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Edible Coating Formulated from Cocoa Pod Husk Pectin and Sungkai Leaf Extract to Extend Tomato Shelf Life

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A B S T R A C T

Tomato (*Solanum lycopersicum* L.) is a climacteric fruit that continues to ripen after harvest, leading to rapid spoilage and a short shelf life. This study investigated the use of cocoa pod husk pectin (*Theobroma cacao* L.) extracted via acid hydrolysis as a base material for edible coating, characterized by Fourier Transform Infrared (FTIR) spectroscopy. Various formulations were developed by combining cocoa pectin with sungkai leaf extract (*Peronema canescens* Jack) and compared to standard pectin (K, PC1–PC6). Physicochemical properties of tomatoes were analyzed over 15 days of storage (days 0, 3, 6, 9, 12, and 15), focusing on weight loss, decay rate, total soluble solids, titratable acidity, total antioxidant content, and total phenolic content. FTIR confirmed similar functional groups between cocoa pectin and standard pectin. Among the formulations, PC2 (pectin + aqueous sungkai extract) showed the best performance with 8.10% weight loss, 8.89% decay rate, 2.50° Brix, 0.36% titratable acidity, 0.65 mg AA/g FW antioxidant content, and 4.90 mg GAE/g FW phenolic content after 15 days at room temperature. Overall, cocoa pectin combined with sungkai leaf extract effectively maintained tomato quality and extended shelf life.

Contribution to Sustainable Development Goals (SDGs):
SDG 12: Responsible Consumption and Production
SDG 2: Zero Hunger

1. INTRODUCTION

1.1. Research Background

Tomato (*Solanum lycopersicum*), is a climacteric fruit that continue to ripen after harvest, during which carotenoid synthesis occurs due to the degradation of chlorophyll pigments [1]. Numerous postharvest preservation techniques have been developed to reduce losses and extend tomato shelf life, such as refrigeration and Modified Atmosphere Packaging (MAP). Nevertheless, these methods are often ineffective due to chilling injury and fermentation, especially in soft-textured fruits. One promising alternative is the application of edible coatings to prevent microbial growth and preserve fruit quality [2].

Edible coatings are thin, biodegradable layers applied to fruit or vegetable surfaces to minimize moisture loss while allowing selective gas permeability. These coatings can be applied through dipping, foaming, molding, or spraying techniques [3]. They serve as semi-permeable barriers that regulate moisture, oxygen, and lipid transfer, while also maintaining fruit appearance and extending shelf life. Starch-based biopolymers such as tapioca, corn starch, wheat starch, and pectin are commonly used in edible coating formulations [4].

Pectin is a complex polysaccharide rich in galacturonic acid, primarily located in plant cell walls. It is widely utilized in the food, pharmaceutical, and cosmetic industries due to its gelling and stabilizing properties [5]. The yield and composition of pectin are influenced by the plant source and extraction conditions, making the extraction process a critical step in pectin isolation. Notably, cacao pod husks are a promising pectin source, containing up to 16.27% pectin and 78.33% crude fiber, with strong gelling capabilities suitable for food applications [6].

Sungkai (*Peronema canescens*), a medicinal plant of the Verbenaceae family, is widely used in traditional Indonesian remedies for conditions such as fever, flu, ringworm, and dental pain. Its leaves are rich in bioactive compounds with antimicrobial and antioxidant properties, making them a potential additive for food preservation [7].

1.2. Literature Review

Food safety and quality standards are crucial in the food industry. However, the decline in fruit quality can have a significant negative impact on the entire food supply chain. It is estimated that almost 33% of the total food supply is lost due to spoilage. The worst impact is food waste, which has the potential to harm the environment, as it can become a place for pathogenic microorganisms to grow.

To obtain a more comprehensive understanding of the latest challenges and innovations in extending the shelf life of tomatoes, particularly through the use of edible coatings, it is necessary to review recent literature addressing food safety and quality, tomato storage stability, as well as physicochemical property evaluations [8].

1.2.1. Tomatoes Preservation

Tomatoes are a significant source of antioxidants, particularly lycopene, which is known to play a crucial role in mitigating the effects of free radicals implicated in carcinogenesis. Beyond lycopene, tomatoes also contain a diverse range of other antioxidants, including polyphenols, naringenin, and chlorogenic acid. Notably, tomatoes are characterized by low caloric and fat content, while being abundant in carotenoids, lutein, sugars, vitamin A, vitamin C, folate, and potassium [9].

When selecting fresh tomatoes, consumers and buyers primarily consider two key attributes: skin texture and color. However, the softening of tomatoes during storage, transportation, and ripening poses a significant challenge, given the fruit's high susceptibility to physical damage. Despite large-scale tomato production, inefficient post-harvest handling and storage practices frequently lead to rapid deterioration and substantial post-harvest losses [10].

1.2.2. Edible Coating

An edible coating is a thin layer composed of materials that are safe for human consumption. Several application techniques can be used to apply this coating to fruits and vegetables, including dipping, spraying, injection, and controlled droplet application. Among these methods, dipping is the most commonly employed, especially for vegetables, fruits, meat, and fish. In this technique, the product is submerged in a coating solution, enabling the formation of a uniform protective layer on the surface [11].

Edible coating functions as a barrier to moisture and gas exchange, while also contributing to sensory perception, mechanical properties, and microbial protection, thereby extending the shelf life of fruits. This coating exhibits selective permeability to oxygen (O_2), carbon dioxide (CO_2), and water vapor, which helps delay the natural physiological ripening process. Edible coatings are typically composed of biobased materials such as polysaccharides (e.g., starch, starch derivatives, cellulose, pectin, and alginate), proteins (e.g., gelatin, casein, gluten, wheat protein, zein, and soy protein), and lipids (including beeswax, acetylated monoglycerides, fats, alcohols, and fatty acids) [12].

Figure 1 Cacao pod husk and sungkai leaf as the base materials for edible coating

Cocoa pod husk is a by-product of the cocoa fruit. It accounts for approximately 52–76% of the fruit's fresh weight [13]. The high demand for cocoa beans in the chocolate industry has led to the accumulation of cocoa husks, contributing to environmental concerns due to waste disposal issues. Therefore, utilizing cocoa pod husks as a potential source of pectin offers a promising solution [14].

Pectin is a naturally occurring complex heteropolysaccharide, predominantly composed of D-galacturonic acid units. Commonly present in fruits and vegetables, pectin has gained extensive application in both the food and pharmaceutical industries owing to its versatile functional properties and potential for use across multiple fields [15]. Pectin can be obtained through extraction from cocoa pod husks, which are recognized as a rich source of antioxidant polyphenols. These polyphenols are mainly categorized as flavonoids, with catechin and epicatechin being the predominant compounds identified in the cocoa pod husk. Consequently, cocoa pod husks can be valorized into valuable products, including edible coatings [16].

Sungkai (*Peronema canescens* Jack), a plant native to Indonesia, is predominantly found across Kalimantan and Sumatra. It possesses significant antioxidant properties, primarily due to its rich content of secondary metabolites, which can be isolated through extraction techniques. The leaf extract of *P. canescens* is known to contain various phytochemical compounds such as alkaloids, phenolics, flavonoids, tannins, and saponins. These bioactive components make the plant a promising candidate for enhancing the functional attributes of edible coating formulations [17].

1.3. Research Objective

This study aimed to analyze the functional groups using Fourier Transform Infrared (FTIR) spectroscopy on pectin extracted from cocoa pod husk, standard pectin, aqueous extract of Sungkai leaves, 50% ethanol extract of Sungkai leaves, and the edible coating formulated from cocoa pod husk pectin and Sungkai leaf extracts. Additionally, the study sought to evaluate the physicochemical properties of tomatoes coated with the edible coating materials derived from pectin and Sungkai leaf extracts.

2. MATERIALS AND METHODS

2.1. Materials

The research was carried out in November 2024 in Padang, Indonesia. The materials used in this study included tomato (***Solanum lycopersicum***), cocoa pod husk (***Theobroma cacao***

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L.), sungkai leaves (***Peronema canescens***), standard pectin, hydrochloric acid 37% (Merck), oxalic acid (Merck), ethanol, sodium carbonate (Merck), phenolphthalein (Merck), 1,10-phenanthroline monohydrate chloride (Sigma), ferric chloride hexahydrate (Merck), Folin-Ciocalteu reagent (Sigma), ascorbic acid (Merck), gallic acid (Merck), carboxymethyl cellulose (CMC), glycerol, aluminum foil, filter paper, and distilled water.

2.2. Methods

2.2.1. Edible Coating Preparation

Pectin was extracted from dried cocoa pod husk by mixing 100 g of cocoa husk powder with 500 mL of 5% HCl, followed by heating and stirring at 75°C for 120 minutes. The resulting filtrate was combined with 250 mL of 96% ethanol and 2 mL of 37% HCl, then left to stand for 10–14 hours to allow pectin precipitation. The precipitate was separated by filtration and washed five times with 96% ethanol until the pH reached approximately 2,11. The pectin was then dried in an oven at 40°C for 8 hours to obtain dry, alcohol-free pectin powder [18,19].

Sungkai leaf powder (100 g) was extracted using two methods. For aqueous extraction, the powder was mixed with 500 mL of distilled water, heated in a water bath at 90°C for 30 minutes with continuous stirring, then allowed to stand and filtered using filter paper. For ethanolic extraction, 100 g of the powder was macerated in 500 mL of 50% ethanol for three days with occasional stirring, followed by filtration.

Edible coatings were prepared using cocoa pod husk pectin, sungkai leaf extract, standard pectin, CMC as an emulsifier and mechanical strength enhancer, and glycerol as a plasticizer, diluted with distilled water to 1000 mL. Coating formulation variations are shown in Table 1. Tomatoes were immersed in each formulation for 5 minutes, dried, and stored at room temperature. FTIR and physicochemical analyses were conducted on days 0, 3, 6, 9, 12, and 15.

Table 1. Composition of the edible coating in 1000 mL of solution for application on tomatoes

Code	Cocoa pod husk pectin (%)	Standard pectin (%)	Sungkai leaf water extract (%)	Ethanol extract of sungkai leaves (%)	CMC (%)	Glycerol (%)
K	0	0	0	0	0	0
PC1	0.75	0	0	0	1	2
PC2	0.75	0	20	0	1	2
PC3	0.75	0	0	10	1	2
PC4	0	0.75	0	0	1	2
PC5	0	0.75	20	0	1	2
PC6	0	0.75	0	10	1	2

2.2.2. Characterization by FTIR

After the coating materials—pectin from cocoa pod husks, aqueous extract of sungkai leaves, and ethanol extract of sungkai leaves—were prepared according to Table 1, they were subsequently analyzed using Fourier Transform Infrared (FTIR) spectroscopy to identify the functional groups.

2.2.3. Tomato Weight Loss

The tomatoes from each treatment were weighed using an analytical balance at the beginning of storage and subsequently at 3-day intervals (days 0, 3, 6, 9, 12, and 15). Tomato weight loss was calculated by determining the difference between the initial weight (W_0) and the weight at the time of measurement (Wt), divided by the initial weight (W_0), as described in Equation 1. This procedure was performed in triplicate, and the results were expressed as a percentage [20].

$$\text{Weight Loss (\%)} = \frac{Wo-Wt}{Wo} \times 100\% \qquad (1)$$

2.2.4. Determination of Fruit Decay

Fruit decay was assessed through visual observation of physical symptoms on the fruit surface and evaluated using a decay severity scale to determine the rate of spoilage [21].
0 = no signs of decay,
1 = 1–10% decay,
2 = 11–25% decay,
3 = 26–40% decay
4 = 40–50% decay,
5 = 50% decay.

$$\text{\% Decay} = 100 \times \frac{AB}{CD} \qquad (2)$$

Where:
A : total damage level value
B : number of samples at this level
C : number of samples at this level
D : number of samples at this level

2.2.5. Total Soluble Solids (TSS)

The total soluble solids (TSS) content was measured using a refractometer, with results expressed in percentage as degrees Brix (°Brix). The instrument was calibrated with distilled water and adjusted to read 0° Brix prior to each measurement. The tomato flesh samples were homogenized using a mortar and pestle, and a small portion of the sample was placed on the refractometer's glass prism for measurement [22].

2.2.6. Total Titratable Acidity (TTA)

Tomato samples weighing 25 g were blended with clean water and diluted to 100 mL in a volumetric flask, then filtered to obtain a clear extract. Sodium hydroxide (NaOH) solution was standardized by titrating against 0.05 N oxalic acid using phenolphthalein as the indicator. For the acidity determination, 2 mL of the tomato extract was titrated with standardized 0.01 N NaOH until a faint pink endpoint was reached, indicating the total titratable acidity. The total titratable acidity (TTA) was calculated using Equation 2 and reported as a percentage [23].

$$\text{TTA (\%)} = \frac{\text{N NaOH x V NaOH}}{fruit\ weight} \times 100\% \qquad (3)$$

2.2.7. Total Antioxidant Content

Determination of Antioxidant Activity Using the Modified Phenanthroline Method. Calibration curves were prepared using ascorbic acid standard solutions at concentrations of 0, 5, 10, 15, 20, and 25 mg/L. For each standard, 1 mL was pipetted into test tubes, followed by the addition of 2 mL distilled water, 1 mL of 0.1% ferric chloride ($FeCl_3$) solution, and 1 mL of 0.1% 1,10-phenanthroline solution. The mixtures were then incubated at room temperature for 20 minutes to allow the reaction to occur. Absorbance measurements were taken at 510 nm using a UV-Vis spectrophotometer to construct the calibration curve.

For the determination of total antioxidant content in the samples, 1 mL of each extract was mixed with 2 mL distilled water, 1 mL of 0.1% $FeCl_3 \cdot 6H_2O$, and 1 mL of 0.1% 1,10-orthophenanthroline. The solutions were incubated for 20 minutes at room temperature, after which the absorbance was measured at 510 nm to quantify antioxidant activity based on the calibration curve [24].

2.2.8. Total Phenolic Content

Assessment of Total Phenolic Content by the Folin-Ciocalteu Method. Calibration curves were prepared using gallic acid standards at concentrations of 0, 40, 80, 120, 160, and 200 mg/L. For each, 0.4 mL was mixed with 0.2 mL of Folin-Ciocalteu reagent and left to stand for 5 minutes, then 4 mL of 2% sodium carbonate (Na_2CO_3) was added. After shaking, the mixture was incubated for 90 minutes. Absorbance was measured at 750 nm using a UV-Vis spectrophotometer to generate the calibration curve.

Total phenolic content in the samples was determined by treating 0.4 mL of extract with 0.2 mL Folin-Ciocalteu reagent, followed by a 5-minute incubation, addition of 4 mL 2% Na_2CO_3, shaking, and a 90-minute incubation. Absorbance at 750 nm was then measured and compared to the calibration curve [25].

3. RESULT AND DISCUSSION

3.1. Characterization of Edible Coating Formulation

The resulting edible coating solutions made from cocoa pod husk pectin, standard pectin, aqueous sungkai leaf extract, and ethanolic sungkai leaf extract exhibited distinct color variations for each formulation, as shown in Figure 2.

Figure 2. Edible coating formulations

Description:

PC1	:	Cocoa pod husk pectin (CPHP) edible coating
PC2	:	CPHP and aqueous sungkai leaf extract edible coating
PC3	:	CPHP and ethanol sungkai leaf extract edible coating
PC4	:	Standard pectin (SP) edible coating
PC5	:	SP and aqueous sungkai leaf extract edible coating
PC6	:	SP and ethanol-sungkai leaf extract edible coating

Color differences in edible coating formulations (PC1–PC6) are influenced by the type of pectin and the extraction solvent used for sungkai (Peronema canescens) leaves. Cocoa pod husk pectin results in a more turbid solution due to residual phenolics and natural pigments, while commercial pectin is clearer due to purification [26]. Aqueous extracts produce lighter brown color from polar compounds like flavonoids and tannins, whereas ethanolic extracts yield darker tones due to non-polar compounds such as chlorophyll and alkaloids [27, 28]. The darkest appearance was observed in PC3, and the clearest in PC4. These color differences may also reflect variations in bioactive content like antioxidants and antibacterial compounds [29, 30]. CMC enhances coating properties by acting as a thickener and gas barrier, while glycerol serves as a [21].

3.2. Functional Groups of Edible Coating Materials

FTIR analysis was conducted in this study to identify the functional groups present in pectin and sungkai leaves. The FTIR spectra results are presented in Figure 3.

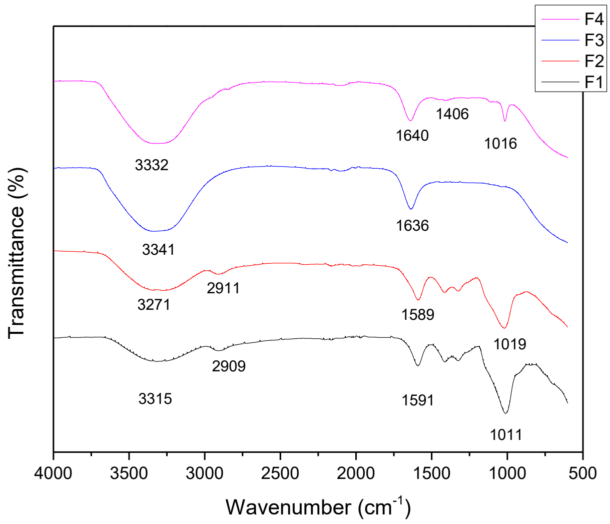

Figure 3. FTIR spectra of edible coating materials

Description:

F1	:	Cocoa pod husk pectin
F2	:	Standard pectin
F3	:	Aqueous sungkai leaf extract
F4	:	Ethanol sungkai leaf extract

Figure 3 shows the FTIR spectra of the edible coating materials. Similar spectral patterns across samples indicate similar functional groups. F1 exhibited O–H at 3315 cm^{-1}, $-CH_3$ at 2909 cm^{-1}, C=O at 1591 cm^{-1}, and ether (–O–) at 1011 cm^{-1}. F2 showed slight shifts but no new functional groups, indicating structural similarity [31].

F3 showed O–H at 3341 cm^{-1} and C=O at 1636 cm^{-1}, while ethanolic extract (F4) showed O–H at 3332 cm^{-1}, C=O at 1637 cm^{-1}, C=C at 1406 cm^{-1}, and primary alcohol at 1016 cm^{-1}. These peaks were also observed in coatings combining F1 with F3 or F4.

Overall, FTIR analysis showed that each material exhibited functional group characteristics consistent with its basic structure. Cocoa peel pectin and commercial pectin displayed similar absorption patterns, while sungkai leaf extract revealed the presence of bioactive compounds such as phenolics. These findings provide a fundamental basis for subsequent formulation of the edible coating [21].

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3.3. *Effect of Edible Coating Materials on the Physicochemical Properties of Tomatoes During Storage*

3.3.1. *Tomato Weight Loss*

This study used seven different edible coating formulations, each with a unique composition. The treatments included: control (K), cocoa pod husk pectin coating (PC1), cocoa pod husk pectin with aqueous sungkai leaf extract (PC2), cocoa pod husk pectin with ethanolic sungkai leaf extract (PC3), standard pectin coating (PC4), standard pectin with aqueous sungkai leaf extract (PC5), and ethanolic sungkai leaf extract coating (PC6). The tomato weight loss data for each treatment is shown in Figure 4.

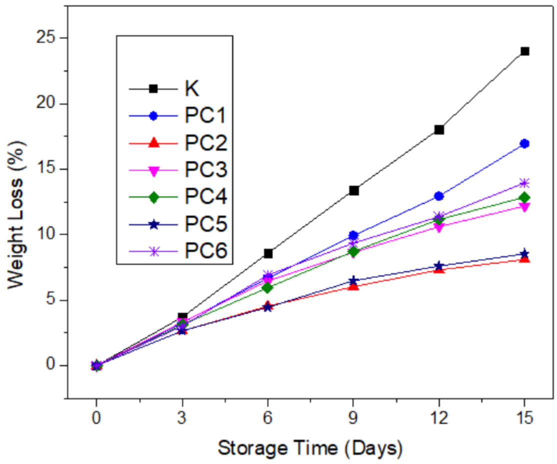

Figure 4. Effect of edible coating materials on tomato weight loss during the storage period

Based on the results obtained, tomatoes treated with edible coatings made from cocoa pod husk pectin combined with aqueous sungkai leaf extract (PC2) and standard pectin coating with aqueous sungkai leaf extract (PC5) exhibited the lowest weight loss, at 8.10% and 8.54%, respectively. In contrast, the control treatment (K) showed the highest weight loss of 24.04% on the 15th day of storage. These findings indicate that cocoa pod husk pectin supplemented with aqueous sungkai leaf extract effectively prolongs the shelf life of tomatoes. Furthermore, no significant difference in weight loss was observed between the use of cocoa pod husk pectin and standard pectin throughout the storage period.

Tomato weight loss during storage is caused by transpiration and respiration, leading to water and nutrient loss [32, 33]. Edible coatings slow this process by forming a partial barrier that reduces moisture and gas exchange, preserving fruit mass longer than uncoated tomatoes [34]. In this study, cocoa pod husk pectin combined with aqueous sungkai leaf extract effectively reduced weight loss due to bioactive compounds enhancing the coating's protective effect. Thus, natural edible coatings show promise for extending tomato shelf life and maintaining quality.

3.3.2. *Tomato Decay*

Tomato decay significantly increased over 15 days of storage, reaching its highest level at the end of the period. However, coatings made from cocoa pod husk pectin combined with sungkai leaf extract effectively maintained tomato quality and reduced decay rates. This study tested seven types of edible coatings with different compositions: control (K), cocoa pod husk pectin (PC1), cocoa pod husk pectin with aqueous sungkai leaf extract (PC2), cocoa pod husk pectin with ethanolic sungkai leaf extract (PC3), standard pectin (PC4), standard pectin with aqueous sungkai leaf extract (PC5), and standard pectin with ethanolic sungkai leaf extract (PC6). Decay percentage data are presented in the decay percentage diagram shown in Figure 5.

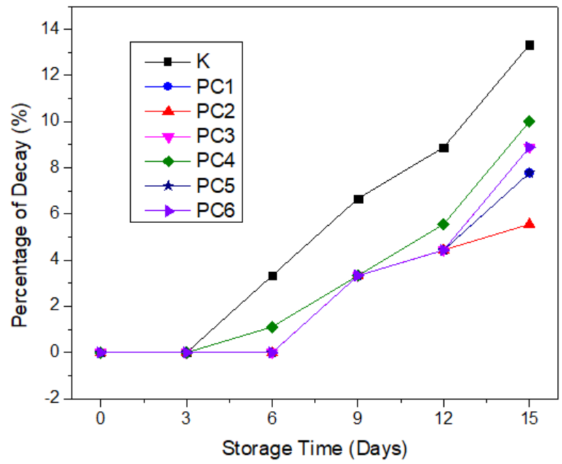

Figure 5: Effect of edible coating materials on tomato decay percentage during storage time

Figure 5 illustrates the effect of edible coating materials on the percentage of tomato decay during the storage period. The results indicate that decay increased over time in both coated and uncoated tomatoes. However, uncoated tomatoes exhibited a significantly faster decay rate compared to coated ones. Tomatoes treated with edible coatings demonstrated extended shelf life, maintaining red color despite signs of softening, wrinkling, and aroma changes. The cocoa pod husk pectin combined with aqueous sungkai leaf extract coating (PC2) showed the lowest decay rate at 5.56%, whereas the control treatment (K) reached 13.33% decay by day 15. These findings suggest that the addition of sungkai leaf extract to cocoa pod husk pectin enhances the effectiveness of edible coatings in reducing tomato decay.

Tomatoes are prone to spoilage due to rapid respiration and microbial activity during storage [32]. Cocoa pod husk pectin forms a breathable barrier that slows respiration and water loss [35]. Sungkai leaf extract contains bioactive compounds that inhibit spoilage microbes [36]. Combining these as an edible coating reduces respiration, weight loss, and delays decay in tomatoes, offering a natural, eco-friendly preservation method that also utilizes agricultural waste [37].

3.3.3. *Total Soluble Solids (TSS) of Tomatoes*

TSS are commonly used as indicators of maturity and quality in fruits and vegetables [38]. During storage, TSS values tend to decrease. This study tested six different edible coating formulations with varying compositions: control (K), cocoa pod husk pectin coating (PC1), cocoa pod husk pectin with aqueous sungkai leaf extract (PC2), cocoa pod husk pectin with ethanolic sungkai leaf extract (PC3), standard pectin coating (PC4), standard pectin with aqueous sungkai leaf extract (PC5), and standard pectin with ethanolic sungkai leaf extract (PC6). The graph showing the percentage of total soluble solids is presented in Figure 6. Figure 6 shows the effect of edible coating materials on the total soluble solids (TSS) of tomatoes during storage. All treatments showed a gradual decrease in TSS over time. The control (K) had the lowest TSS value at 0.400°Brix on day 15, while PC2 (cocoa pod husk pectin with aqueous sungkai extract) showed the highest at 2.500°Brix. This suggests that edible coatings help delay carbohydrate breakdown by forming a semi-permeable barrier that limits gas exchange, reduces respiration, and slows metabolic activity [38].

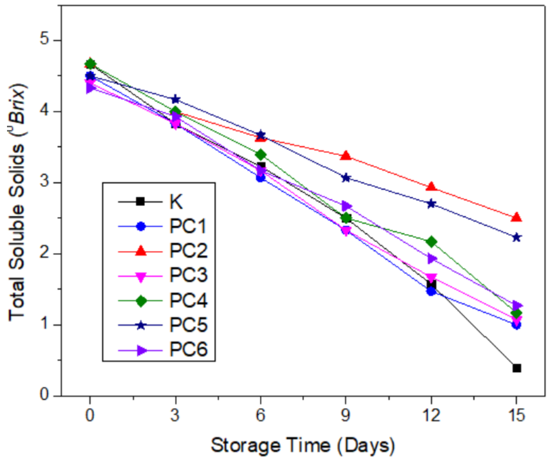

Figure 6. Effect of edible coating materials on total soluble solids of tomatoes during storage

TSS is a key indicator of sugar, organic acids, and other soluble compounds that affect fruit flavor and quality. Its decline during storage reflects natural ripening and metabolic degradation [32, 21]. The use of cocoa pod husk pectin, enriched with antimicrobial sungkai leaf extract, can inhibit microbial growth and preserve soluble compounds [35, 36]. Thus, tomatoes coated with this combination experienced a slower TSS reduction, indicating better retention of internal quality during storage.

3.3.4. *Total Titratable Acidity (TTA)*

TTA is a key indicator for assessing the acidity level and ripeness of tomatoes (*Solanum lycopersicum* L.). This acidity primarily results from the presence of organic acids, such as citric and malic acids, which contribute to the characteristic flavor of tomatoes. During storage, the acid content typically decreases due to metabolic activities, particularly respiration, and microbial degradation [32].

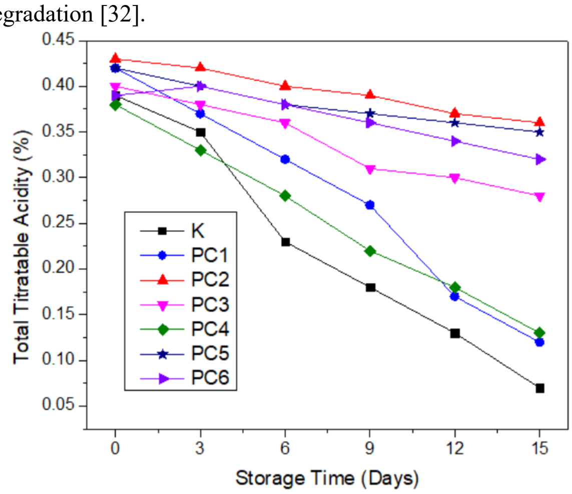

Figure 7. Effect of edible coating materials on total titratable acidity during storage time

This study employed six types of edible coatings with different compositions. The treatments included: control (K), cocoa peel pectin coating (PC1), cocoa peel pectin with aqueous sungkai leaf extract (PC2), cocoa peel pectin with ethanolic sungkai leaf extract (PC3), commercial pectin coating (PC4), commercial pectin with aqueous sungkai leaf extract (PC5), and commercial pectin with ethanolic sungkai leaf extract (PC6). A decline in TA values was observed across all fruit samples throughout the storage period, is presented in Figure 7.

Tomatoes treated with PC2 and PC5 retained significantly higher titratable acidity (TTA), reaching 0.36% and 0.35%, compared to the control (K), which dropped to 0.07% after 15 days of storage. This decline in the control was due to organic acid consumption driven by respiration and microbial activity.

TTA generally decreases during storage as key organic acids like citric and malic acid are metabolized [32]. Untreated tomatoes lose acidity more rapidly due to unprotected respiration and microbial degradation. Edible coatings made from cocoa pod husk pectin form a semi-permeable barrier, limiting gas exchange and moisture loss [35]. The addition of sungkai leaf extract, rich in antimicrobial compounds, further inhibits microbial activity [36]. Together, these natural materials help maintain acid levels, slowing TTA reduction and preserving fruit quality and freshness.

3.3.5. *Total Antioxidant Content of Tomatoes*

The antioxidant content, measured using the MPM method, showed a decreasing trend across all treatments during the storage period. Antioxidant levels were expressed as milligrams of ascorbic acid per gram of fresh weight (mg AA/g FW). Antioxidant content data are provided in the Appendix, with corresponding trends illustrated in Figure 8.

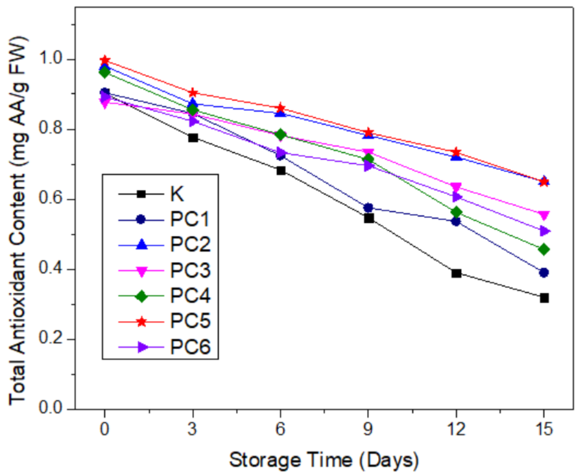

Figure 8: Effect of edible coating materials on the total antioxidants of tomatoes during storage time

This study involved six different edible coating formulations: control (K), cocoa pod husk pectin coating (PC1), cocoa pod husk pectin with aqueous sungkai leaf extract (PC2), cocoa pod husk pectin with ethanolic sungkai extract (PC3), standard pectin coating (PC4), standard pectin with aqueous sungkai extract (PC5), and standard pectin with ethanolic sungkai extract (PC6).

Figure 8 shows that tomatoes treated with PC2 and PC5 retained the highest total antioxidant content, reaching 0.65 mg AA/g FW on day 15 of storage. This is attributed to the combination of cocoa peel pectin and *Sungkai* (Peronema canescens) leaf extract, which provide synergistic effects in slowing antioxidant degradation. Pectin forms a semi-permeable

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barrier that reduces oxygen diffusion and respiration rate, while the *Sungkai* extract, rich in flavonoids and phenolic compounds, contributes to scavenging free radicals and stabilizing bioactive compounds in tomatoes [36].

Tomatoes naturally contain antioxidants such as vitamin C, lycopene, and phenolics, which are susceptible to degradation during storage due to oxidation, enzymatic activity, and microbial action [39]. The edible coating combining pectin and *Sungkai* extract effectively delayed this degradation, demonstrating its potential to maintain nutritional and functional quality. These findings support the use of natural edible coatings to extend shelf life and preserve the antioxidant content of fresh produce.

3.3.6. Total Phenolic Content of Tomatoes

The determination of total phenolic content in this study was conducted using the Folin–Ciocalteu method. Results showed a decline in phenolic content across all treatments during the storage period. The phenolic content was expressed in milligrams of gallic acid equivalents per gram of fresh weight (mg GAE/g FW). This decrease is likely due to oxidation and enzymatic degradation that occur over time during storage.

The study applied six types of edible coatings with varying compositions: control (K), cocoa peel pectin (PC1), cocoa peel pectin with aqueous Sungkai leaf extract (PC2), cocoa peel pectin with ethanolic Sungkai leaf extract (PC3), standard pectin (PC4), standard pectin with aqueous Sungkai extract (PC5), and standard pectin with ethanolic Sungkai extract (PC6). The percentage of total phenolic content for each treatment during storage is presented in Figure 9.

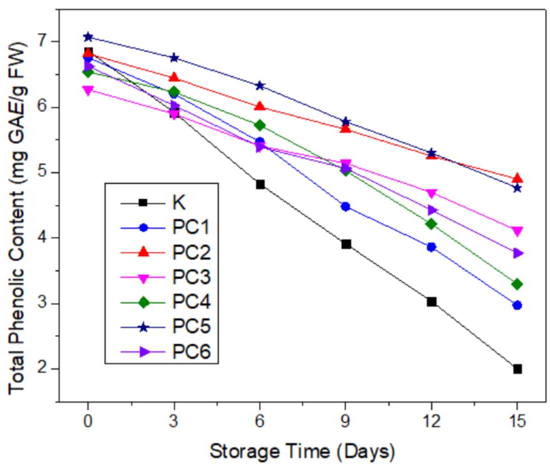

Figure 9. Effect of edible coating materials on total phenolic content of tomatoes during storage

Figure 9 shows that tomatoes coated with PC2 (cocoa peel pectin combined with *Sungkai* leaf extract) maintained the highest total phenolic content of 4.90 mg GAE/g FW on day 15 of storage. Higher phenolic levels enhance resistance to pathogens, indicating that this edible coating effectively preserves phenolic compounds during storage.

Total phenolics act as natural antioxidants that protect tomatoes from oxidative stress and microbial damage, but they typically decline during storage due to enzymatic oxidation and tissue degradation [40]. The cocoa peel pectin coating forms a barrier that limits oxygen and microbial contact, while the *Sungkai* extract contributes additional antioxidant and antimicrobial effects, helping to maintain phenolic stability [35, 36]. This combination effectively improves the nutritional quality and shelf life of tomatoes.

3.4. Optimal Functional Groups of Edible Coating

Physicochemical analysis revealed that the PC2 formulation yielded the most optimal results. FTIR analysis was then employed to identify functional group changes due to the incorporation of sungkai leaf extract into the pectin matrix.

In the PC1 sample (pectin + CMC + glycerol), characteristic peaks appeared at 3340 cm^{-1} (O–H), 2911 cm^{-1} (aliphatic –CH), 1601 cm^{-1} (C=O carboxyl), and 1018 cm^{-1} (C–O ether). In PC2 (pectin + sungkai extract + CMC + glycerol), notable shifts occurred: O–H to 3290 cm^{-1}, C=O to 1640 cm^{-1}, and C–O to 1050 cm^{-1}, indicating hydrogen bonding and possible complexation with bioactive compounds in sungkai. The FTIR spectral profiles of the edible coatings are illustrated in Figure 10.

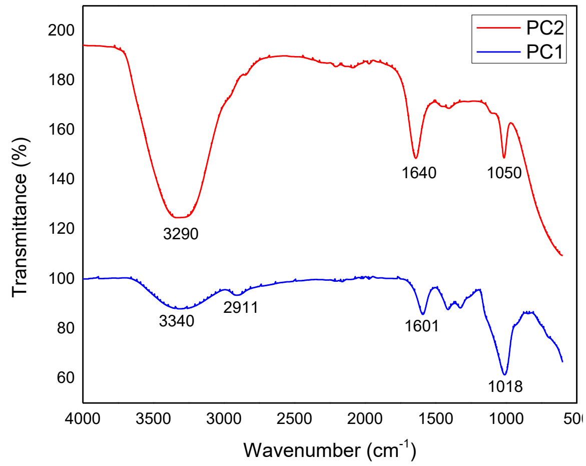

Figure 10 FTIR spectra of edible coating

Limited CMC and glycerol additions had minimal spectral impact, confirming that the observed shifts stem primarily from pectin–sungkai interactions. These interactions likely enhance the chemical stability and functional performance of the edible coating.

4. CONCLUSION

Based on the results of this study, it can be concluded that the edible coating formulated from pectin extracted from cocoa (*Theobroma cacao* L.) peel, with the addition of sungkai leaf extract (P. *canescens* Jack), significantly preserved the physicochemical quality of tomatoes during 15 days of storage. Tomatoes coated with various edible coating formulations exhibited better physicochemical stability compared to the uncoated control (K). Among the treatments, PC2 (pectin with sungkai leaf extract) showed the best performance, with weight loss of 8.10%, decay rate of 8.89%, total soluble solids of 2.50°Brix, titratable acidity of 0.36%, total antioxidant content of 0.65 mg AA/g FW, and total phenolic content of 4.90 mg GAE/g FW after 15 days. FTIR functional group analysis indicated no significant difference between cocoa peel pectin and standard pectin. However, the FTIR spectra of the PC2 sample showed notable shifts in absorption bands, suggesting that the addition of sungkai leaf extract alters the chemical structure of pectin, enhancing molecular interactions within the edible coating solution.

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