 = 1.0 g

Appendix K; Calculation of weight loss

$$\text{Weight Loss (\%)} = \frac{F_0 - F_1}{F_0} \times 100$$

Where:

F_0 is the initial fresh weight and F_1 is the weight measured on each sampling day (Hassan *et al.*, 2022).