

Study on the Effectiveness of Cassava Starch-Based Edible Films Incorporating Senduduk Fruit and Tomato in Maintaining Galamai Quality

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Abstract: This study aimed to evaluate the effectiveness of cassava starch-based edible films enriched with Senduduk fruit extracts (*Melastoma malabathricum*) and tomato fruit extracts (*Solanum lycopersicum*) in preserving the quality of galamai during storage. Galamai is a traditional food product prone to oxidation and quality deterioration, necessitating packaging that can extend its shelf life. Edible films were selected as a biodegradable packaging alternative that functions not only as a barrier against oxygen and water vapor but also as a carrier for natural bioactive compounds capable of enhancing product stability. A Completely Randomized Design (CRD) was employed, utilizing various concentration combinations of the senduduk and tomato extracts. Observed parameters included the antioxidant activity and physical characteristics of the edible films, as well as the chemical and sensory quality of the galamai during storage. The results indicated that the incorporation of senduduk and tomato extracts into the edible films influenced antioxidant activity, film physical properties, and galamai quality stability. A balanced combination of senduduk and tomato extracts yielded the best results in preserving *galamai* quality during storage, evidenced by increased antioxidant activity, maintained physical film characteristics, and the inhibition of lipid oxidation in the product. Furthermore, *galamai* packaged with these edible films demonstrated superior sensory acceptance compared to other treatments. Overall, the combination of senduduk and tomato extracts in edible films shows potential as an effective active packaging solution to extend the shelf life of *galamai* by enhancing antioxidant stability and inhibiting oxidative degradation during storage.

Keywords: Antioxidant activity; Edible film; Galamai; *Melastoma malabathricum*; *Solanum lycopersicum*

Introduction

The use of plastic packaging in the food industry continues to rise due to its practicality, lightweight nature, and ability to protect products during distribution and storage. However, most plastic packaging is non-biodegradable, leading to serious environmental issues. Data from the National Waste Management Information System (SIPSN, 2024) indicates that waste generation in Indonesia reached 69.9 million tons in 2023, with plastic waste accounting

for approximately 18.71% of the total. A significant portion of this plastic waste originates from single-use food and beverage packaging. This situation highlights the need to develop packaging materials that are more environmentally friendly, safe, and sustainable in order to support an environmentally conscious food system.

One widely developed alternative is the edible film a thin, natural-based layer that can be consumed along with the food product. Edible films serve as a barrier against the transfer of oxygen, water vapor, and other compounds that can cause quality deterioration

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during storage; furthermore, they can be enriched with bioactive compounds, such as antioxidants, thereby functioning as active packaging that not only provides physical protection but also helps maintain food quality. Consequently, the development of natural-based edible films represents a promising strategy for reducing the use of conventional plastics while simultaneously extending the shelf life of food products.

Starch is a widely used biopolymer for edible films due to its film-forming ability, availability, relatively low cost, and biodegradability. It is composed primarily of amylose and amylopectin. Both components contribute to film network formation through intermolecular interactions, particularly hydrogen bonding (Perera et al., 2021). However, starch-based films generally suffer from relatively poor mechanical properties and water vapor resistance; consequently, the addition of other components is required to improve their characteristics. Thakur et al. (2019) explain that the characteristics of starch films are influenced by the starch type, film-forming conditions, plasticizers, additional biopolymers, and storage conditions.

Cassava starch (*Manihot esculenta* C.) is a promising material for use as an edible film matrix due to its abundant availability, relatively low production cost, and ability to form high-quality films. According to Ismaya et al. (2021), starch constitutes 20–40% of the wet weight, and the resulting films are flexible, transparent, and biodegradable (Dewi et al., 2023; Kawijia et al., 2017; Syarifuddin et al., 2019). Research by Saleh et al. (2017) also demonstrates that cassava starch is suitable for producing edible films for food packaging. Jiang et al. (2024) developed a smart packaging film based on *Manihot esculenta* starch combined with gum ghatti and blackcurrant extract. Their study indicates that a cassava starch matrix can be combined with plant-derived bioactive ingredients to create packaging materials that offer functionality beyond serving merely as a physical barrier.

One approach that can be adopted is the incorporation of plant extracts rich in natural antioxidant compounds. For instance, Bitencourt et al. (2014) developed a gelatin-based film enriched with turmeric ethanol extract and demonstrated that the addition of plant extract could impart antioxidant activity to the film. This concept supports the development of the edible film in the present study by incorporating plant extract as an active component, allowing the film to function not only as packaging but also to potentially protect food from oxidation.

Senduduk fruit is known to contain phenolic compounds, flavonoids, and saponins that have the potential to scavenge free radicals. Meanwhile, tomatoes are a source of lycopene, which is recognized for its effectiveness in inhibiting lipid oxidation. Natural

antioxidant compounds, such as extracts from senduduk fruit (*Melastoma malabathricum*) and tomatoes (*Solanum lycopersicum*), can be incorporated into the formulation. Senduduk fruit contains flavonoids, phenols, and saponins, exhibiting potent antioxidant activity with an IC₅₀ of 12.568 ppm (Diana, 2022). In contrast, tomatoes are rich in lycopene, a fat-soluble antioxidant with an IC₅₀ of 59.52 ppm (Shafe et al., 2024). Combining these two extracts offers the potential for a synergistic effect; as they contain distinct antioxidant components, the combination can enhance antioxidant activity and improve the functional characteristics of the edible film. Consequently, utilizing a combination of senduduk and tomato extracts is expected to yield an active edible film that is more effective than one produced using a single type of extract.

Research by Isnaini et al. (2019) also demonstrated that the ethanolic extract of *Melastoma malabathricum* fruit possesses antioxidant activity. These findings reinforce the premise that senduduk can serve as a source of natural antioxidants for application in food products or active packaging systems. Fadhli et al. (2020) also evaluated the antioxidant activity of the methanolic extract of (*Clidemia hirta*) fruit a species also belonging to the Melastomataceae family. Their results indicate that plants within the Melastomataceae family hold potential as sources of antioxidant compounds. Melianti (2018) specifically investigated the isolation of natural pigments specifically anthocyanins from senduduk fruit. The presence of these pigments is significant because anthocyanins not only offer coloring potential but also exhibit antioxidant activity. Consequently, incorporating senduduk extract into edible films offers the potential for dual functionality: serving as a source of active compounds while also influencing the film's color.

The potential of edible films enriched with natural antioxidants is increasingly significant for food products susceptible to oxidative deterioration during storage, such as galamai. Galamai is a traditional West Sumatran delicacy made from rice flour, palm sugar, and coconut milk. Its high fat content derived from the coconut milk and high sugar levels make the product prone to lipid oxidation, which can compromise quality; this deterioration manifests as rancidity, textural changes, and a decline in sensory attributes. Consequently, there is a need for a packaging system that not only protects the product from environmental factors but also helps maintain quality stability throughout storage.

Previous studies have reported on the use of starch-based edible films and the incorporation of plant extracts as active ingredients in food packaging. Rusli et al. (2024) reported that using an edible film based on sea grape extract reduced the water vapor transmission rate

and extended the shelf life of dodol during storage. Research by Jiang et al. (2024) demonstrated the development of a *Manihot esculenta* (cassava) starch-based film containing bioactive compounds for smart packaging applications with beef. This indicates that cassava starch is not only a potential film-forming material but can also serve as a matrix for active or smart packaging systems. However, research regarding the use of a combination of senduduk fruit and tomato extracts in cassava starch-based edible films to preserve the quality of galamai during storage remains very limited. Furthermore, information concerning the effect of this extract combination on antioxidant activity, the physical characteristics of the edible film, and the quality stability of galamai has not been widely reported. Therefore, this study offers novelty through the use of a combination of senduduk fruit and tomato extracts as natural antioxidant sources in cassava starch-based edible films, as well as the evaluation of their effectiveness in maintaining galamai quality during storage.

Based on the foregoing, this study aims to evaluate the effectiveness of cassava starch-based edible films enriched with senduduk and tomato fruit extracts regarding antioxidant activity, physical film characteristics, and the chemical and sensory quality stability of galamai during storage. The research findings are expected to provide an eco-friendly active packaging alternative, support the utilization of local resources, and contribute to the development of sustainable food packaging technology.

Method

Research Location and Schedule

This research was conducted at the FATETA Central Instrumentation Laboratory, the Agricultural Product Biochemistry and Food Nutrition Laboratory, the Total Quality Control Laboratory, and the Agricultural Product Microbiology and Biotechnology Laboratory (Department of Agricultural Product Technology, Faculty of Agricultural Technology), as well as the Andalas University Central Laboratory in Padang, from December to February 2025.

Research Plan

The research plan is illustrated in the flowchart in Figure 1. This study employed an experimental method using a Completely Randomized Design (CRD) consisting of six treatments and three replications, resulting in 18 experimental units. The treatments involved combinations of *senduduk* fruit extract and tomato fruit extract within a cassava starch-based edible film formulation, as presented in Table 1.

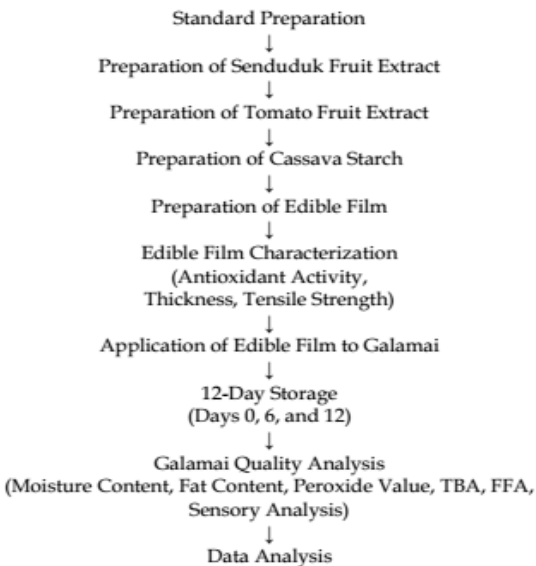


Figure 1. Research design flowchart

Table 1. Formulation of Cassava Starch-Based Edible Films

Treatment	Senduduk Extract (%)	Tomato Extract (%)
P0	0	0
P1	5	0
P2	5	3
P3	5	5
P4	3	5
P5	0	5

Materials and Equipment

The biological materials used included senduduk fruit (*Melastoma malabathricum*), tomato fruit (*Solanum lycopersicum*), cassava tubers, and galamai. The chemical reagents used consisted of 96% ethanol, citric acid, glycerol, DPPH (1,1-diphenyl-2-picrylhydrazyl), hexane, chloroform, potassium iodide (KI), sodium thiosulfate (Na2S2O3), sodium hydroxide (NaOH), hydrochloric acid (HCl), thiobarbituric acid (TBA), phenolphthalein indicator, diethyl ether, and distilled water.

The equipment used includes a blender, analytical balance, oven, magnetic hot plate stirrer, Petri dish, desiccator, UV-Vis spectrophotometer, Universal Testing Machine (UTM), digital micrometer, Soxhlet apparatus, pH meter, and various laboratory glassware.

Production of Raw Materials

The raw materials used in this study are senduduk fruit and tomatoes, as shown in Figures 2 and 3.

Production of Senduduk Fruit Extract

The preparation of senpadu fruit extract refers to the method of Mutia et al. (2023). Ripe sundul fruit is sorted, washed, then crushed using a blender. The fruit pulp obtained is filtered using a filter cloth to separate

the dregs and filtrate. The resulting filtrate is then purified using a rotary vacuum evaporator to obtain a thick extract which is used as natural fruit extract for edible film formulations.



Figure 2. Senduduk fruit



Figure 3. Tomato fruit

Preparation of Tomato Fruit Extract

The preparation of tomato fruit extract followed the method of Mutia et al. (2023). Ripe tomatoes were sorted and washed, then blended. The resulting mixture was filtered to obtain the filtrate, which served as the tomato extract for the edible film formulation.

Cassava Starch Production

Cassava starch preparation followed the method of Dewi et al. (2023), with modifications involving the

addition of senduduk fruit extract and tomato extract. Cassava starch was used at a concentration of 4% (v/v), while glycerol was added at 1.75% (v/v) as a plasticizer. These concentrations were selected based on the study by Dewi et al. (2023), which yielded edible films with optimal mechanical characteristics and stability. The cassava starch was mixed with distilled water and heated on a magnetic stirrer hot plate while stirring until the gelatinization temperature of 64–70°C was reached. This gelatinization temperature is necessary to disrupt starch granules, thereby forming a homogeneous polymer matrix capable of producing a film with good mechanical properties. Once the solution was homogeneous, glycerol was added, and the mixture was stirred thoroughly. The solution was then cooled to 40°C to minimize the degradation of bioactive compounds caused by heat. The senduduk fruit extract and tomato extract were pre-mixed to homogeneity according to the treatment ratio and then added to the film-forming solution; a spatula was used during this process to eliminate air bubbles. Drying was carried out in an oven at 60°C for 24 hours. The resulting films were then conditioned in a desiccator for 2–3 days prior to analysis and application on galamai.

Application of Edible Film on Galamai

The formed edible film was removed from the Petri dish and used to wrap the galamai. Each galamai sample was evenly wrapped with the edible film according to the specific treatment until the entire product surface was covered. The coated galamai was then stored at room temperature for 12 days. Observations were conducted on days 0, 6, and 12 to evaluate changes in product quality during storage.

Observation Parameters

The parameters observed included the characteristics of the edible film and the quality of galamai during storage.

Table 2. Parameters and Analytical Methods

Parameter	Method	Reference
Antioxidant activity	DPPH	Tristantini et al. (2016)
Tensile strength	Universal Testing Machine	Qotimah et al. (2020)
Film strength	Digital micrometer	Warkoyo et al. (2014)
Moisture content	Oven method	AOAC (1995)
Fat content	Soxhlet	Sudarmadji et al. (2007)
Peroxide value	Titrimetry	AOAC (1995)
TBA value	Spectrophotometry	Sudarmadji et al. (1997)
Free Fatty Acids (FFA)	Titrimetry	Sudarmadji et al. (1997)
Sensory evaluation	Hedonic test	Setyaningsih et al. (2010)

Data Analysis

The data were analyzed using Analysis of Variance (ANOVA) with the aid of SPSS software (version 23). If

the analysis indicated a significant effect ($p < 0.05$), Duncan’s Multiple Range Test (DMRT) was performed at the 95% confidence level to determine differences

between treatments. Data regarding antioxidant activity and sensory evaluation are presented descriptively in the form of tables and graphs.

Result and Discussion

Antioxidant Activity of Edible Films

Antioxidant activity is a key parameter for evaluating the potential of edible films as active packaging, as it relates to their ability to inhibit oxidation reactions in food products during storage. The results of antioxidant activity tests on cassava starch-based edible films incorporated with Senduduk fruit and tomato extracts are presented in Figure 4.

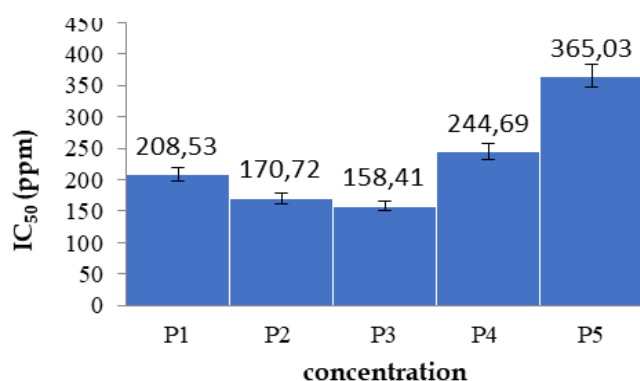


Figure 4. Antioxidant activity of edible films

Based on the analysis of variance (ANOVA) results, the addition of fruit extracts had a significant effect ($p < 0.05$) on the antioxidant activity of the edible films. In general, films containing a combination of senduduk and tomato extracts exhibited higher antioxidant activity than the control film, indicating that the incorporation of bioactive compounds from both extracts enhanced the film's free-radical scavenging capacity.

The observed increase in antioxidant activity is closely linked to the phenolic and carotenoid compounds present in both extracts. Agustikawati et al. (2017) demonstrated that phytochemical screening can identify groups of bioactive compounds potentially contributing to antioxidant activity. Senduduk fruit is known to contain anthocyanins, flavonoids, tannins, quercetin, and kaempferol, as well as various phenolic compounds that act as hydrogen atom or electron donors, thereby stabilizing free radicals and terminating oxidative chain reactions (Isnaini et al., 2019; Susanti et al., 2013). The incorporation of extracts containing phenolic compounds and flavonoids enhances the film's free-radical scavenging capacity. Isnaini et al. (2019) reported that senduduk fruit extract contains quercetin and kaempferol at levels of 67.78 $\mu\text{g/g}$ and 43.52 $\mu\text{g/g}$, respectively, with corresponding antioxidant activities

(expressed as IC₅₀ values) of 16.82 ± 0.24 ppm and 7.38 ± 0.41 ppm.

On the other hand, tomato extract is a source of lycopene, β -carotene, and vitamin C, which operate through distinct mechanisms. Lycopene acts as an antioxidant that effectively inactivates singlet oxygen and peroxy radicals in the lipid phase, whereas vitamin C functions as a hydrophilic antioxidant, protecting the aqueous phase while also helping to regenerate oxidized phenolic compounds. These differing mechanisms of action mean that combining the two extracts provides broader antioxidant protection than using either extract alone.

Tomato fruit (*Solanum lycopersicum*) contains bioactive phenolic compounds that potentially exhibit antioxidant activity. Fuentes et al. (2013) reported that the total phenolic content in ripe tomatoes is distributed across the skin, pulp, and seeds, with levels of 36.9 ± 0.8 , 33.3 ± 0.5 , and 17.6 ± 0.9 mg GAE/100 g, respectively. The presence of these phenolic compounds contributes to the antioxidant activity of tomato extracts. Consequently, tomato fruit extract has the potential to serve as a source of antioxidants in edible films, providing protection for food products against oxidative deterioration.

In addition to being influenced by the content of bioactive compounds, the increase in antioxidant activity is also linked to interactions between the extract's active components and the cassava starch matrix. Hydroxyl groups found in flavonoids, tannins, and anthocyanins can form hydrogen bonds with amylose and amylopectin chains, resulting in a more uniform distribution of antioxidant compounds within the film structure. These interactions help maintain the stability of the bioactive compounds during film formation and reduce degradation caused by the drying process. Thus, the starch matrix serves not only as a film-forming agent but also as a carrier medium capable of preserving antioxidant activity during storage.

The results of this study indicate a synergistic effect between senduduk fruit extract and tomato extract. The combination of phenolic compounds predominant in the senduduk extract and carotenoid compounds predominant in the tomato extract provides oxidative protection across two distinct phases: the aqueous phase and the lipid phase. This synergism enables the more effective neutralization of free radicals generated during oxidation, thereby enhancing the film's antioxidant capacity. Similar phenomena have been reported in various starch-based edible films enriched with plant extracts, where combining multiple antioxidant sources yields higher free-radical scavenging activity compared to using a single type of extract.

These research findings align with the report by Fadhlil et al. (2020), which states that senduduk fruit

exhibits high antioxidant activity due to its anthocyanin and flavonoid content. Similarly, Mu'nisa (2012) reported that lycopene in tomatoes effectively inhibits lipid oxidation through a singlet oxygen-neutralizing mechanism. More recent studies also indicate that incorporating plant extracts into starch-based edible films enhances antioxidant activity and improves active packaging functionality by increasing oxidative stability and protecting against lipid degradation during storage; therefore, a combination of senduduk fruit and tomato extracts has the potential to serve as a natural antioxidant source in edible films, extending the shelf life of galamai by inhibiting oxidation processes.

Tensile Strength of Edible Film

Tensile strength is a mechanical parameter that determines an edible film's ability to maintain its integrity during handling, storage, and application as packaging material. The tensile strength value reflects the film's capacity to withstand tensile force before failing or breaking. The results of tensile strength testing for edible films based on cassava starch enriched with senduduk fruit and tomato extracts are presented in Figure 5. Analysis of variance (ANOVA) results indicate that the addition of the extracts had a significant effect ($p < 0.05$) on the film's tensile strength. In general, the addition of senduduk fruit extract increased tensile strength compared to the control film, whereas increasing the proportion of tomato extract tended to reduce the film's mechanical properties.

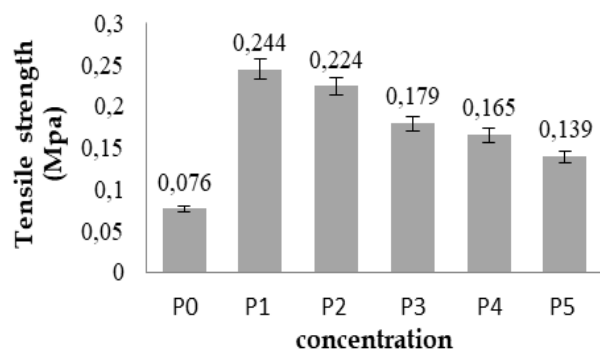


Figure 5. Tensile strength values of edible films

The increase in tensile strength observed in films containing senduduk extract indicates that the bioactive compounds present contribute to the formation of a more compact film structure. Senduduk fruit is rich in flavonoids, tannins, and phenolic compounds, all of which possess numerous hydroxyl (-OH) groups. These groups are capable of forming hydrogen bonds with the amylose and amylopectin molecules in the cassava starch, thereby enhancing inter-chain polymer cohesion. Stronger hydrogen bonding results in a denser film network, increasing tensile strength and reducing the

likelihood of cracking under mechanical load. This phenomenon demonstrates that phenolic compounds function not only as antioxidants but also as natural reinforcing agents within the biopolymer matrix.

Conversely, increasing the concentration of tomato extract tends to reduce tensile strength. This phenomenon is likely attributed to the relatively high content of pectin, simple sugars, organic acids, and moisture in the tomato extract. These components can enhance polymer chain mobility thereby increasing the flexibility of the film matrix while simultaneously weakening intermolecular bonding. Consequently, the film becomes more prone to deformation under tensile stress. Thus, although tomato extract contributes to functional properties through its antioxidant content, excessive concentrations can compromise the film's mechanical strength. Rusli et al. (2024) also reported findings indicating that the use of hydrocolloids influences the tensile strength of the resulting edible films.

The results of this study indicate that the compositional balance between senduduk and tomato extracts is a crucial factor in producing edible films with optimal mechanical characteristics. The combination of extracts yielded superior mechanical properties compared to the control film; however, an excessive proportion of tomato extract resulted in a plasticizing effect that outweighed the structural reinforcement effect. This suggests that the interaction between phenolic compounds from senduduk and cassava starch is stronger than the interaction involving bioactive compounds derived from tomatoes.

These research findings align with the study by Huri et al. (2014), which reported that phenolic compounds can enhance the tensile strength of starch-based films through the formation of hydrogen bonds with the polymer matrix. Fahrullah et al. (2023) also reported that the type of plasticizer used can influence the physical characteristics including mechanical properties of edible films based on whey and chia seeds. The addition of certain components can increase polymer chain mobility, making the film more flexible and altering its tensile strength. Furthermore, Hamsina et al. (2024) demonstrated that modifying the composition of cassava peel starch through the addition of chitosan and seaweed can affect the characteristics of the resulting edible films. Thus, the observed changes in tensile strength in this study are likely attributable to interactions among the starch, plasticizer, and active compounds incorporated into the edible film matrix.

Plasticizers increase polymer chain mobility, thereby making the film more flexible; however, excessively high concentrations can lead to a reduction in mechanical strength (Al-Hassan et al., 2012; Suderman et al., 2018). Ballesteros-Martinez et al. (2020)

also demonstrated that glycerol and sorbitol concentrations influence the mechanical properties of starch films. Therefore, the changes in mechanical properties observed in this study likely result from interactions among the cassava starch, plasticizer, and bioactive components of the senduduk extract.

Thickness

Thickness is a physical characteristic that determines the quality of edible films, as it influences mechanical properties, water vapor permeability, transparency, and the film's ability to protect food products. The thickness values of cassava starch-based edible films enriched with senduduk fruit and tomato extracts are presented in Figure 6.

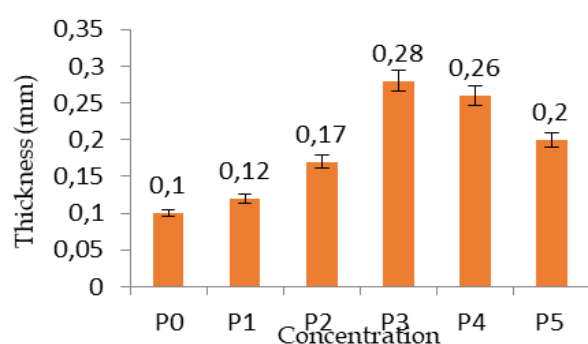


Figure 6. Thickness of edible film

Analysis of variance (ANOVA) results indicate that the addition of the extract had a significant effect ($p < 0.05$) on film thickness. In general, increasing the extract concentration resulted in greater film thickness compared to the control treatment, although the magnitude of the increase varied across formulations. This increase in film thickness is associated with the higher total solids content in the film-forming solution.

Edible film thickness is influenced by the composition and concentration of film-forming materials. Ulyarti et al. (Ulyarti et al., 2018) demonstrated that increasing starch concentration can increase film thickness, as a greater amount of solids forms the matrix during the drying process. These findings align with those of Hamsina et al. (2024) and Julyaningsih et al. (2025), which showed that modifying the matrix composition with additives can also alter film thickness. In this study, the change in thickness following the addition of senduduk extract is attributed to the increase in total solids within the film-forming solution and the interaction between the extract components and the starch matrix.

Senduduk and tomato fruit extracts contain not only bioactive compounds but also various solid components such as phenolic compounds, pectin, soluble fiber, sugars, and organic acids that remain

within the matrix during the drying process. The increase in total solids raises the solution's viscosity, resulting in a greater amount of material remaining after water evaporation and producing a thicker film. This phenomenon is commonly observed in starch-based edible films enriched with plant extracts.

The contribution of each extract to film structure formation differs. Tomato extract is known to contain natural pectin, which acts as a gel-forming polysaccharide, thereby enhancing the compactness and volume of the film matrix. In contrast, senduduk fruit extract primarily contributes phenolic compounds specifically flavonoids, tannins, and anthocyanins that interact with starch chains via hydrogen bonding. Although these phenolic compounds strengthen the film structure, their impact on increasing thickness is relatively minor compared to that of pectin. Consequently, formulations with a higher proportion of tomato tend to yield films of greater thickness.

Rusli et al. (2024) also reported findings indicating that the use of hydrocolloids influences the thickness of the resulting edible films. Beyond the influence of solids content, the increase in thickness is also linked to changes in the film's microstructure. Bioactive compounds can fill the spaces between polymer chains, thereby forming a denser network during the drying process. Interactions among amylose, amylopectin, pectin, and phenolic compounds result in a more stable three dimensional structure. However, the increase in thickness is not necessarily accompanied by improved mechanical properties. Excessively thick films may exhibit uneven stress distribution, making them more susceptible to deformation or cracking if the internal structure lacks sufficient strength. Therefore, thickness must be considered alongside other mechanical parameters, particularly tensile strength and elongation.

These research findings align with the report by Martinez et al. (2018), which states that increasing the pectin content in starch-based film formulations increases thickness due to the rise in the solution's total solids. Research by Van Puyvelde et al. (2020) also demonstrates that adding plant extracts rich in phenolic compounds increases film thickness through the formation of a denser polymer network. Similarly, Wahyuni et al. (2021) reported that increasing the concentration of tomato extract in starch-based films resulted in thicker layers, attributed to pectin's contribution to matrix formation. However, excessive thickness does not always yield optimal performance, as it can affect the film's flexibility and mechanical properties. Research by Amini (2023) further indicates that variations in starch and carrageenan composition, as well as sorbitol concentration, can influence the physical characteristics of edible films, including thickness. The greater the amount of solids dispersed in

the solution and the more material formed after the drying process, the thicker the resulting edible film layer tends to be.

The increase in thickness observed in this study indicates that the combination of senduduk fruit and tomato extracts modifies the cassava starch matrix structure through complementary mechanisms. Phenolic compounds from senduduk strengthen inter-polymer chain interactions, while pectin from tomato enhances gel network formation; the combination of these mechanisms yields an edible film with a more stable structure, potentially offering superior protection for galamai products during storage.

Water Content

Moisture content is a key parameter for evaluating the quality of galamai during storage, as it influences the product's texture, physical stability, and shelf life. The moisture content measurements for the coated galamai are presented in Figure 7.

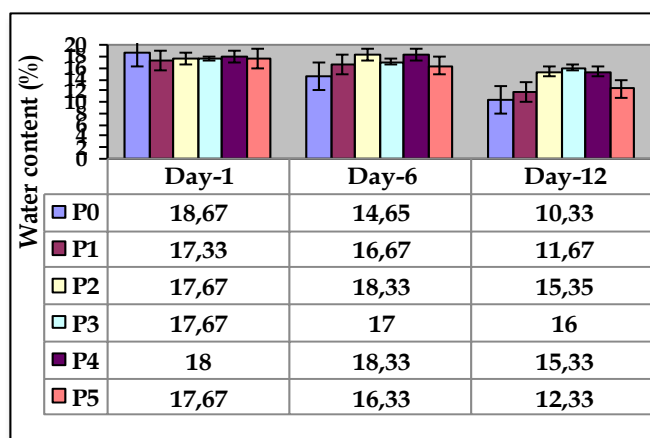


Figure 7. Value of galamai water level

Analysis of variance (ANOVA) results indicate that the treatments had a significant effect ($p < 0.05$) on the moisture content of galamai during storage. In general, the moisture content across all treatments decreased as storage time progressed; however, the rate of decrease varied depending on the edible film formulation used.

A decrease in moisture content is a common phenomenon in semi-moist food products, resulting from the migration of water vapor from the product's interior to an environment with lower relative humidity. Due to its high sugar and fat content, galamai continues to undergo slow water diffusion through its surface during storage. In samples without a film coating, water vapor transfer occurs more rapidly because there is no barrier to reduce the diffusion rate. Conversely, the use of an edible film creates a protective layer that slows down water loss, thereby better preserving the product's moisture content during storage.

The ability of the edible film to retain moisture is influenced by the starch matrix structure and the presence of bioactive compounds from senduduk fruit and tomato extracts. Phenolic compounds in senduduk fruit such as flavonoids, tannins, and anthocyanins possess hydroxyl groups capable of forming hydrogen bonds with both starch and water molecules, thereby enhancing the compactness of the film network. Meanwhile, tomato extract contains pectin, which facilitates gel structure formation and reduces the spacing between polymer chains. The combination of these two extracts results in a denser film matrix, leading to reduced water vapor permeability. This denser structure slows the rate of water diffusion from the galamai to the surrounding environment compared to the control treatment.

In addition to serving as a physical barrier, the bioactive compounds within the film contribute to maintaining the product's structural stability during storage. Films with a denser polymer network are capable of retaining internal moisture, thereby minimizing textural changes caused by water loss. This is particularly crucial for galamai, a semi-moist product whose characteristics are heavily influenced by moisture content. Excessive water loss leads to a hard, less elastic texture and reduces consumer acceptance; conversely, excessively high moisture content is undesirable as it promotes microbial activity and accelerates product spoilage.

The results of this study indicate that a formulation combining Senduduk fruit extract and tomato extract is more effective at retaining moisture than using either extract alone or no extract at all. This suggests a synergistic effect between phenolic compounds and pectin in improving the film's water vapor barrier properties. This effect stems not only from increased film thickness but also from the formation of a more homogeneous polymer network, which lengthens the water vapor diffusion path and makes it more difficult to penetrate. Thus, the film's ability to retain product moisture is determined not solely by thickness, but also by its microstructure and the interactions between its constituent components.

These findings align with the research of Bitencourt et al. (2014), which also demonstrated that the addition of bioactive compounds to edible films enhances their ability to inhibit water loss through the formation of stronger hydrogen bonds within the polymer matrix. Similar results were reported by Murtius et al. (2016) regarding starch-based edible films derived from Zingiberaceae; these films were able to better maintain the moisture content of galamai during storage compared to uncoated products.

Overall, the results of this study indicate that a combination of senduduk fruit and tomato extracts

enhances the effectiveness of the edible film as a barrier against water vapor transmission. This capability contributes to moisture retention, the preservation of textural characteristics, and the extension of galamai is shelf life during storage.

Fat Content

Fat content is a key parameter for evaluating the quality stability of galamai during storage, as it directly influences flavor, texture, and the product's resistance to oxidation. Since the fat in galamai is derived from coconut milk, the product is susceptible to degradation via hydrolysis and oxidation during storage.

The results of fat content measurements for galamai coated with cassava starch-based films enriched with senduduk fruit and tomato extracts are presented in Figure 8. Analysis of variance (ANOVA) indicated that the treatments had a significant effect ($p < 0.05$) on fat content during storage.

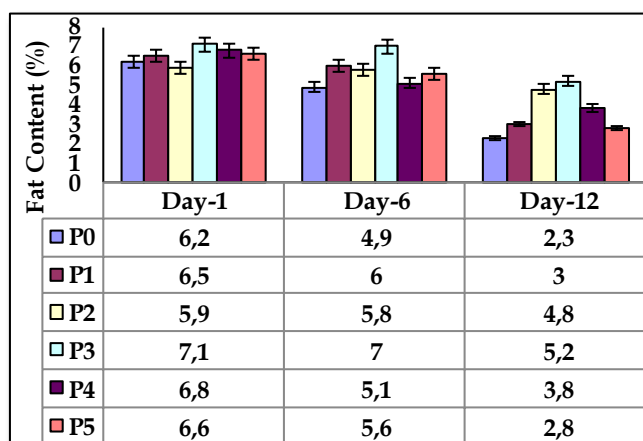


Figure 8. Fat content of galamai

The reduction in fat content during storage is a consequence of progressive lipid oxidation reactions. In the initial stage, unsaturated fatty acids react with oxygen to form hydroperoxides as primary oxidation products. Subsequently, these hydroperoxides decompose into various secondary compounds such as aldehydes, ketones, and organic acids leading to a decrease in fat content and a decline in the product's sensory quality. This process occurs more rapidly in uncoated samples because the galamai surface is directly exposed to oxygen and light, allowing oxidation reactions to proceed without adequate protection.

Edible films enriched with senduduk fruit and tomato extracts can retard the loss of fat content through two primary mechanisms: acting as a physical barrier against oxygen diffusion and serving as an active barrier through antioxidant activity. The cassava starch matrix forms a protective layer that minimizes direct contact between the galamai surface and the environment.

Meanwhile, senduduk fruit extract contributes phenolic compounds such as flavonoids, anthocyanins, and tannins that act as hydrogen atom donors to stabilize free radicals. Concurrently, tomato extract provides lycopene, β -carotene, and vitamin C, which effectively inhibit the formation of peroxy radicals within the lipid phase. The combination of these two extracts offers broader oxidative protection by acting simultaneously in both the aqueous and lipid phases.

Treatments utilizing a combination of extracts demonstrated a superior ability to preserve fat content compared to treatments using a single extract. This indicates a synergistic effect between the phenolic compounds from senduduk fruit and the carotenoids from tomatoes in inhibiting lipid oxidation. Flavonoids function by terminating chain reactions through a free-radical scavenging mechanism, whereas lycopene effectively inactivates singlet oxygen, a primary trigger of fat oxidation. Furthermore, the presence of vitamin C helps regenerate oxidized phenolic antioxidants, thereby sustaining antioxidant activity throughout storage; this synergism results in a slower rate of fat degradation compared to the control treatment.

Beyond antioxidant activity, the film's ability to preserve fat content is also linked to its oxygen barrier properties. Films with a denser matrix structure extend the diffusion path for oxygen reaching the product surface, thereby reducing the rate of lipid oxidation. Thus, protection of fat content is determined not only by the composition of bioactive compounds but also by the physical characteristics of the resulting film. This demonstrates that mechanical properties, thickness, and antioxidant activity collectively contribute to the effectiveness of edible films as active packaging.

These findings align with various studies reporting that incorporating plant extracts rich in phenolic compounds into edible films enhances the oxidative stability of food products during storage. Kouser et al. (2023) demonstrated that edible films containing plant-based bioactive ingredients can impart active functionality to food products, including the preservation of lipid stability and microbiological quality. Putri et al. (2022) also showed that combining multiple natural antioxidant sources yields more effective protection than using a single type of extract. Variations in effectiveness across studies are likely influenced by factors such as the film's raw materials, the composition of bioactive compounds, storage conditions, and the characteristics of the protected food product.

Lumingkewas et al. (2023) reported that extracts from clove (*Syzygium aromaticum*) leaves and flowers contain phytochemical compounds with potential antioxidant activity. These compounds can inhibit lipid oxidation; consequently, the use of edible films enriched

with plant extracts has the potential to preserve the quality of dodol during storage, including by slowing changes in fat and free fatty acid (FFA) levels.

Research by Kouser et al. (2023) also demonstrated that bioactive, Aloe barbadensis based edible films can enhance the lipid stability and microbiological quality of cheese. Based on these findings, it can be concluded that a combination of senduduk fruit and tomato extracts not only boosts the antioxidant activity of the edible film but also preserves the fat content of galamai during storage. This capability indicates that the developed edible film has the potential to serve as natural active packaging, slowing oxidative deterioration while maintaining the chemical and sensory quality of traditional food products.

Peroxide Value

The peroxide value is a key indicator for evaluating the extent of primary oxidation in fatty food products. This parameter reflects the amount of hydroperoxides formed as initial products of oxidation reactions that precede the formation of secondary products such as aldehydes, ketones, and organic acids. Consequently, an increase in peroxide value during storage indicates an intensification of the oxidation process occurring in the galamai. The results of peroxide value testing for galamai coated with a cassava starch-based edible film enriched with senduduk fruit and tomato extracts are presented in Figure 9.

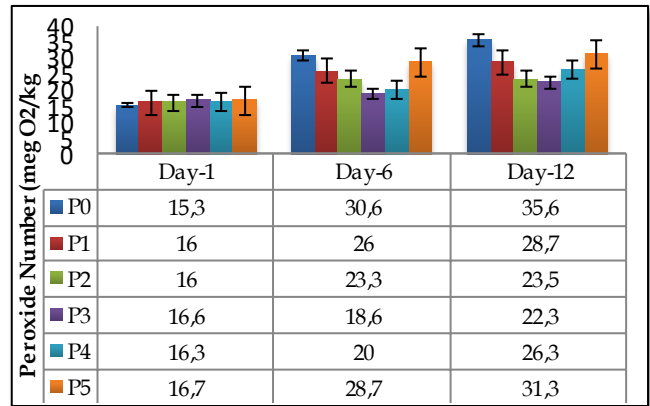


Figure 9. Galamai peroxide number

Analysis of variance (ANOVA) revealed that the treatments had a significant effect ($p<0.05$) on changes in peroxide values during storage. Generally, peroxide values increased across all treatments as storage time progressed, indicating that lipid oxidation reactions continued despite the application of the edible film. However, the rate of increase varied among the treatments. Edible films containing a combination of senduduk fruit and tomato extracts were able to retard hydroperoxide formation more effectively than films

without extracts or those containing only a single type of extract. These results demonstrate that the presence of bioactive compounds within the film matrix provides protection against lipid oxidation during the initial stages of storage.

Hydroperoxide formation begins with the abstraction of a hydrogen atom from an unsaturated fatty acid, which subsequently reacts with oxygen to form a peroxy radical. This reaction proceeds as a chain reaction; consequently, the quantity of hydroperoxides continues to rise unless a compound capable of terminating free radical propagation is present. In the control treatment, the absence of antioxidant compounds allowed the propagation reaction to proceed more rapidly, leading to a significant increase in formation. Conversely, edible films enriched with senduduk and tomato extracts provided antioxidant compounds capable of donating hydrogen atoms to free radicals, thereby terminating the chain reaction at an earlier stage.

The effectiveness of the edible film in suppressing peroxide formation stems not only from antioxidant activity but also from its ability to reduce oxygen diffusion toward the product surface. The cassava starch matrix forms a semi-permeable layer that slows oxygen transfer, while phenolic compounds from the senduduk extract reinforce the polymer network through hydrogen bonding. Simultaneously, natural pectin from the tomato extract contributes to a more homogeneous film structure, effectively lengthening the oxygen diffusion pathway. The combination of these mechanisms makes it more difficult for oxygen the primary reactant in lipid oxidation to reach the product surface, thereby inhibiting hydroperoxide formation.

The presence of flavonoids, anthocyanins, and tannins in senduduk fruit extract provides protection in the aqueous phase by scavenging hydroxyl and superoxide radicals. Meanwhile, lycopene and beta-carotene from tomato extract act in the lipid phase by inhibiting peroxy radical formation and neutralizing singlet oxygen. This combination of hydrophilic and lipophilic antioxidants produces a synergistic effect that broadens the spectrum of protection against oxidation; this synergy explains why a formulation combining both extracts demonstrates superior ability in maintaining oxidative stability compared to using either extract alone.

These findings are consistent with various studies reporting that the addition of plant extracts rich in phenolic compounds to edible films can reduce hydroperoxide formation during food product storage. These results align with research by Agustini et al. (2023), which showed that incorporating antioxidant sources into dodol products could suppress the formation of peroxides. This effect is likely attributed to

the antioxidant compounds in senduduk fruit specifically phenolics, flavonoids, and anthocyanins which play a role in scavenging free radicals and inhibiting oxidative reactions. Wang et al. (2020) explained that phenolic compounds can inhibit the propagation stage of lipid oxidation by donating hydrogen atoms to peroxy radicals. Meanwhile, Lan et al. (2022) reported that combining hydrophilic and lipophilic antioxidants offers more effective oxidative protection than using a single antioxidant, as the combination can act simultaneously across both phases of the food system. Differences in effectiveness across studies may be influenced by the type of film-forming material, extract concentration, food product characteristics, and storage conditions.

Overall, the research results indicate that cassava starch-based edible films enriched with a combination of senduduk fruit and tomato extracts are effective in inhibiting hydroperoxide formation during the storage of galamai. This capability demonstrates that the film functions not only as a physical protective layer but also as a delivery system for natural antioxidants capable of slowing the initial stages of lipid oxidation. Consequently, using a combination of the two extracts has the potential to enhance chemical stability and extend the shelf life of galamai.

Thiobarbituric Acid (TBA)

Thiobarbituric acid (TBA) is a key indicator for evaluating the extent of secondary lipid oxidation in fatty food products. This parameter reflects the amount of malondialdehyde (MDA) formed through the decomposition of hydroperoxides during lipid oxidation. Higher TBA values indicate more advanced oxidative deterioration of the fat, resulting in a decline in the product's chemical and sensory quality. The results of TBA value testing for galamai coated with a cassava starch-based edible film—enriched with senduduk fruit and tomato extracts—are presented in Figure 10. Analysis of variance (ANOVA) revealed that the treatments had a significant effect ($p < 0.05$) on changes in TBA values during storage.

In general, TBA values increased across all treatments as storage time progressed, indicating that secondary lipid oxidation continued throughout the storage period. However, the rate of increase in TBA values varied among the treatments. The control treatment (P0), with no added extract, exhibited the highest increase in TBA value, reaching 0.47 ± 0.02 mg MA/g by day 12. Conversely, treatment P3 containing a combination of 5% senduduk fruit extract and 5% tomato extract yielded the lowest TBA value at 0.24 ± 0.15 mg MA/g, while treatments P2, P4, P1, and P5 showed values of 0.29 ± 0.02 , 0.31 ± 0.02 , 0.34 ± 0.03 , and 0.41 ± 0.17 mg MA/g, respectively. These results

demonstrate that edible films enriched with a combination of senduduk fruit and tomato extracts were more effective at inhibiting the formation of secondary oxidation products compared to the other treatments.

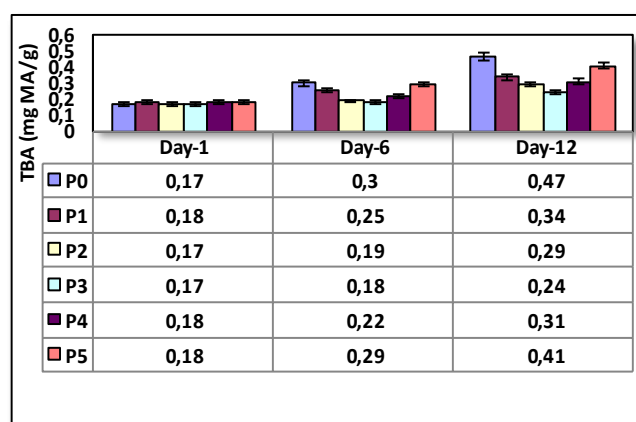


Figure 10. Thiobarbituric acid value

The formation of malonaldehyde is initiated by the decomposition of hydroperoxides formed during the primary oxidation stage. Unstable hydroperoxides decompose into various carbonyl compounds such as aldehydes, ketones, and malonaldehyde which are subsequently detected as the TBA value. In the control treatment, the absence of antioxidants allows hydroperoxide decomposition to proceed more rapidly, leading to a significant increase in malonaldehyde formation. Conversely, edible films enriched with senduduk fruit and tomato extracts provide antioxidants capable of halting the oxidation chain reaction by donating hydrogen atoms to free radicals, thereby suppressing the formation of secondary oxidation products.

The effectiveness of the edible film in reducing TBA values stems not only from antioxidant activity but also from its ability to form a barrier against oxygen diffusion toward the galamai surface. The cassava starch matrix creates a semi-permeable layer that slows oxygen transfer, while phenolic compounds from the senduduk fruit extract reinforce the polymer network through hydrogen bonding. Meanwhile, the natural pectin content in the tomato extract helps produce a denser, more homogeneous film structure, thereby lengthening the oxygen diffusion path. The combination of these two mechanisms results in a lower rate of malonaldehyde formation during storage.

The presence of flavonoids, anthocyanins, and tannins in the senduduk fruit extract provides protection in the aqueous phase by scavenging hydroxyl and superoxide radicals. Meanwhile, lycopene and β -carotene from the tomato extract act in the lipid phase by neutralizing singlet oxygen and inhibiting the formation

of peroxy radicals. This combination of hydrophilic and lipophilic antioxidants creates a synergistic effect that broadens the spectrum of protection against lipid oxidation. This synergism explains why the P3 treatment offers superior oxidative stability compared to treatments utilizing only a single type of extract.

These research findings align with Rasak et al. (2023), who reported that the addition of moringa leaf extract could reduce TBA values during food product storage. Overall, the results indicate that cassava starch-based edible films enriched with a combination of senduduk fruit and tomato extracts are effective in inhibiting malondialdehyde formation during the storage of galamai. This capability demonstrates that the edible film functions not only as a physical protective layer but also as a delivery system for natural antioxidants capable of slowing down secondary lipid oxidation, thereby enhancing the chemical stability and shelf life of galamai.

Free Fatty Acid Content

Free Fatty Acid (FFA) content is a key indicator for evaluating the extent of fat deterioration in food products during storage. This parameter reflects the amount of free fatty acids generated through triglyceride hydrolysis and lipid oxidation. An increase in FFA levels indicates intensified fat degradation, which can compromise chemical quality, accelerate rancidity, and reduce the product's shelf life. The results of FFA content testing for galamai coated with cassava starch-based edible films enriched with senduduk fruit and tomato extracts are presented in Figure 11. Analysis of variance (ANOVA) indicates that the treatments had a significant effect ($p < 0.05$) on changes in FFA levels during storage.

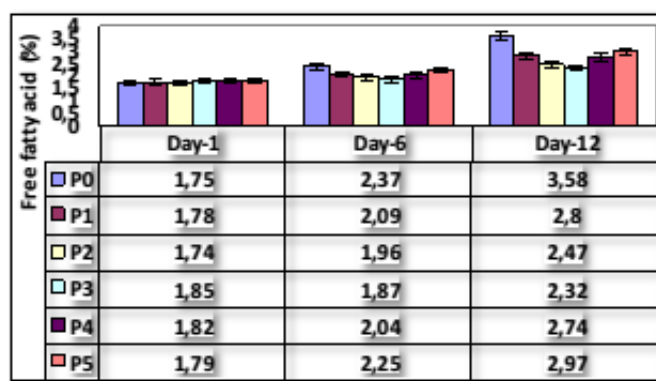


Figure 11. Free fatty acid (FFA) values of galamai

In general, FFA levels increased across all treatments as storage time progressed, indicating that fat hydrolysis and oxidation processes continued throughout storage. However, the rate of increase in FFA levels varied among treatments. On day 1, FFA

levels across all treatments were relatively uniform, ranging from 1.74 to 1.85 mg NaOH/g, indicating that the initial galamai product maintained good fat quality. After 12 days of storage, FFA levels had risen in all treatments. The control treatment (P0) exhibited the highest FFA levels, whereas treatment P3 containing the combination of extracts resulted in the lowest levels. These results demonstrate that edible films enriched with a combination of senduduk fruit and tomato extracts were more effective at inhibiting the rise in FFA levels compared to edible films containing no extracts or only a single type of extract.

The formation of free fatty acids begins with the hydrolysis of triglycerides into glycerol and free fatty acids, a process catalyzed by lipase enzymes derived from either the product ingredients or microbial activity during storage. Additionally, lipid oxidation of unsaturated fatty acids can accelerate triglyceride degradation, thereby increasing free fatty acid formation. These reactions are influenced by various factors, such as temperature, oxygen, moisture content, and the presence of transition metal ions acting as oxidation catalysts. In the control treatment, the absence of antioxidant compounds allowed hydrolysis and oxidation processes to proceed more rapidly, leading to a significant increase in FFA levels. Conversely, edible films enriched with senduduk fruit and tomato extracts were able to retard these processes through antioxidant activity while simultaneously reducing the product's exposure to oxygen and moisture.

The effectiveness of the edible films in suppressing the rise in FFA levels stems not only from antioxidant activity but also from their ability to form a barrier against the diffusion of oxygen and water vapor. The cassava starch matrix creates a semi-permeable layer that slows the transfer of oxygen to the galamai surface. The phenolic compounds in senduduk fruit extract strengthen the polymer network through the formation of hydrogen bonds, while the natural pectin from tomato extract helps produce a denser and more homogeneous film structure so that the permeability to oxygen and water vapor is lower. The combination of these two mechanisms is able to slow down the hydrolysis and fat oxidation reactions so that the formation of free fatty acids can be suppressed during storage.

The presence of flavonoids, anthocyanins, and tannins in senduduk fruit extract provides protection in the aqueous phase through free radical scavenging and the inhibition of oxidation reactions. Furthermore, phenolic compounds have been reported to inhibit lipase activity, thereby slowing the rate of triglyceride hydrolysis. Meanwhile, lycopene and β -carotene in tomato extract act in the lipid phase by neutralizing singlet oxygen and inhibiting the formation of peroxy

radicals. This combination of hydrophilic and lipophilic antioxidants produces a synergistic effect, offering broader protection against lipid degradation than the use of a single extract. This synergism explains why treatment P3 demonstrated the highest effectiveness in maintaining the lipid stability of *dodol* during storage.

The reduction or inhibition of the increase—in free fatty acid levels in dodol treated with edible films can be attributed to the activity of antioxidant compounds present in the plant extracts. These antioxidant compounds play a role in inhibiting lipid oxidation reactions during storage, thereby suppressing the formation of lipid degradation products. This finding is supported by research conducted by Rahmadhia et al. (2023) on klutuk banana leaf (*Musa balbisiana* Colla) extract incorporated into cassava starch-based active packaging for dodol their study demonstrated that the use of active ingredients derived from plant extracts helps maintain the chemical quality of *dodol* during storage.

Indrianti et al. (2019) also reported that the use of edible films for dodol resulted in lower free fatty acid levels compared to polypropylene plastic packaging. Additionally, Sharma et al. (2021) and Kouser et al. (2023) demonstrated that incorporating plant extracts containing bioactive compounds into edible films effectively suppresses increases in free fatty acids (FFA) and lipid oxidation. Thus, the presence of antioxidant compounds in the edible film is thought to play a role in maintaining fat stability and slowing the quality deterioration of dodol during storage. Overall, the research results indicate that cassava starch-based edible film enriched with a combination of senduduk fruit and tomato extracts is effective in inhibiting the rise in free fatty acid levels during the storage of galamai. This capability demonstrates that the edible film functions not only as a physical protective layer but also as a delivery system for natural antioxidants capable of slowing lipid degradation, maintaining the product's chemical stability, and extending the shelf life of galamai.

Organoleptic Test

Organoleptic evaluation of galamai was conducted regarding the attributes of color, aroma, taste, and texture after 12 days of storage. Assessment utilized a 1–5 hedonic scale with the following criteria: 1 = like very much, 2 = like, 3 = somewhat like, 4 = dislike, and 5 = dislike very much. The test results are presented in Figure 12.

Color is the first attribute observed by consumers and plays a crucial role in product acceptance. Test results indicate that the control treatment (P0) and the combined senduduk tomato extract treatments (P3 and P4) achieved relatively better acceptance levels

compared to treatments dominated by tomato extract. This suggests that the addition of tomato extract at high concentrations can alter the characteristic color of galamai, which is typically dark brown. The edible film incorporating senduduk fruit extract and galamai is shown in Figure 13.

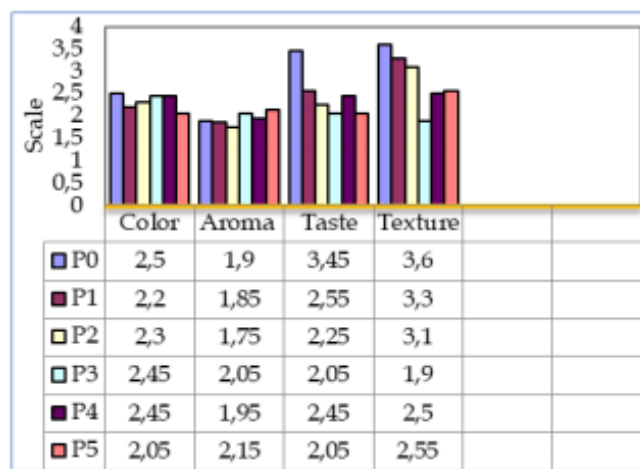


Figure 12. Organoleptic test

Melianti (2018) demonstrated that senduduk fruit contains anthocyanin pigments that can be extracted using an ethanol solvent. Therefore, if increasing the extract concentration in this study resulted in higher film color intensity, this change could be attributed to a greater amount of pigment being incorporated into the film matrix.



Figure 13. Edible film

Lycopene is the primary pigment in tomatoes; it possesses high color intensity and can significantly influence the visual appearance of the product. Consequently, the combined extract formulation in treatment P3 yielded a color balance that was more acceptable to the panelists than the use of a single extract.

Aroma

The aroma of galamai is influenced by volatile compounds derived from both the raw materials and the added extracts. Treatments containing tomato extract

demonstrated higher aroma acceptance levels compared to treatments dominated by senduduk extract. This is likely because tomatoes contain volatile compounds such as hexanal, cis-3-hexenal, and 6-methyl-5-hepten-2-one that impart a fresh, fruity aroma preferred by consumers.

Conversely, senduduk fruit contains phenolic compounds and tannins that can produce a distinctive herbal aroma. At certain concentrations, this aroma is less familiar, thereby reducing consumer preference. The interaction of volatile compounds from the two extracts resulted in differing aroma perceptions across the treatments.

Taste

The addition of tomato extract improved the taste acceptance of galamai compared to the control. The natural sweet and sour taste derived from the simple sugars and organic acids present in tomatoes provided a fresher flavor sensation. In contrast, senduduk fruit extract contains phenolic compounds and tannins that can produce a bitter or astringent sensation when used at high concentrations. Phenolic compounds have the ability to bind with salivary proteins, creating an astringent sensation in the oral cavity. Therefore, a balanced combination of senduduk and tomato extracts resulted in better taste acceptance, as it suppressed the dominance of astringency while maintaining high antioxidant activity.

Texture

Texture is the attribute most closely associated with the physical and chemical stability of the product during storage. The treatment combining senduduk and tomato extracts yielded the highest texture preference scores. These results align with observations regarding moisture content, fat content, TBA and peroxide values, and free fatty acid levels, all of which indicated superior galamai quality compared to other treatments. The pectin content in tomatoes contributes to enhanced product elasticity and softness, while phenolic compounds from senduduk help maintain tissue structure and reduce moisture loss during storage. Furthermore, the high antioxidant activity in the combined treatment inhibits lipid oxidation, ensuring the galamai texture remains soft and does not harden prematurely.

A clear relationship between chemical and organoleptic parameters is evident in treatment P3, which exhibited the lowest TBA values, peroxide values, and free fatty acid levels. These conditions indicate a lower degree of lipid degradation, thereby preserving the product's aroma, taste, and texture throughout storage. Thus, the combination of senduduk and tomato extracts not only boosts the antioxidant activity of the

edible film but also maintains the sensory quality of the *galamai* until the end of the storage period.

Conclusion

Research results indicate that cassava starch-based edible films enriched with senduduk fruit and tomato extracts significantly influence the films' physical, chemical, and functional characteristics while effectively preserving the quality of galamai during storage. The combination of senduduk fruit and tomato extracts in treatment P3 yielded the best performance in enhancing antioxidant activity, improving mechanical properties, and inhibiting lipid oxidation and degradation during storage. Furthermore, the use of this edible film maintained the sensory characteristics of galamai, ensuring its continued acceptability to panelists. These findings demonstrate that the combination of hydrophilic bioactive compounds from senduduk fruit and lipophilic compounds from tomatoes acts synergistically to enhance the film's effectiveness as active packaging. Beyond serving as a barrier against oxygen and water vapor transmission, the edible film acts as a delivery vehicle for natural antioxidants capable of retarding oxidative deterioration in food products. This study highlights the potential of cassava starch-based edible films enriched with senduduk fruit and tomato extracts as an eco-friendly packaging alternative to extend the shelf life of high-fat traditional foods like galamai. Future research should focus on evaluating the film's stability over longer storage periods, assessing microbiological characteristics, and optimizing the formulation for application across a wider range of food products.

Author Contributions

Individual author contributions to this research include material preparation, product fabrication, observation, and physicochemical testing: Hijratun Amini; Writing – Original Draft: Hijratun Amini; Writing – Review and Editing: Hijratun Amini, Tuty Anggraini, Daimon Syukri; Supervision: Tuty Anggraini, Daimon Syukri. All authors have read and agreed to the published version of the manuscript

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No conflict interest.

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