

# Enhancing Shelf-Life and Microbial Safety of Fresh-Cut Pineapple Using Coffee Pulp Pectin-Based Films

Girma Biratu<sup>1,2\*</sup>, Henock Woldemichael Woldemariam<sup>1,2</sup>, Asefa Niguse<sup>2,3</sup>, Hiwot Meresa<sup>1,2</sup>

<sup>1</sup>Department of Chemical Engineering, College of Engineering, Addis Ababa Science and Technology University, P.O. Box 16417, Addis Ababa, Ethiopia

<sup>2</sup>Biotechnology and Bioprocess Center of Excellence, Addis Ababa Science and Technology University, P.O. Box 16417, Addis Ababa, Ethiopia

<sup>3</sup>Biotechnology Department, Addis Ababa Science and Technology University, P.O. Box 16417, Addis Ababa, Ethiopia

## Article Information

### Article history:

Received 5 November 2025

Received in revised form 8 December 2025

Accepted 10 December 2025

### Keywords:

Pineapple

Edible film

Coffee pulp pectin

Firmness

Sensory analysis

### Corresponding author:

E-mail: [girma.biratu@aastu.edu.et](mailto:girma.biratu@aastu.edu.et)

(Girma B)

<https://doi.org/10.69660/jmpt.v2i1.126>

## Abstract

This study investigated the application of coffee pulp pectin-based edible films on the physicochemical, sensory, and microbial qualities of fresh-cut pineapples stored at room temperature. After 132 h of storage, pineapples wrapped with pectin propolis glycerol (PPG) maintained higher firmness (2.5 N) compared to pectin honey (PH, 2.3 N) and showed lower weight loss (23.3%). The PPG samples also exhibited titratable acidity (16.3%) and total soluble solids (7.4%), indicating better preservation of fruit quality. Sensory evaluation revealed that PH-treated pineapples received the highest overall acceptability score (6.25), surpassing both the control and PPG groups. Although both coated and uncoated samples scored above the hedonic scale average (5), they were still less preferred compared to freshly cut unwrapped pineapple. Microbial analysis highlighted that PPG provided a higher antimicrobial effect, showing the lowest growth of bacteria (1.15 cm), yeast (2 cm), and mould (2 cm), followed by PH, whereas the control exhibited the highest microbial growth (3 cm bacteria, 4 cm yeast, 5 cm moulds). Kinetic modelling of the physicochemical parameters revealed that quality changes followed a first-order model. Overall, the findings demonstrate that coffee pulp pectin-based films, particularly PPG, effectively enhance shelf-life, microbial safety, and quality retention in fresh-cut pineapples.

## 1. Introduction

Pineapple (*Ananas comosus*) is a spiky crown and juicy, sweet, tangy flesh with a yellowish colour and fibrous texture. It is a year-round fruit grown in tropical and subtropical regions. It is medium-sized and has a composition that varies with ripeness, cultivar, and handling [1]. Pineapples are a rich source of vitamins, minerals, and antioxidants, offering numerous health benefits, including boosting immunity, aiding digestion, and reducing inflammation [1, 2]. There are many pineapple varieties with various colours, shapes, sizes, and flavours, of which the Smooth Cayenne cultivar is commonly preferred in the commercial sector. Thailand, Brazil, and Costa Rica are the top global pineapple producers, with Nigeria occupying the top position in Africa [3, 4]. In Ethiopia, the primary pineapple production areas are located in the southern and southwestern regions of the country [5].

Pineapples are used to produce jam, jellies, desserts and also eaten fresh [6]. During fresh consumption, pineapples are subject to minimal processing that exposes them to the environment. In the absence of a protective layer, the product becomes susceptible to microbial spoilage. This spoilage is primarily caused by microorganisms adhering to the available nutrients and a favourable pH for their growth [7]. The absence of a protective layer can lead to unwanted properties such as browning,

softening, decay, altered flavour, and microbial growth. Hence, it is important to use active film to wrap the fresh-cut surface of the pineapple to prevent quality loss and extend its shelf life.

Edible films are thin layers of material that can be consumed along with the food they cover, are safe for human consumption, and provide an alternative to traditional packaging materials [8]. They are typically made from biodegradable materials like starches, proteins, or lipids [8, 9]. Edible films offer a promising solution to the concerns related to plastic waste and environmental impact in the food industry. They can be used in the food industry to increase the shelf life of perishable products, safeguard them from contamination, and enhance their overall quality [10, 11]. These films can also act as a barrier against moisture, oxygen, and other gases, and can also be used to add flavour, colour, or nutrients to the food they are applied to [12]. Additionally, edible films can be utilized to provide active ingredients such as vitamins or preservatives, directly to the food, which means they not only enhance the shelf life of products but also add value in terms of flavour and nutrition.

Some literature reported the application of edible coating to coat fresh-cut pineapples. Treviño-Garza [7] employed edible coatings composed of chitosan, pullulan, linseed, nopal cactus, and aloe mucilage to

augment the quality attributes. The researchers observed that these edible coatings effectively extended the shelf-life of fresh-cut pineapples, encompassing improvements in colour, odour, flavour, texture, and overall acceptability. Ismillayli et al. [13] used edible film made of Carrageenan-chitosan and reduced vitamin C and weight loss. Azarakhsh et al. [14] reported the incorporation of 0.3% (m/v) to alginate-based edible coating improved the quality and shelf life of fresh-cut pineapples. Edible films have been used to preserve some perishable food products. Edible films made of chitosan and starch have been found to effectively extend the shelf life of cherry tomatoes [15]. Another study by Issa et al. [9] utilized a packaging film made of sweet potato starch, thyme essential oil, and montmorillonite nano-clay to pack spinach leaves. These studies showed that the packaging film tended to extend the shelf life by inhibiting the growth of harmful bacteria.

There are rare reports with regard to the preservation of fresh-cut pineapples by edible film, which is relatively cheaper as compared to edible coating. To the best of our understanding, there has been little or no research conducted on the utilization of active film derived from coffee pulp, propolis and honey to increase the shelf life of pineapples. Our previous work shows that edible film made from these ingredients has shown antimicrobial and antioxidant properties [16]. In the current study, coffee pulp pectin blended with honey, propolis, and glycerol was evaluated for its effectiveness in extending the shelf life of fresh-cut pineapples by assessing physicochemical, microbiological, and sensory properties.

## 2. Materials and methods

### 2.1. Materials

Ten matured pineapple fruits were purchased on August 22, 2024, from a supermarket in Addis Ababa, Ethiopia. The samples were prepared using the method reported by Azarakhsh et al. [14] with some modifications. The fruits were then washed in a solution of 50 mg/L NaOCl, peeled, and cut into 2 cm × 2 cm × 2 cm pieces. The processing was done at approximately 10 °C, using equipment sanitized with an organic chlorine solution at a concentration of 2 g/L. The prepared pineapple slices were then stored at this temperature until applying the edible film. Ascorbic acid (99%), NaOCl solution (15%) and H<sub>2</sub>SO<sub>4</sub> (98%) were obtained from Merck, Germany.

### 2.2. Methods

#### 2.2.1. Edible film preparation

In this study, pectin was extracted from coffee pulp using a 0.1 M H<sub>2</sub>SO<sub>4</sub> solution, with a solid-to-liquid ratio of 1:20, a temperature of 84 °C, and a pH of 1.5 using the method reported by our research team [17]. The resulting mixture was filtered through a double muslin cloth to separate the residue from the extract, which was then precipitated with 95% ethanol and kept at 4 °C for 16 h. The precipitate was subsequently filtered, washed with 100 mL of absolute ethanol, and air-dried to obtain coffee pulp pectin (CPP). Propolis was extracted following the method reported by Oroian et al. [18]. Briefly, 1.0 g of raw propolis was dissolved in 50 mL of 70% ethanol and subjected to microwave heating at 140 W for 1 min, maintaining the temperature at 60 °C. The mixture was then cooled to room temperature, centrifuged at 4000 rpm for 10 min, and filtered. The residue from the first extraction was re-extracted

under the same conditions. Finally, the combined crude extracts were dried in a vacuum dryer at 45 °C and stored at 4 °C under refrigeration.

Two pectin-based films were prepared from coffee pulp to assess their effects on fresh-cut pineapples. The first one is a pectin-propolis-glycerol (PPG) film made from 2% (pectin/water), 20% propolis (propolis/pectin ratio), and 20% (glycerol/pectin). The second one is pectin-honey (PH) film with 2% (gpectin/gwater) and 20% (ghoney/gpectin). Pectin was initially dissolved in water by continuous stirring at 800 rpm for 6 h using a magnetic stirrer. The solution was then heated to 70 °C and maintained under stirring for 45 min. Subsequently, glycerol and propolis for pectin-propolis-glycerol (PPG) film and honey for pectin-honey (PH) film were incorporated at a ratio of 0.20 g per 1.0 g of pectin, followed by an additional 20 min of stirring. The homogeneous gelatinous solution was cast onto 14 × 14 cm plastic sheets, dried at 35 °C for 12 h, and stored in a desiccator at room temperature until use.

#### 2.2.2. Pineapple cut coating

Pineapple slices were coated with edible films to evaluate their effects on the physical, chemical, and microbiological properties. The uncovered slices served as the control, while the coated samples were designated as PPG and PH according to the type of film used. All samples were stored at 4 °C, 15 °C, and 25 °C under different storage conditions.

#### 2.2.3. Characterization of fresh-cut pineapple

The firmness of wrapped and unwrapped fresh-cut pineapple was determined using the procedure reported by Azarakhsh et al. [14]. The firmness of the samples was investigated on the first day and after the storage period using a Fruit pressure Tester (EFFEGI, Italy). Penetration tests were conducted using a cylindrical probe with a diameter of 2 mm and a test speed of 0.5 mm/s. The maximum peak measured during the test was taken as the firmness value. The weight loss of fresh-cut pineapples was measured using a gravimetric method [14]. This entailed comparing the weight of the pineapple after storage with its initial weight using a digital balance. The findings were expressed as a percentage and computed using Equation (1).

$$\text{Weight loss (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where,  $W_i$  represents the initial weight and  $W_f$  represents the weight at the end of storage.

The total soluble solids in pineapple were determined using a method described by Estrada-Girón et al. [19]. The pineapple fruit was crushed using a juicing machine. The resulting blend was then filtered, and the extracted juice was analysed for its total soluble solids by using a Digital Refractometer (A.KRÜSS Optronic, Germany). The pH measurement of the sample was performed using a pH meter as described by Estrada-Girón et al. [19]. A 5 g of fresh-cut samples was macerated in 50 mL of distilled water. Subsequently, the pH of the macerated solution was determined by immersing the electrode in it. Titrable acidity was determined using a method reported by Azarakhsh et al. [14].

The titration method was used to measure the titrable acidity of the fresh-cut pineapples. A solution used to determine pH was titrated with 0.1 N

sodium hydroxide until the pH reached  $8.3 \pm 0.2$ . This parameter was expressed in percentage of citric acid as shown in Equation (2).

$$\text{Titrateable acidity (\%)} = \frac{V \times N \times M_{Eq} \text{ citric acid}}{m} \times 100 \quad (2)$$

where, V is NaOH volume (mL), N is normality of NaOH,  $M_{Eq}$  is citric acid milliequivalents (0.064), and m: mass of sample (g).

Microbial analysis was conducted using a methodology previously reported by Ravimannan et al. [20]. Fresh-cut pineapple samples with specified lengths were prepared for analysis. The growth medium was prepared by dissolving 39 g of Potato Dextrose Agar in 1000 mL of distilled water. This solution was subsequently autoclaved, poured into petri dishes, and solidified. Fresh-cut pineapple samples were introduced to the solidified dishes in triplicate and incubated at room temperature until microbial growth was observed. The diameter of the microbial growth for PPG-wrapped, PH-wrapped, and control was measured using a ruler.

Sensory analysis for fresh-cut pineapples was conducted following the procedure established by Azaraksh et al. [14]. The sensory characteristics of wrapped fresh-cut pineapple samples, and control after 48 h of storage, as well as newly fresh-cut samples, were evaluated by 30 semi-trained assessors. Some staff and students who frequently eat pineapple were selected from Addis Ababa Science and Technology University, Ethiopia. The assessors used a 9-point hedonic scale (extremely dislike to extremely like) to evaluate the colour, appearance, odour, texture, and overall acceptability of the samples. The samples were presented in plastic containers and randomly assigned and distributed among assessors. The assessors recorded their responses on paper scorecards.

#### 2.2.4. Statistical analysis

All experiments were conducted in triplicate and the results are presented as mean  $\pm$  standard deviation. A one-way analysis of variance (ANOVA) was conducted to compare the mean values between the wrapped and control samples using Tukey's test using Minitab Statistical Software (version 20.3). Statistical analyses were carried out using Minitab Statistical Software (version 20.3), and differences were considered statistically significant at  $p < 0.05$ .

### 3. Results and discussion

#### 3.1. Pectin, propolis and edible film physicochemical properties

The pectin used in this study had anhydrouronic acid of  $58.8 \pm 1.1$ , methoxyl content of  $7.8 \pm 0.2\%$ , degree of esterification of  $75 \pm 3\%$  and equivalent weight of  $1430 \pm 25$  g/mol. The obtained AUA meets the quality standard for pectin established by the International Pectin Producers Association [21], which specifies a minimum value of 35%. These values may vary depending on the raw materials, solvents, and extraction methodologies utilized. Furthermore, these properties are essential for determining the applications of pectin in film production. The PH film employed in this study demonstrated a thickness of 0.119 mm, a water solubility of  $79.0 \pm 5.9\%$ , an oxygen permeability of  $(1.28 \pm 0.02) \times 10^{-10}$  mL/m.s.Pa and a carbon dioxide permeability of  $(4.23 \pm 0.01) \times 10^{-10}$  mL/m.s.Pa. Furthermore, the water vapour permeability

was also found to be  $(3.1540 \pm 0.0001) \times 10^{-10}$  g/m.s.Pa. In the case of PPG, the thickness was  $0.123 \pm 0.03$  mm, water solubility was  $80.3 \pm 4.9\%$ , oxygen permeability of  $(1.89 \pm 0.01) \times 10^{-10}$  mL/m.s.Pa, carbon dioxide permeability of  $(5.99 \pm 0.01) \times 10^{-10}$  mL/m.s.Pa, and a water vapour permeability of  $(3.43700 \pm 0.00005) \times 10^{-10}$  g/m.s.Pa. The propolis used in the film preparation also had antimicrobial properties, as its values explained in our previous work [16].

#### 3.2. Physicochemical properties of fresh-cut pineapple

This study analyzed the firmness, total soluble solids, titrateable acidity, pH, and weight loss properties of fresh-cut pineapple wrapped with only a PVC sheet (Control), edible film, and a PVC sheet (PPG and PH).

##### 3.2.1. Firmness

The firmness values of fresh-cut pineapple, both wrapped and unwrapped in a pectin-based film, over a period of 0 to 132 h ranged from 2 to 11 N (Figure 1). The firmness of the samples was affected by both the storage time and the type of wrapping film used. Samples wrapped in PPG showed significantly higher firmness values, while the control samples had the lowest firmness among the fresh-cut samples stored for the same time. The firmness properties are strongly affected by the type of packaging material. This may be due to the permeability properties of films. The PPG has a better gas and water vapour permeability than pectin honey-based film. Additionally, firmness decreased as the storage duration increased, from 0 to 132 h. A gradual decrease in firmness values could be related to the textural changes of the fruit as the storage duration increased. The changes in textural properties indicated the corresponding variation in the internal quality attributes of the fruit along with the ripening process. The pineapple fruit was reported to have firmness values ranging from 0.33 to 2.92 N at different storage temperatures that could be linked to pectin degradation Mohd Ali et al. [22]. The composition of pineapple flesh might also vary between different varieties, the harvest maturity and time, fruit variety, and environmental conditions. Thus, the evaluation of quality attributes of different pineapple varieties is vital to ensure the fruit is within an acceptable quality range.

##### 3.2.2. Total soluble solids (TSS)

Total soluble solids are a key indicator of sweetness and ripeness that reflects the sugar content in fruit. Figure 1 shows TSS values of three different pineapples during 132 h of storage at room temperature. The TSS values of fresh-cut pineapple wrapped with PPG, PH and unwrapped (control) vary from 9.4-7.4%, 9.4-6.3% and 9.4-5.7%, respectively. The results indicated a significant difference among the TSS values of control, PPG-wrapped, and PH-wrapped pineapples. The TSS values indicated a slight increase during the first 48 h, followed by a slight decrease as the storage duration extended. This is due to the slight conversion of starch to soluble sugar at the initial stage, and then after decrease due to the respiration process in the fruits and fermentation of soluble sugars, which favours the formation of acids [23, 24]. These trends have some similarities with the findings reported by Mohd Ali et al. [22]. The TSS of pineapple in this study is lower in comparison to previous reports, which may be attributed to factors such as the cultivar, historical context, and degree of maturity [25].

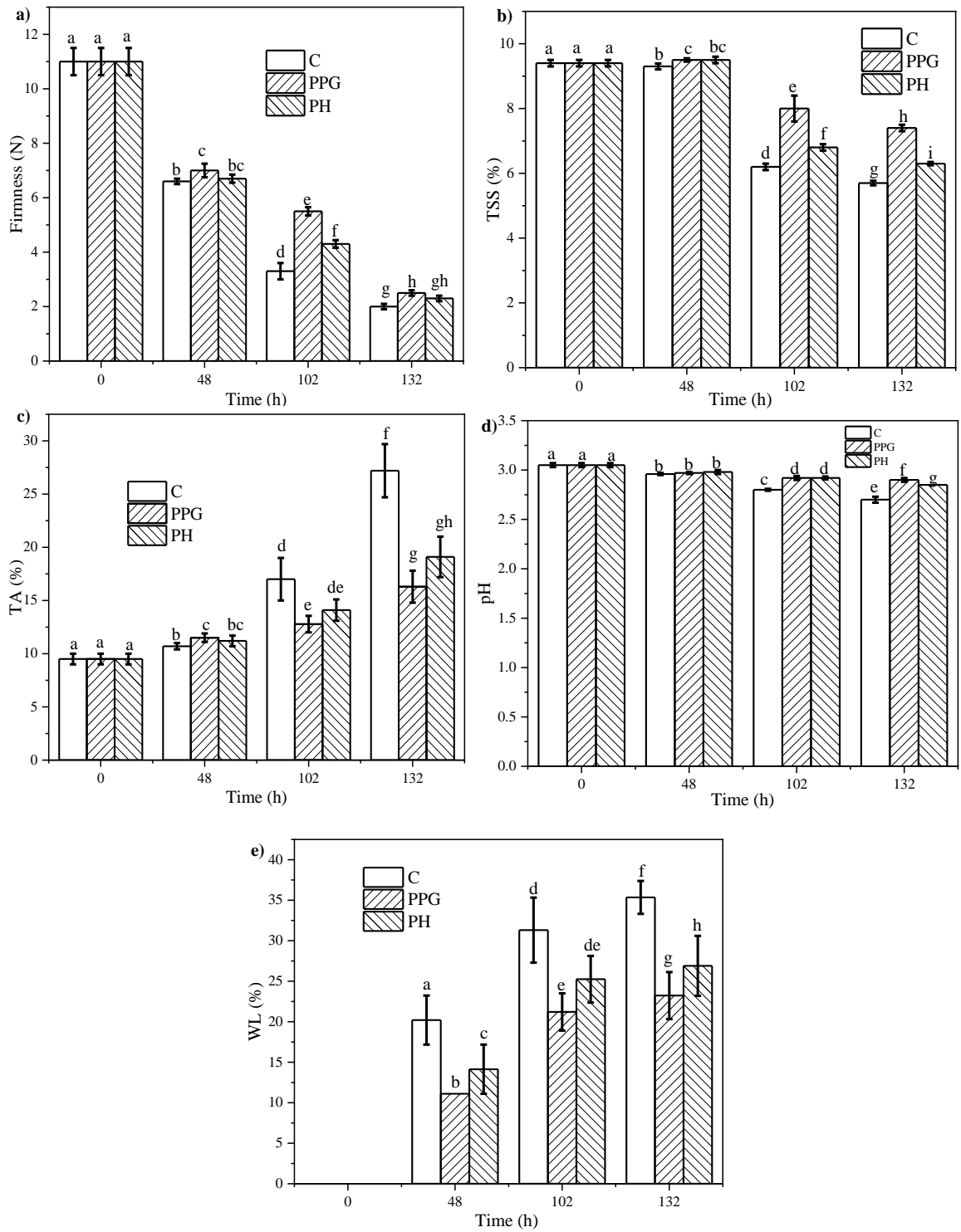


Figure 1. Physicochemical properties of pineapple wrapped with PVC only (C=control) and PVC and film (PPG and PH). (a) Firmness, (b) TSS, (c) TA, (d) pH and (e) WL (weight loss).

### 3.2.3. pH

The pH values of stored wrapped and unwrapped fresh-cut pineapple varied from 2.40 to 3.05 (Fig. 1). No significant difference ( $P > 0.05$ ) was found between samples wrapped in edible films, but a notable difference ( $p < 0.05$ ) was observed between wrapped and unwrapped samples. The control sample showed a quicker decrease in pH, while the sample wrapped in PPG had a slower decline. This disparity can be attributed to the presence of the film, which inhibits fermentation rates by affecting microbial activity. The pH values reported in this study were a little bit lower than those reported by Bitencourt et al. [26] ranging from 3.70 to 4.30 for pineapples. Similar to other properties of pineapple, pH values have been reported to vary depending on the maturity stage of the fruit and its respiratory metabolic activity.

### 3.2.4. Weight loss

The weight loss values of wrapped and control fresh-cut pineapples are presented in Figure 1, ranging from 0% to 35.4%. The results indicated that all samples experienced moisture loss, with the PPG and PH wrapped samples having a lower rate of loss in comparison to the control. This observation suggests that the wrapping film may absorb moisture, thereby influencing the moisture content of the pineapple during storage. The statistical analysis revealed there is a significant difference ( $p < 0.05$ ) in weight loss between samples wrapped in PPG and PH edible films; however, a significant difference was observed between wrapped and unwrapped fresh-cut pineapples. From the preliminary run, the weight loss can be reduced by wrapping with edible film such as PPG and PH as compared to exposed fresh-cut pineapple to the environment at room temperature. These findings agreed with the previous reports. Wrapping fresh-cut pineapples with edible film can effectively reduce weight loss. The previous work by Azarakhsh et al. [14] revealed that coating fresh-cut pineapple with an edible coating can reduce weight loss. The use of freshly-cut pineapple packaging helps not only maintains its weight, but also improves its overall quality and longevity in storage, making it a better option than non-packaged pineapple [27, 28].

### 3.2.5. Titrable Acidity

Titration acidity (TA) is a critical parameter in the assessment of fresh-cut pineapple quality, as it significantly influences flavour, shelf life, and consumer acceptance [25]. The titration acidity of fresh-cut pineapple is depicted in Figure 1. Although the rate of increase is not uniform, total acidity varied from 9.5 to 32.2 during the storage period of 0 to 132 h, generally adhering to the order of PPG < PH < Control. The increment may be due to the presence of microorganisms, such as bacteria, yeasts and moulds, which metabolize sugars to produce organic acids [29]. Though they are not necessarily inversely related, the fermentation increases titration acidity while decreasing the pH, as both phenomena are related to acidity level [30].

## 3.3. Kinetic Models for physicochemical properties

Kinetic models provide a systematic framework for understanding and predicting changes in the physicochemical properties of fresh-cut pineapple during storage, which is essential for maintaining product quality and improving consumer acceptability. In this study, kinetic analyses were conducted to evaluate the changes in firmness, total soluble solids (TSS), weight loss, titration acidity (TA), and pH of

fresh-cut pineapple during storage. The reaction order was determined by fitting both zero-order and first-order kinetic models to the experimental data obtained from wrapped and unwrapped pineapple samples. The estimated reaction orders and kinetic parameters are presented in Table 1, and model suitability was evaluated based on the coefficient of determination ( $R^2$ ).

The degradation of firmness in pineapples wrapped with coffee pulp pectin-based edible film was best described by a first-order kinetic model, with a regression coefficient of  $R^2 = 0.99$  and a rate constant ( $k$ ) of 0.013, compared with  $R^2 = 0.98$  and  $k = 0.068$  obtained from the zero-order model. The higher  $R^2$  value for the first-order model indicates that the rate of firmness loss depends on the remaining structural integrity of the fruit tissue. This behavior suggests that softening occurs through the progressive degradation of cell wall components such as pectin and hemicellulose. A similar trend was reported by Mohd Ali et al. (2022), who observed that firmness deterioration in stored pineapple followed first-order kinetics. Likewise, the changes in weight loss, pH, and titration acidity were better described by first-order kinetics than by zero-order kinetics, with  $R^2$  values ranging from 0.86 to 0.99 for the first-order model and from 0.812 to 0.98 for the zero-order model. The predominance of first-order behavior suggests that the rate of change in these quality attributes depends on their current state within the fruit matrix.

In contrast, the variation in total soluble solids (TSS) was better represented by the zero-order kinetic model, indicating that the change in soluble sugar content occurred at a relatively constant rate during storage. This trend may be attributed to the gradual conversion of complex carbohydrates into simpler sugars and the effect of moisture loss. Overall, the kinetic modeling results indicate that the application of coffee pulp pectin-based edible film effectively slows the deterioration of key quality attributes in fresh-cut pineapple. The edible film likely acts as a semi-permeable barrier that limits moisture transfer and gas exchange, thereby reducing respiration and metabolic activity. Consequently, the coating helps maintain structural integrity, minimize weight loss, and stabilize chemical properties, demonstrating the potential of coffee pulp pectin as a sustainable hydrocolloid-based material for extending the shelf life of minimally processed fruits.

## 3.4. Sensory analysis

The sensory analysis of fresh-cut pineapples was conducted on newly cut samples and those stored for 48 h (Control, PPG, and PH). This study conducted a sensory analysis of wrapped and unwrapped samples based on colour, appearance, odour, texture, and overall acceptability after a 48 h storage period at room temperature. These durations were selected based on the firmness and odour characteristics, as the samples approached the thresholds of firmness (5 N) and flavour acceptability (pronounced sourness). The results of the sensory evaluations are illustrated in Fig. 2. A significant difference was observed in the sensory ratings between the newly cut and the 48-h stored pineapple samples. Additionally, a statistically significant ( $p < 0.05$ ) difference was noted among the attributes of colour, flavour, and texture in the stored fresh-cut pineapple. The newly cut pineapple demonstrated superior quality,

whereas the stored samples exhibited both inferior and superior qualities with respect to various attributes. The samples wrapped in PPG and PH displayed favourable quality in terms of flavour, texture, and appearance when compared to the control sample. Conversely, the control sample received higher acceptance regarding colour. Previous research conducted by Sime et al. [31] demonstrated a significant effect of active components on sensory properties. The wrapping of fresh-cut pineapple

using PPG and PH resulted in a reduction of its colour appeal, attributable to the migration of certain colouring components from the film to the pineapple. No significant difference ( $p > 0.05$ ) was found between the PPG and PH samples in attributes such as colour, appearance, flavour, overall acceptability, and texture. The overall acceptance scores indicated no significant differences among the control, PPG, and PH wrapped samples.

Table 1.  $R^2$  and  $k$  values for physicochemical properties associated with first-order and zero-order kinetic models.

	Control				PPG				pH			
	Zero order		First order		Zero order		First order		Zero order		First order	
	$R^2$	K	$R^2$	K	$R^2$	K	$R^2$	K	$R^2$	K	$R^2$	K
F	0.98	0.068	0.99	0.013	0.96	0.059	0.89	0.010	0.98	0.064	0.97	0.011
TSS	0.889	0.032	0.89	0.004	0.86	0.017	0.86	0.002	0.98	0.024	0.99	0.003
pH	0.96	0.059	0.96	0.02	0.96	0.030	0.96	0.01	0.956	0.024	0.959	0.008
WL	0.97	0.382	0.98	0.044	0.93	0.549	0.96	0.069	0.930	0.431	0.950	0.051
TA	0.812	2.651	0.90	0.165	0.863	0.964	0.90	0.078	0.869	1.423	0.926	0.106

Where, F, TSS, pH, WL and TA are firmness, total soluble solids, pH, weight loss and titrable acidity of pineapples.

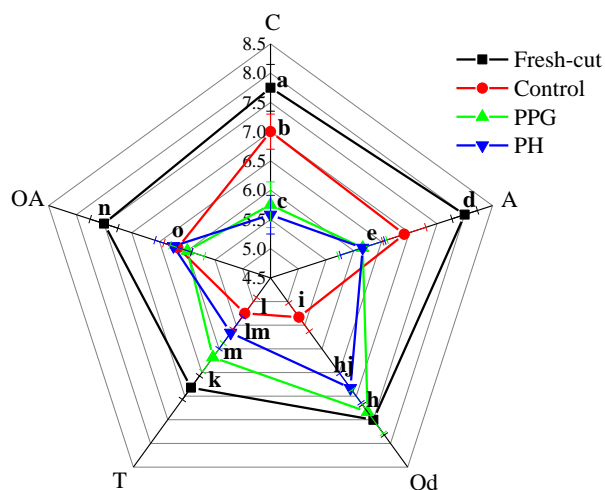


Figure 2. Sensory analysis of fresh-cut pineapples. (C, A, Od T, and OA represented colour, appearance, odour, texture and overall acceptability).

### 3.5. Microbial Analysis

Microbial analysis of fresh-cut pineapple is essential for evaluating product safety and quality after processing and during storage, as minimally processed fruits are highly susceptible to microbial contamination due to tissue damage and exposure of nutrient-rich internal tissues [32].

Fresh-cut pineapple provides a favorable environment for microbial growth because of its high moisture content, sugars, and organic acids.

In this study, the growth of bacteria, yeasts, and moulds was evaluated after 24, 72, and 148 h of incubation at room temperature, respectively. The bacterial growth sizes for the control, PH, and PPG treatments were  $3.00 \pm 0.75$ ,  $1.5 \pm 0.5$ , and  $1.15 \pm 0.45$  cm, respectively. Similarly, mould growth sizes were  $5.00 \pm 1.20$  cm,  $3.40 \pm 0.75$  cm, and  $2.00 \pm 0.78$  cm for the control, PH, and PPG treatments, respectively. Yeast growth diameters were  $4.0 \pm 0.9$  cm for the control,  $3.0 \pm 1.3$  cm for PH, and  $2.0 \pm 1$  cm for PPG. These results demonstrate that the application of pectin-based edible films significantly reduced ( $p < 0.05$ ) microbial proliferation during storage. The microbial growth pattern followed the order PPG < PH < Control, indicating that the propolis-enriched pectin film (PPG) provided the greatest inhibitory effect against bacteria, yeasts, and moulds.

The enhanced antimicrobial performance of PPG-treated samples can be attributed to the synergistic effect between the barrier properties of the pectin matrix and the antimicrobial activity of propolis. Pectin-based films act as semi-permeable barriers that limit oxygen availability and moisture migration, which can suppress microbial metabolism and slow spoilage processes. Furthermore, propolis contains bioactive compounds such as phenolic acids, flavonoids, and aromatic esters that disrupt microbial cell membranes and inhibit enzymatic activity, thereby reducing microbial growth. These combined effects contribute to improved microbial stability of the coated pineapple samples. Previous studies have also reported efforts to extend the shelf life of fresh-cut pineapple under different storage conditions. For instance, Torri et al.

(2010) reported shelflife of approximately 120 h at 4 °C, 48 h at 7.6 °C, and 24 h at 16 °C using electronic nose technology, while Di Egidio et al. (2009) reported shelf lives of 8-10 days at 5.3 °C, 4-5 days at 8.6 °C, and around 2 days at 15.8 °C using infrared spectroscopy and microbiological analysis. In contrast, Bierhals et al. (2011) found that cassava starch coatings did not improve the shelf life of fresh-cut

pineapple and even promoted microbial growth. In the present study, the application of coffee pulp pectin-based edible film extended the shelf life of fresh-cut pineapple to approximately 48 h at room temperature, showing its potential for controlling microbial growth and improving the stability of minimally processed fruits.

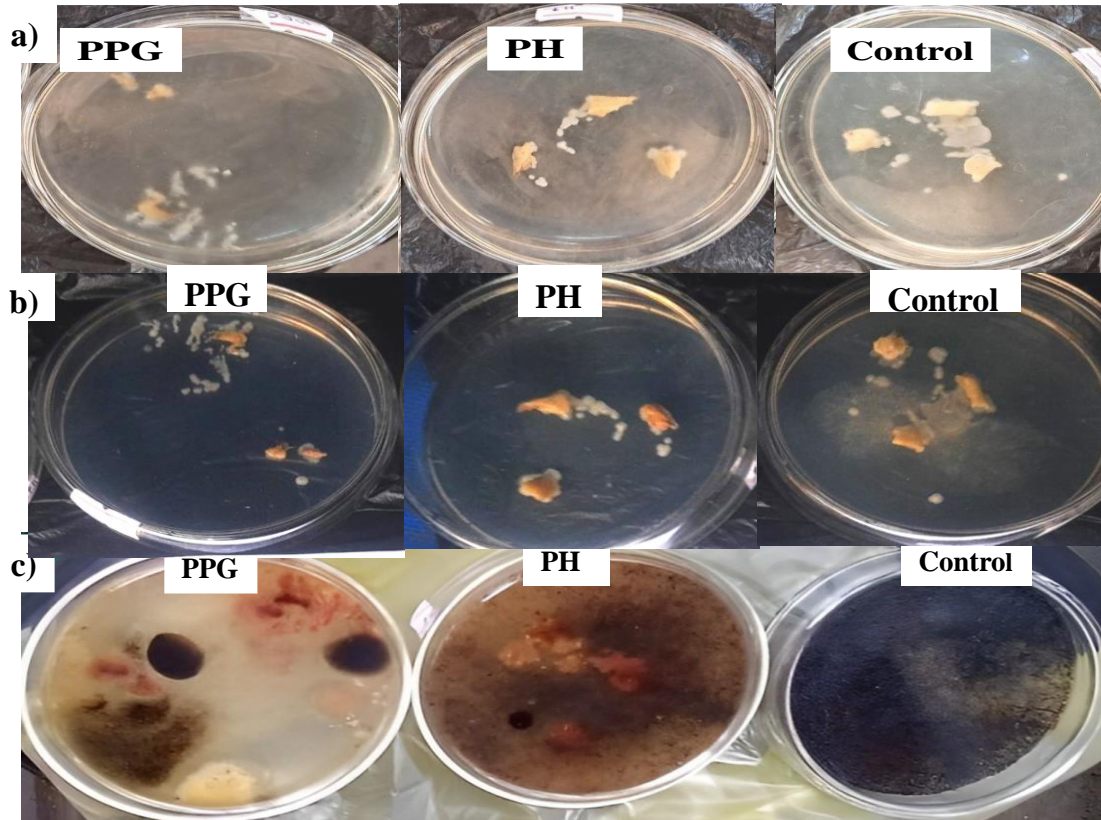


Figure 3. Microbial growth on samples (PPG wrapped, PH wrapped and Control): a) Bacteria, b) yeast and c) Mould.

#### 4. Conclusions

This study examined the effects of edible films on the physicochemical, sensory, and microbial properties of fresh-cut pineapples during storage for 48 h. The findings revealed a positive impacts of the films on the sensory, microbial, and physicochemical attributes of the pineapple. Specifically, the physicochemical properties such as firmness, pH, titratable acidity, and total soluble solids were improved in the pineapples wrapped with PPG and PH films as compared to the control samples. The film-wrapped fresh-cut pineapples showed reduced growth of bacteria, yeast, and mould relative to the control. Sensory analysis further indicated preservation in texture, appearance, and overall acceptability. The study also concluded that the influence of wrapping conditions on the physicochemical properties follows a first-order kinetic model.

#### Declaration of competing interest

The authors declare that they have no competing interests.

#### Acknowledgments

The authors gratefully acknowledge Addis Ababa Science and

Technology (AASTU).

#### References

- [1] M.M. Ali, N. Hashim, S. Abd Aziz, O. Lasekan, Pineapple (*Ananas comosus*): A comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products, *Food Research International* 137 (2020) 109675.
- [2] W.M. Hikal, A.A. Mahmoud, H.A. Said-Al Ahl, A. Bratovcic, K.G. Tkachenko, M. Kačániová, R.M. Rodríguez, Pineapple (*Ananas comosus* L. Merr.), waste streams, characterisation and valorisation: An Overview, *Open Journal of Ecology* 11(9) (2021) 610-634.
- [3] J. Wei, L. Peng, Z. He, Y. Lu, F. Wang, Potential distribution of two invasive pineapple pests under climate change, *Pest management science* 76(5) (2020) 1652-1663.
- [4] M. Aidoo, Effects of Pineapple Cultivation on Rural Smallholder Farmers in the Ekumfi District of Central Region, Ghana, University of Cape Coast, 2021.
- [5] S. Alo, A. Gezahegn, D. Geremew, W. Getachew, Evaluation of Pineapple (*Ananascomosus* L.) Varieties at Teppi, South Western

- Ethiopia, Greener Journal of Agricultural Sciences (2019).
- [6] A. Kocira, K. Kozłowicz, K. Panasiewicz, M. Staniak, E. Szpunar-Krok, P. Hortyńska, Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review, *Agronomy* 11(5) (2021) 813.
- [7] M.Z. Treviño-Garza, S. García, N. Heredia, M.G. Alanís-Guzmán, K. Arévalo-Niño, Layer-by-layer edible coatings based on mucilages, pullulan and chitosan and its effect on quality and preservation of fresh-cut pineapple (*Ananas comosus*), *Postharvest Biology and Technology* 128 (2017) 63-75.
- [8] S. Chhikara, D. Kumar, Edible coating and edible film as food packaging material: A review, *Journal of Packaging Technology and Research* 6(1) (2022) 1-10.
- [9] A. Issa, S.A. Ibrahim, R. Tahergorabi, Impact of sweet potato starch-based nanocomposite films activated with thyme essential oil on the shelf-life of baby spinach leaves, *Foods* 6(6) (2017) 43.
- [10] S.A. Mohamed, M. El-Sakhawy, M.A.-M. El-Sakhawy, Polysaccharides, protein and lipid-based natural edible films in food packaging: A review, *Carbohydrate polymers* 238 (2020) 116178.
- [11] J.J. Jeevahan, M. Chandrasekaran, S. Venkatesan, V. Sriram, G.B. Joseph, G. Mageswaran, R. Durairaj, Scaling up difficulties and commercial aspects of edible films for food packaging: A review, *Trends in Food Science & Technology* 100 (2020) 210-222.
- [12] V. Falguera, J.P. Quintero, A. Jiménez, J.A. Muñoz, A. Ibarz, Edible films and coatings: Structures, active functions and trends in their use, *Trends in Food Science & Technology* 22(6) (2011) 292-303.
- [13] N. Ismillayli, H. Harmiati, S.S. Handayani, D. Hermanto, Effect of coating sliced pineapple (*Ananas comosus*) using carrageenan-chitosan edible film on vitamin C loss, *AIP Conference Proceedings*, AIP Publishing, 2023.
- [14] N. Azaraksh, A. Osman, H.M. Ghazali, C.P. Tan, N.M. Adzahan, Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple, *Postharvest Biology and Technology* 88 (2014) 1-7.
- [15] R.A. Shapi'i, S.H. Othman, N. Nordin, R.K. Basha, M.N. Naim, Antimicrobial properties of starch films incorporated with chitosan nanoparticles: In vitro and in vivo evaluation, *Carbohydrate polymers* 230 (2020) 115602.
- [16] G. Biratu, H.W. Woldemariam, G. Gonfa, Development of active edible films from coffee pulp pectin, propolis, and honey with improved mechanical, functional, antioxidant, and antimicrobial properties, *Carbohydrate Polymer Technologies and Applications* 8 (2024) 100557.
- [17] H.-m. Jiang, Z.-p. Yan, Y. Zhao, X. Hu, H.-z. Lian, Zinco-immobilized silica-coated magnetic Fe<sub>3</sub>O<sub>4</sub> nanoparticles for solid-phase extraction and determination of trace lead in natural and drinking waters by graphite furnace atomic absorption spectrometry, *Talanta* 94 (2012) 251-256.
- [18] Z. Zhang, J. Kong, Novel magnetic Fe<sub>3</sub>O<sub>4</sub>@ C nanoparticles as adsorbents for removal of organic dyes from aqueous solution, *Journal of hazardous materials* 193 (2011) 325-329.
- [19] Y.-P. Chang, C.-L. Ren, Q. Yang, Z.-Y. Zhang, L.-J. Dong, X.-G. Chen, D.-S. Xue, Preparation and characterization of hexadecyl functionalized magnetic silica nanoparticles and its application in Rhodamine 6G removal, *Applied Surface Science* 257(20) (2011) 8610-8616.
- [20] D. Mohan, A. Sarswat, V.K. Singh, M. Alexandre-Franco, C.U. Pittman Jr, Development of magnetic activated carbon from almond shells for trinitrophenol removal from water, *Chemical Engineering Journal* 172(2-3) (2011) 1111-1125.
- [21] S. Shewatek, G. Gonfa, S. Mekuria, B. Tessema, Response Surface Optimization of Lead Adsorption onto Teff Straw-Derived Activated Carbon, *Results in Surfaces and Interfaces* (2024) 100378.
- [22] J. Wang, S. Zheng, Y. Shao, J. Liu, Z. Xu, D. Zhu, Amino-functionalized Fe<sub>3</sub>O<sub>4</sub>@ SiO<sub>2</sub> core-shell magnetic nanomaterial as a novel adsorbent for aqueous heavy metals removal, *Journal of colloid and interface science* 349(1) (2010) 293-299.
- [23] A. Donia, A. Atia, F. Abouzayed, Preparation and characterization of nano-magnetic cellulose with fast kinetic properties towards the adsorption of some metal ions, *Chemical Engineering Journal* 191 (2012) 22-30.
- [24] V. Ranjithkumar, A.N. Hazeen, M. Thamilselvan, S. Vairam, Magnetic activated carbon-Fe<sub>3</sub>O<sub>4</sub> nanocomposites—synthesis and applications in the removal of acid yellow dye 17 from water, *Journal of nanoscience and nanotechnology* 14(7) (2014) 4949-4959.
- [25] Z. Akbari-Jonoush, S. Naseri, M. Farzadkia, H.-R. Mohajerani, M. Shirzad-Siboni, J.-K. Yang, Application of C14/SiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> and AC-Fe<sub>3</sub>O<sub>4</sub> nanocomposite for U (VI) removal, *Desalination and Water Treatment* 57(47) (2016) 22519-22532.
- [26] M. Kosmulski, The pH dependent surface charging and points of zero charge. IX. Update, *Advances in Colloid and Interface Science* 296 (2021) 102519.
- [27] R. Foroutan, S.J. Peighambaroust, R. Mohammadi, M. Omidvar, G.A. Sorial, B. Ramavandi, Influence of chitosan and magnetic iron nanoparticles on chromium adsorption behavior of natural clay: adaptive neuro-fuzzy inference modeling, *International journal of biological macromolecules* 151 (2020) 355-365.
- [28] Y. Li, T. Ran, H. Yang, Z. Dong, Y. Shi, Ir-reversible on/off switching hydrogel for efficient dye capture and release, *Journal of Environmental Chemical Engineering* 11(3) (2023) 109829.
- [29] J. Fito, M. Abewaa, T. Nkambule, Magnetite-impregnated biochar of parthenium hysterophorus for adsorption of Cr (VI) from tannery industrial wastewater, *Applied Water Science* 13(3) (2023) 78.
- [30] K. Brungesh, B. Nagabhushana, M. Harish, R. Hari Krishna, An efficient removal of toxic Cr (VI) from aqueous solution by MnO<sub>2</sub> coated polyaniline nanofibers: kinetic and thermodynamic study, *J. Environ. Anal. Toxicol* 7(2161) (2017) 2161-0525.1000442.
- [31] Z. Deng, S. Gu, H. Cheng, D. Xing, G. Twagirayezu, X. Wang, W. Ning, M. Mao, Removal of phosphate from aqueous solution by zeolite-biochar composite: adsorption performance and regulation mechanism, *Applied Sciences* 12(11) (2022) 5334.