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Variation of Polymer Matrix On the Quality of Bioplastic from Cassava Peel Waste from *Tapai* Industry in Bogor

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Abstract
Plastic waste originating from commercial sources presents significant environmental challenges, leading to the creation of biodegradable alternatives derived from renewable materials. This research investigates the feasibility of utilizing cassava peel starch (CPS), an agro-industrial by-product, as a foundational material for bioplastic manufacturing. To overcome the limitations of pure starch, such as brittleness and insufficient water resistance, a bioplastic was produced through solvent casting by combining a blend of chitosan, a natural biopolymer, and polyvinyl alcohol (PVA), a synthetic polymer, to improve its mechanical and physical properties. CPS was extracted and then analyzed for yield, moisture, and starch content. The interactions among components in bioplastics were examined utilizing FTIR and SEM techniques. FTIR analysis revealed physical interactions devoid of chemical bonding, whereas SEM demonstrated heterogeneous surfaces characterized by cracks. Among the five formulations, the formulation containing 5.0 g of PVA and 1.5 g of chitosan (F5) exhibited optimal performance, characterized by a thickness of 0.25 mm, a tensile strength of 11.95%, an elongation of 17.83%, and a biodegradation rate of 49.16% after 12 days. The material met JIS Z 1707:1997 standards for mechanical properties, although it did not fully comply with biodegradation requirements. The novelty of this research presents to the valorization of cassava peel starch as local-agro industrial waste into bioplastics enhanced with chitosan and PVA, revealing a cost-effective, renewable alternative that meets key mechanical standards while advancing sustainable plastic innovation. The results indicate that CPS-based bioplastics, when combined with suitable polymer matrices, offer a feasible and sustainable substitute for conventional plastics.

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INTRODUCTION

According to data from the Indonesian Ministry of Environment, plastic usage in Indonesia is on the rise. In 2020, the country generated plastic waste amounting to 22.5 kg per capita per year, with 35% of total plastic consumption attributed to packaging materials (KLHK 2020). A potential solution to mitigate these issues is the use of natural materials that can be converted into biodegradable plastics. Biodegradable plastic, or bioplastic, refers to a category of plastic

made from natural polymers that can be readily decomposed, including starch, cellulose, and carbohydrates (Wening & Amalia, 2023). The availability of these components is abundant in nature and can be renewed due to their high biodegradability, indicating significant potential for use in the production of biodegradable plastics (Wening & Amalia, 2023).

Root crops typically contain natural biopolymer components, including carbohydrates (starch), proteins, natural rubber, and biomass (Gea et al., 2022). Cassava ranks among the most extensively cultivated crops in the Bogor region. In 2020, cassava production in Bogor Regency was recorded at 85,861 tons, as reported by the Central Bureau of Statistics (BPS Kab. Bogor, 2020). As cassava production rises, the generation of cassava peel waste correspondingly increases. Wening and Amalia (2023) report that each kilogram of cassava yields 15-20% in cassava peel. The underutilization of cassava peel waste by the community may lead to additional issues. Notably, cassava peel contains a starch content ranging from 44% to 59% (Alfian et al., 2020), with an amylose proportion of 9.69% and the remainder being amylopectin (Mudaffar, 2021). Cassava peels may serve as a viable source of starch to produce biodegradable plastics.

Starch is a natural polymer that serves as a biodegradable material, characterized by its environmental sustainability, widespread availability, and cost-effectiveness (Wu et al., 2024). Starch consists of two primary polymers: amylose and amylopectin. Nisah (2018) indicates that amylose compounds influence cohesiveness, whereas amylopectin or starch impacts the stability of biodegradable plastics. In the fabrication of starch-based bioplastic films, the incorporation of plasticizers can mitigate the brittleness of the films attributed to elevated intermolecular forces. Water, glycerol, and sorbitol are frequently utilized as plasticizers in starch-based bioplastic films. It is not advisable to use water directly as a plasticizer due to the high volatility of its molecules, which can result in brittleness in the film. Glycerol contains hydroxyl groups that facilitate inter- and intra-molecular interactions, specifically hydrogen bonding, within polymeric chains. Consequently, it is considered the most effective plasticizer for water-soluble polymers, enhancing the flexibility of bioplastic films (Warsiki et al., 2020). Consequently, it is considered the most effective plasticizer or other reinforced copolymer for water-soluble polymers, enhancing the flexibility of bioplastic films.

Recent years have seen a significant increase in research focused on the synthesis of chitosan and polyvinyl alcohol (PVA)-derived biopolymers due to physical and mechanical properties. Chitosan is a polysaccharide derived from chitin or from the shells of shrimp and crabs. Chitosan is commonly employed as a thickening agent, gelling agent, and for enhancing texture. Chitosan possesses film-forming capabilities, hydrophobic characteristics, biodegradability, non-toxicity, and the ability to enhance transparency. Furthermore, chitosan contributes to the enhancement of tensile strength, as the presence of hydrogen bonds (both intramolecular and intermolecular) in bioplastics increases, necessitating greater energy to disrupt these bonds (Qadri et al., 2023). Moreover, polyvinyl alcohol (PVA) demonstrates significant properties, including high compactness, increased crystallinity, strong adhesion, non-toxicity, and a favorable interaction with water molecules. The PVA macromolecule contains a significant number of hydroxyl functional groups, making it highly hydrophilic (Mustapa et al., 2017).

Starch-based bioplastics offer a renewable and biodegradable alternative; however, their practical application is constrained by issues such as brittleness, inadequate water resistance, and suboptimal mechanical properties. Cassava peel waste, although underutilized, presents a significant potential as a raw material for bioplastic production due to its high starch content. Efforts to enhance cassava peel starch (CPS)-based bioplastics frequently depend on individual plasticizers or copolymers, which have not adequately resolved these deficiencies. Furthermore, there is a paucity of research investigating the synergistic effects of chitosan and

polyvinyl alcohol (PVA) as dual reinforcing agents in starch-based bioplastics, indicating a gap in the optimization of their composition to improve mechanical strength and biodegradability. This study presents the use of cassava peel starch, a plentiful agro-industrial byproduct, as a sustainable base material for bioplastic production and explores the innovative application of chitosan and PVA as dual copolymer reinforcements. This study systematically varies polymer concentrations to elucidate the synergistic interactions between natural and synthetic polymers. The findings enhance the structural, mechanical, and biodegradation properties of starch-based bioplastics, contributing to the advancement of eco-friendly alternatives to conventional plastics.

METHOD

Materials and Equipments

The starch raw materials originated from cassava peels from Mekarwangi Village, Tanah Sareal District, Bogor City, West Java, Indonesia. The chemical materials utilized included polyvinyl alcohol (PVA), chitosan, distilled water, glycerol, hydrochloric acid (HCl 37%), sodium hydroxide (NaOH 40%), potassium iodate (KIO_3), potassium iodide (KI 20%), sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$), and sulfuric acid (H_2SO_4 98%). All materials were procured from Pure Analysis and Sigma Aldrich. The equipment utilized in this study included an oven, hotplate, 30 cm x 30 cm mold, 100 mesh sieve, and magnetic stirrer.

Extraction of cassava peel starch (Weligama Thuppahige et al., 2023)

The cassava peels that are employed are reddish-white or yellowish-white skins, which are commonly referred to as epidermis. The yellowish-white epidermis is less amenable to processing than the red epidermis, which is typically thicker. To eradicate any remaining dirt, the epidermis that has been obtained is rinsed with running water. The cassava peels are cut into pieces that are approximately 3.00 cm in size and soaked for 24 hours, with the water being replenished every 8 hours. The cassava epidermis was drained and subsequently mashed with water in a 1:3 ratio after a 24-hour soaking period (Weligama Thuppahige et al., 2023). The cassava rind pulp was subsequently filtered through a calico cloth. To facilitate the sedimentation of starch, the filtrate is subjected to precipitation for 24 hours. The clarity of the filtrate is indicative of the formation of starch. The starch was drained after the filtrate was progressively removed. Subsequently, solar exposure is implemented to dry the starch. The desiccated starch was subsequently filtered and mashed using a 100-mesh sieve.

Analysis of starch from cassava peels (Abdo & Ali, 2019)

The calculation of the ratio between the starch obtained from extraction and the cassava peels used as the substrate for the starch was the focus of the cassava peel starch yield analysis. The gravimetric method was employed to determine the moisture content of the starch. After weighing 3 g into a porcelain cup, the starch was dried in an oven at 105°C for 3 hours. The sample was subsequently chilled in a desiccator for 10 minutes and reweighed until it was stable. The Luff Schoorl method was employed to analyze the starch content in accordance with SNI 01-2891-1992.

The experiment entailed the addition of 50.00 mL of 25% w/w HCl to an Erlenmeyer flask containing 0.5000 g of cassava peel flour, followed by the hydrolysis of the mixture at 100°C for a duration of 3 hours. The suspension was neutralized with 25% w/w NaOH until a pH of 7 was attained after cooling to room temperature. Subsequently, the solution was transferred to a 250.00 mL volumetric flask and diluted with distilled water. Subsequently, filter paper was implemented to filter the solution. In an Erlenmeyer flask, 10 ml of filtrate was transferred, and 25 ml of Luff Schoorl solution was added.

The same procedure was employed to administer a blank treatment, substituting the sample solution with distilled water. The Erlenmeyer flask was subsequently connected to a reverse cooler for reflux, boiled for 10 minutes, and permitted to cool to room temperature. 15.00 mL of 20% w/w KI and 25.00 mL of 25% w/w H_2SO_4 were added to the solution after cooling. Subsequently, the solution was incubated in a dark environment for 30 minutes and covered with aluminum foil. The sample solution and the blank were both treated with three droplets of starch indicator. The solution was subsequently titrated in duplicate using a standardized 0.1000 N sodium thiosulfate (Na_2SO_3) solution (Gurunathan et al., 2025).

Bioplastics preparation (Hardi et al., 2024)

The bioplastics were produced by dissolving all materials, apart from glycerol and chitosan, in distilled water according to the formula presented in Table 1. Chitosan was solubilized in 10.00 mL of 1% v/v acetic acid. Subsequently, the two solutions were combined and heated at 70°C for 40 minutes. Subsequently, glycerol was incorporated and mixed until a uniform solution was attained. The bioplastic solution was applied to a pre-cleaned glass mold after gelatinization. The mold containing the bioplastic solution was dried in an oven at 70°C for a period of 8 hours.

Table 1. Formulation of bioplastics

Component	Formulation				
	F1	F2	F3	F4	F5
Starch (g)	5.50	5.50	5.50	5.50	5.50
Glycerol (mL)	1.00	1.00	1.00	1.00	1.00
PVA (g)	3.00	5.50	-	-	5.50
Chitosan (g)	-	-	3.00	5.50	3.00
Aquades (mL)	100.00	100.00	100.00	100.00	100.00

Bioplastic characterization (Bracciale et al., 2024)

The absorption peaks of functional groups in cassava peel starch (CPS), polyvinyl alcohol (PVA), chitosan, and bioplastics were identified using a Bruker Tensor 37 Fourier Transform Infrared (FTIR) instrument with the KBr pellet method. Sample preparation involved mashing the sample with KBr solids at a ratio of 1:200 at the specified wave number range of 4000-400 cm^{-1} with total of 32 scans (Wu et al., 2024).

The morphological characterization of biodegradable plastics was conducted utilizing Scanning Electron Microscopy (SEM) at magnifications of 400x and 800x to reveal the distribution of constituent particles within the matrix (Crema et al., 2024). Tensile strength and elongation tests were performed using Instron's Universal Testing Machine, in accordance with ASTM D882-12 standards. The samples were initially cut to dimensions of 6.00 cm in length and 2.00 cm in width then operated at a speed of 12.50 mm/minute.

Biodegradable test (Kowser et al., 2025)

The plastic biodegradation test involved measuring the initial weight of a bioplastic sample with size of 3.00 x 3.00 cm^2 and were buried at a depth of 2.00 cm by adding water to maintain soil moisture (Charerntanom et al., 2025). The sample was evaluated bi-daily by rinsing sample to remove residual soil with water, followed by oven drying and subsequent weighing to obtain the final weight. The mass loss corresponds to the percentage of the biodegradation value (Bracciale et al., 2024).

RESULTS AND DISCUSSION

Characterization of cassava peel starch

Starch in cassava peels is obtained through maceration extraction. Prior to extraction, cassava peels obtained from the tapai industry are washed to clean the remaining dirt and soil by changing the soaking water 3 times every 8 hours for 24 hours. This treatment was carried out according to the research of Dian & Astili (2018) which states that the way to reduce cyanide poison from cassava peels is by inhibiting the reaction between metillinamarin and linamarin with the enzyme linamarase. During the soaking process, linamarin compounds will be hydrolyzed by water and form water-soluble cyanide acid. The water-soluble HCN compound will be wasted along with the water, when the soaking water is changed. Water-soluble cyanide acid will be wasted during the process of changing the soaking water so that it will reduce HCN levels in cassava peels. To make the process more effective, the cassava peels were cut to expand the surface contact with water. The results of cassava peel extraction obtained a yield value of 10.54%. The yield is expressed in percentage form which shows the ratio between the amount of product produced and the amount of raw material used. Based on the experimental results, the yield value of cassava peel starch obtained is far below the yield value in the research results of Thuppahige et al., (2023) which obtained a percentage yield of 30.17% due to differences in sample conditions and treatment during the extraction process.

The starch derived from cassava peel exhibits physical characteristics as a fine powder, brownish white in color, with a particle size of 100 mesh and a distinct cassava aroma. The moisture content of cassava peel starch is determined using the gravimetric method. The gravimetric method is a quantitative analytical technique that involves measuring the weight loss of an element or compound at a heating temperature of 105°C (Fikriyah & Nasution, 2021). The moisture content of 10.55% complies with the SNI 01-2997-1992 quality standard, which stipulates a maximum value of 12%. Excessive water content in starch can impair bioplastic production by diminishing the gel-forming capacity of amylose compounds (Syafutri, 2022).

The production of starch-based bioplastics fundamentally relies on the principle of gelatinization (Rinaldi et al., 2014). Gelatinization refers to the swelling of starch granules resulting from the absorption of water molecules, leading to subsequent chemical and physical transformations. Chemical changes arise from the disruption of intra- and intermolecular hydrogen bonds between water and starch molecules. The increasing viscosity of the starch solution indicates physical changes (Fitriani et al., 2020). Excessive water content in a material influences the physical and mechanical properties of bioplastics. The research conducted by Bracciale et al., (2024) indicates that an increase in water content within a material composition correlates with a decrease in tensile strength, while the elongation or extensibility of the plastic is enhanced.

The starch content was determined in this study using the Luff Schoorl method, in accordance with SNI 01-2891-1992. The Luff Schoorl method is a commonly selected approach for determining starch content due to its relative ease of use compared to alternative methods, such as the Nelson-Somogyi and anthrone sulfate methods, which necessitate costly instruments and reagents (Al-kayyis & Susanti, 2016). The Luff shoorl method determines starch content through the reaction between Cu^{2+} and monosaccharide compounds, as illustrated in Figure 1. Cassava peel starch samples require hydrolysis with an HCl acid solution to generate shorter starch molecule chains, facilitating measurement via the Luff Schoorl method. Hydrolysis of sucrose yields reducing sugars, specifically glucose and fructose (Gurunathan et al., 2025).

The hydrolyzed solution must be maintained at an acidic pH of 7.00 (neutral) using NaOH. Fadjria et al. (2019) emphasize the importance of considering the solution's acidity, as an excessively acidic pH will lead to an increase in the volume of peniter ($Na_2S_2O_3$), resulting in

a lower obtained level. Polysaccharides in starch undergo hydrolysis to yield monosaccharides. The Luff schoorl reagent, which contains Cu^{2+}, undergoes reduction by KI in an acidic environment, resulting in the formation of brownish I_2. The liberated I_2 undergoes iodometric titration with sodium thiosulfate, resulting in the formation of pale-yellow iodide ions. The amylum indicator is added near the endpoint of the titration to prevent it from binding with iodine, which would hinder its subsequent release. The blue complex is re-titrated with sodium thiosulfate until the endpoint is reached, indicated by the sample solution becoming colorless with a milky white precipitate (Fadjria et al., 2019). The neutralized sample solution is treated with the Luff Schoorl reagent, resulting in the occurrence of the following reaction (Fadjria et al., 2019).

$$(C_6H_{12}O_6)n + H_2O \xrightarrow{H^+} {}_nC_6H_{12}O_6$$

$$2Cu^{2+} + 4I^- \xrightarrow{\text{acid}} Cu_2I_2 + I_{2\ (\text{brown})}$$

$$I_2 + 2S_2O_3^{2-} \longrightarrow 2I^-_{(\text{transparent yellow})} + S_4O_6^{2-}$$

$$I_2 + \text{amylum} \longrightarrow \text{blue complex}$$

Figure 1. Oxidation reaction between monosaccharide compounds and CuO

The experimental results indicated a starch content of 55.17%. The starch content obtained differs from the findings of Wasistha et al. (2021), which reported a level of 73%. Abdo & Ali (2019) reported that the starch content in cassava peel ranges from 44% to 59%, indicating that the starch content obtained is comparable to their findings. Diverse factors contribute to variations in starch content among different plant species. Factors influencing this include variations in plant varieties, environmental conditions such as soil, climate, temperature, and light, as well as the age at which the plant is harvested (Rahmawati et al., 2023).

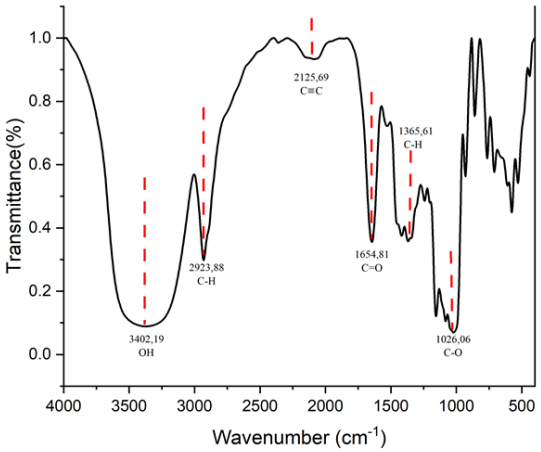


Figure 2. FTIR spectra of cassava peel starch

The starch extracted from cassava peel was characterized by its functional groups utilizing Fourier Transform Infrared (FTIR) spectroscopy depicted in Figure 2 and compared with other literature in Table 2. The absorption pattern observed at a wave number of 3402.19 cm^{-1} indicates the presence of broadened OH vibrations (Sulistyani, 2017). An additional absorption is observed at a wave number of 2923.88 cm^{-1}, indicative of an aliphatic C-H stretch. This finding aligns closely with the research conducted by Mohd-asharuddin et al. (2017), which identified a range of wave numbers from 3000 to 2850 cm^{-1} associated with the aliphatic C-H functional group. The absorption at 1654.81 cm^{-1}, characterized by sharp intensity, is attributed to carbonyl groups (C=O). An additional absorption band was observed at a wave number of 1377.08 cm^{-1}, exhibiting strong intensity, which is attributed to a C-O group (Putu et al., 2023). The presence of absorption bands with low intensity near the wave number 2150 cm^{-1} is

attributed to a C-C functional group (Alauhdin et al., 2015). The peak is observed at a wave number of 1365.61 cm^{-1}, potentially indicating strain vibrations of ionic carbocyclic groups (Maharsih et al., 2022).

Table 2. Comparison of functional groups in research mills and literature

Functional Group	Wavenumber (cm^{-1})	
	This research	Mohd-asharuddin et al., (2017)
-OH	3402.19	3500-3200
C-H aliphatic	2923.88	3000-2850
C=O	1654.81	1750-1630
C-H	1365.61	1375-1300
C-O	1026.06	1300-1000

Characterization of cassava peel starch-based bioplastics

In this study, bioplastics were synthesized through the solvent casting method, which entails the mixing of components in a solvent, followed by heating and molding. This technique is effective and appropriate for small-scale production (Wening & Amalia, 2023). Cassava peel starch (CPS) was utilized as the primary material, combined with PVA and chitosan. CPS and PVA were dissolved in water, as PVA enhances tensile strength, flexibility, and oxygen barrier properties, while remaining biodegradable despite its synthetic composition (Rahim et al., 2024). Chitosan, being insoluble in water, was successfully dissolved in 1% v/v acetic acid, which is effective for 1.5–3.0 g of chitosan, as supported by studies indicating high solubility at this concentration (Nugroho, 2012; Zahiruddin et al., 2018; Muhlis et al., 2021). Glycerol (0.50% v/v) was employed as a plasticizer to improve elongation and tensile strength, demonstrating superior elongation (65%) compared to sorbitol (42%) at a 25% addition (Fitria et al., 2023). The solution was homogenized through stirring at 70 °C for a duration of 40 minutes. This process enhances gelatinization, as evidenced by increased viscosity (Rinaldi et al., 2014), and leads to irreversible crystal damage in starch (Jiang et al., 2020). The bioplastic was molded and dried at 70 °C, adhering to optimal conditions for mechanical strength and biodegradability (Pongmassangka et al., 2021; Utomo et al., 2013).

Thickness measurement is essential for assessing the suitability of produced bioplastics for their intended applications, as thickness influences tensile strength and elongation properties. The thickness measured from samples F1 to F5 is 0.20 mm. The findings align with the study conducted by Marsa et al. (2023), which indicates that bioplastics with a maximum concentration of 5.0 g of carboxy methyl chitosan achieved a thickness of 0.82 mm, whereas a concentration of 2.0 g resulted in a thickness of 0.25 mm. When comparing the thickness values of the research results to the JIS Z 1707 standard: 1997 for plastic film, it is evident that all bioplastic formulations comply with the standard, as their thickness is ≤ 0.25 mm.

The elongation and tensile strength of bioplastics were assessed, as illustrated in Figure 3. The tensile strength of a material is a measure of its ability to withstand force, which is a critical factor in determining its suitability for use as a packaging material. The tensile strength of samples F1 and F2 was the highest, measuring 18.09 MPa and 19.50 MPa, respectively. This strength is likely due to the robust hydrogen bonding. Deliana et al. (2019) reported that the tensile strength increased from 11.91 to 15.88 MPa as the PVA concentration increased. They attributed this improvement to the stronger interactions between starch and PVA. Conversely, samples F3 and F4 demonstrated a decrease in tensile strength, with values of 16.84 and 16.40 MPa, respectively, corresponding to an increase in chitosan content.

Deliana et al. (2019) also observed a similar trend, which suggests that the tensile strength of chitosan decreases as the concentration of the material increases. This can be attributed to the amorphous character of chitosan, which reduces the intermolecular bond distance. Due to its

semi-crystalline structure and robust intermolecular hydrogen bonding capacity, polyvinyl alcohol (PVA) is essential for improving the tensile strength of starch-based bioplastics. The rigidity and resistance to applied force of the material are enhanced by the formation of a dense hydrogen-bonded network by the hydroxyl groups in PVA interacting with starch molecules. Nevertheless, the formation of compatible intermolecular interactions is less efficient when PVA is incorporated simultaneously with chitosan due to the disparities in chain flexibility and crystallinity between the two polymers. Chitosan has a propensity to disrupt the crystalline regions of PVA, resulting in a decrease in tensile strength and a weakened interfacial adhesion and phase separation within the matrix (Shi et al., 2017). This explains why sample F5, which consisted of chitosan, PVA, and CPS, exhibited the lowest tensile strength at 11.95 MPa. Nevertheless, all samples, despite their differences, exceeded the minimum tensile strength standard of 0.392 MPa established by JIS Z 1707:1997.

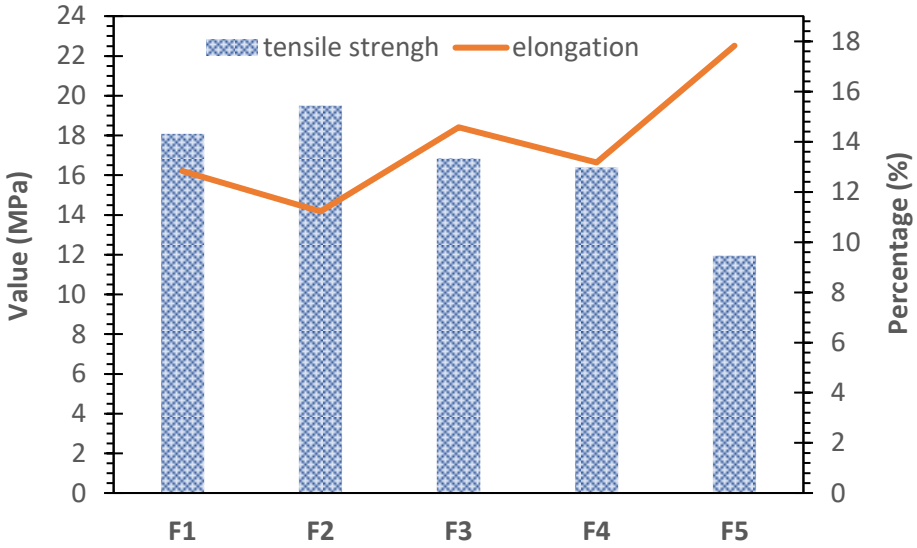


Figure 3. Tensile strength and elongation of various bioplastic formulations

Elongation at break denotes the maximum length a specimen can extend before fracture (Putra et al., 2019). Plasticizers are crucial for preventing brittleness, as amylopectin and amylose, in their absence, produce hard, brittle films (Putra et al., 2019). Glycerol, a widely utilized plasticizer, diminishes intermolecular pressures and enhances the flexibility of bioplastics by decreasing tension inside the polymer matrix, although it concurrently reduces resistance to mechanical stress (Deliana et al., 2019). Elongation values ranged 11.23–94.11%, with commercial plastic (PK) at 94.11% and sample F2 at 11.23%. Increasing PVA concentration from 3.0 g (F1) to 5.5 g (F2) reduced elongation from 12.83% to 11.23%, while higher chitosan content in F3 and F4 yielded 14.58% and 13.17%, respectively. These values exceeded those reported by Limbong et al. (2022), which were 6.59% and 10.99% for comparable PVA concentrations. Samples F1–F5, though below the JIS Z 1707:1997 minimum elongation standard of 70%, fall within the moderate range (10–20%) and demonstrate satisfactory flexibility.

The incorporation of chitosan and PVA in bioplastic formulations aims to evaluate their synergistic influence, as their intermolecular interactions can enhance both mechanical and chemical properties (Nathan et al., 2023). Sample F5 recorded 17.83% elongation with the lowest tensile strength. This inverse trend aligns with the findings of Nurrahmi et al. (2020) and Aripin et al. (2017), which indicate that an increase in tensile strength is generally accompanied by a reduction in elongation. The elongation at break is affected by glycerol, which functions as a plasticizer by reducing intermolecular forces, thereby improving

flexibility (Pamela et al., 2016). Figure 4 illustrates the interaction between PVA and chitosan. PVA, containing hydroxyl groups (-OH), and chitosan, which has amino groups (-NH_2), engage in hydrogen bonding and electrostatic interactions. These factors strengthen physical cross-linking and enhance material performance (Nathan et al., 2023).

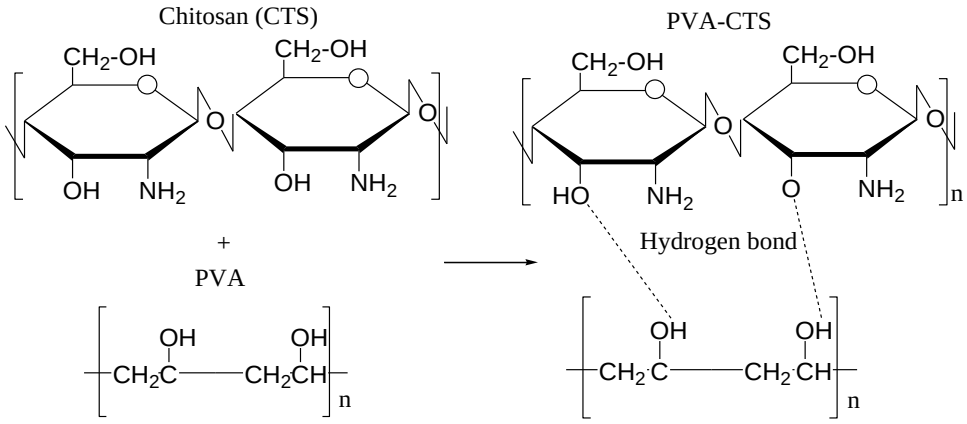


Figure 4. Interaction between chitosan and PVA (Nathan et al., 2023)

The analysis of functional groups via FTIR seeks to identify interactions between starch and other polymers, including PVA, chitosan, and glycerol, as well as to ascertain the formation of new functional groups prior to and following mixing. The bioplastic sample selected was sample F5, which exhibited the highest percentage of physical strength. Figure 5 displays the FTIR spectrum. The spectra of cassava peel starch, PVA, and chitosan exhibit minimal differences, as all three components belong to the categories of polysaccharides and polymers. The primary functional group present in these three components is the -OH hydroxyl group, which is observed in each spectrum within the 3400 cm^{-1} regions, exhibiting a broadened spectral shape (Crema et al., 2024). The aliphatic CH group contributes, as evidenced by absorption bands in the 3400-2400 cm^{-1} region near the -OH spectrum. Carbonyl groups (C=O) in each constituent component exhibit absorption bands at 1654, 1635, and 1728 cm^{-1}. The findings are corroborated by studies (Abral et al., 2020; Salmahaminati, 2022) that identified C=O groups within the wavenumber range of 1715-1637 cm^{-1}. Absorption in the 1373.22-1365.51 cm^{-1} wave number range is likely attributed to the C-O functional group in ester, ether, and alcohol compounds (Yustinah et al., 2023).

The findings are corroborated by Wu et al. (2024), which indicates that the absorption in the 1300-1000 cm^{-1} range is attributed to the C-O group. The spectrum of the F5 bioplastic sample exhibited peak broadening within the 3500-2400 cm^{-1} wavenumber range. The expansion of this absorption area results from the increased presence of hydroxyl groups (-OH) originating from starch, chitosan, and PVA, in addition to water as a solvent. This is also attributed to the substantial quantity of water molecules associated with bioplastics, leading to their moisture content. The presence of absorption bands indicative of hydroxyl groups is supported by the findings of Mohammed et al. (2023), who identified strong intensity of hydroxyl group strain within the wavenumber range of 3550-3200 cm^{-1}. An additional absorption band was observed in the wave number region of 2171 cm^{-1}, exhibiting weak intensity, which is hypothesized to correspond to a functional group C≡C.

According to the findings of Fadlilah and Udjiana (2022), bioplastics should contain functional groups such as carbonyl groups (C=O) and ester groups (C-O). These hydrophilic groups facilitate the entry of microorganisms and their binding to water, thereby promoting the degradation process (Fadlilah and Udjiana 2022). The FTIR spectrum in Figure 5 indicates that

no new functional groups are formed following the mixing process, suggesting that bioplastics interact solely through physical means (Suryanegara et al., 2021). The absence of other functional groups in bioplastics may result from various factors, particularly the elevated water content present in these materials (Guntarti et al., 2020). The thickness and color intensity of the sample being measured also influence the resulting FTIR spectrum. Putu et al. (2023) state that if the sample subjected to infrared rays is excessively thick, the IR rays will scatter suboptimally. This results in the broadening and inaccuracy of the peaks observed in the IR spectrum. Furthermore, each tool exhibits varying degrees of specificity, which are determined by the tool type and its lifespan.

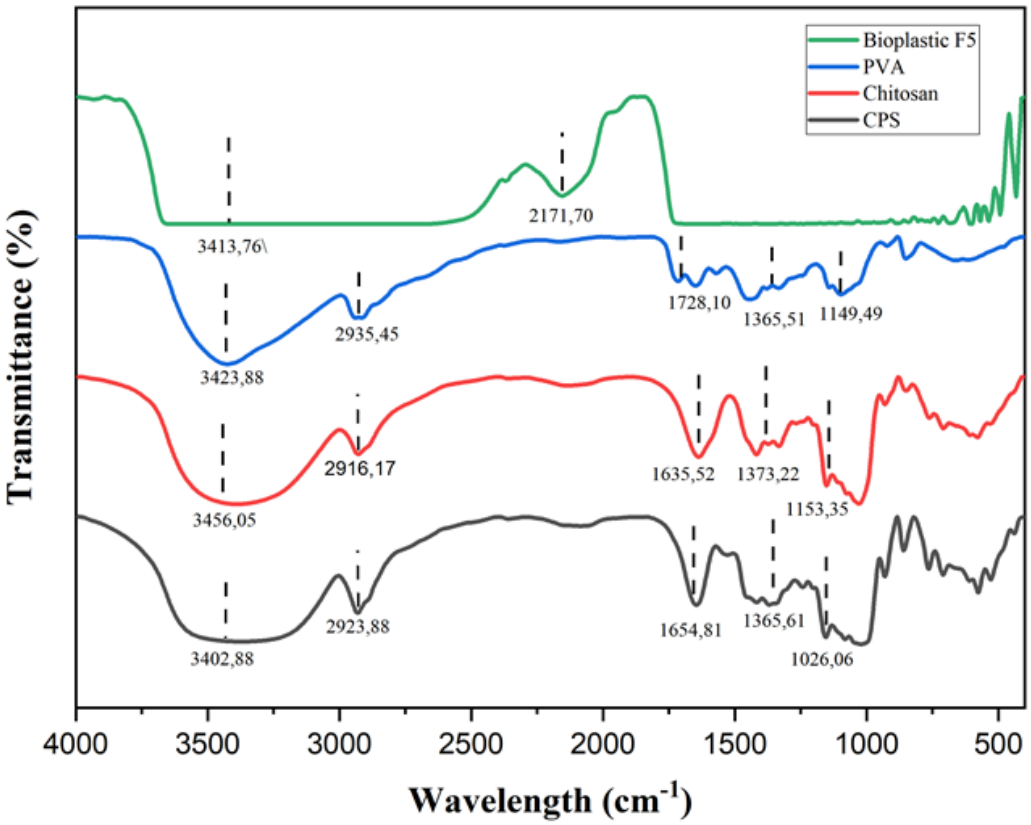


Figure 5. FTIR spectra of bioplastics, PVA, chitosan, and CPS

The surface morphology of bioplastics was analyzed using a scanning electron microscope (SEM) to assess the surface structure and homogeneity of the produced bioplastics. Figure 6 presents the results of the SEM analysis conducted on bioplastic samples. An evaluation was conducted to assess the interaction and contribution of the three materials based on the morphological structure of the constituent components of bioplastics produced. The morphology of the tested bioplastic sample is identified as sample F5. The choice of sample F5 is based on its highest percentage of biodegradation relative to other formulations. Morphological tests indicate significant surface cracks in bioplastics, attributed to the inhomogeneity of constituent matrices, including starch, PVA, and chitosan.

The findings of research (Al Balushi et al., 2021; Cho et al., 2021) indicate that the microstructure of PVA and chitosan results in unevenly distributed particle sizes and shapes, which leads to the polymer matrix facilitating the formation of cracks on the surface of bioplastics. The presence of these cracks may result from undissolved starch granules, indicated by a red color line, which reveals the existence of round or ellipsoidal starch granules measuring 5-10 µm in size. A magnification of 800x reveals air bubbles (indicated by white lines) likely formed during homogenization, as well as white dots presumed to represent the

starch matrix. The findings align with the research conducted by Hernández et al. (2017), which indicates that granule remnants are evidenced by white dots observed on the surface of bioplastics, contributing to crack formation. Starch granule remnants arise from the breaking and disintegration of hydrated starch molecules. The occurrence of surface cracks and inhomogeneity in bioplastics influences their physical properties and soil decomposition (Hernández et al., 2017).

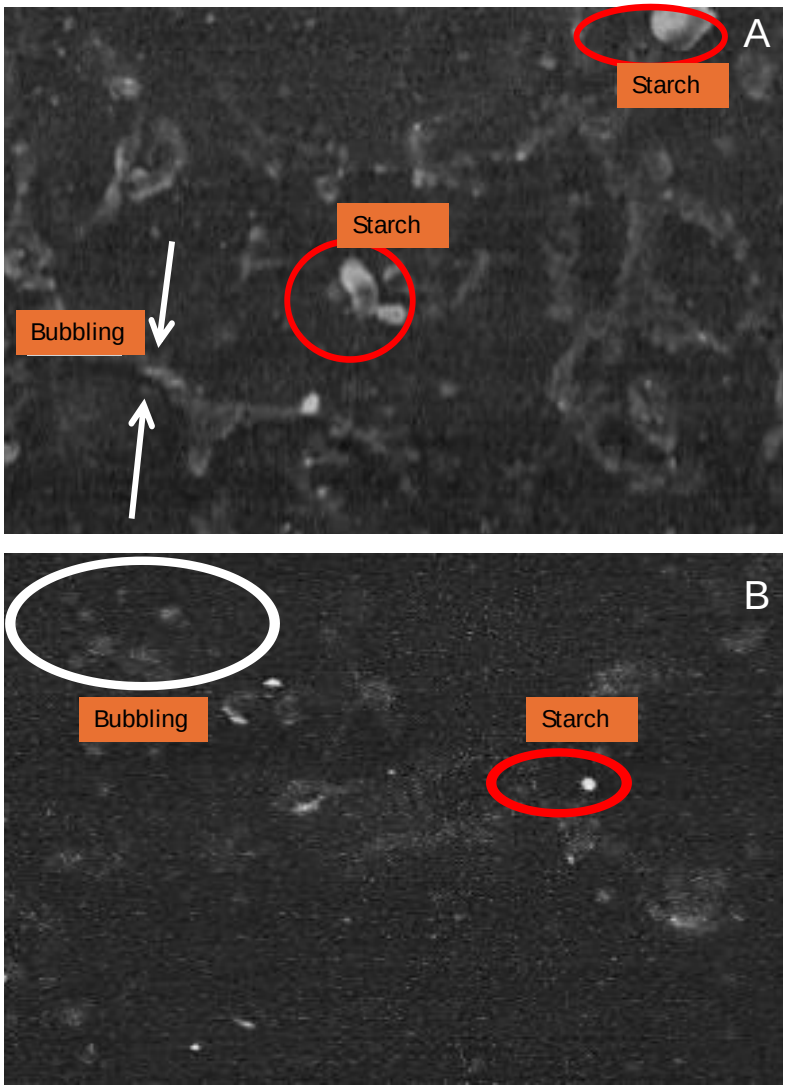


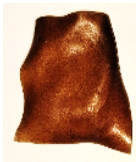
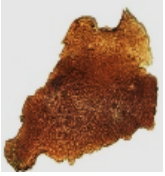
Figure 6. (a) SEM micrograph structure of F5 at magnification of a) 400x and (b) 800x

Biodegradation test

Biodegradation testing utilized the soil burial method to evaluate the decomposition of bioplastics via microbial activity under natural soil conditions (Qadri et al., 2023). Samples (F1–F5) were embedded at a depth of 2 cm in soil previously contaminated with plastic waste, thereby simulating actual environmental conditions, and were observed over a period of 12 days. Soil moisture was sustained through regular watering, with observations conducted every three days. Table 3 demonstrates that all bioplastic samples underwent progressive degradation, as evidenced by color darkening and surface shrinkage. Samples F1 and F2 exhibited surface damage, with weight loss percentages of 45.61% and 47.12% recorded by day 12. Initial changes were minimal (days 0–3), probably attributable to microbial adaptation. Significant degradation was observed after day 6, indicating enhanced microbial colonization and penetration into the bioplastic matrix. Nissa et al. (2019) indicate that prolonged burial duration increases microbial synergy, facilitating macrostructural decomposition. The hydrophilic

characteristics of cassava peel starch (CPS) and PVA enhance moisture absorption and microbial accessibility, thereby expediting degradation (Simarmata et al., 2023).

Table 3. Observation of biodegradation tes ton bioplastics

Day	Sample Code				
	F1	F2	F3	F4	F5
0					
3					
6					
9					-
12					

The biodegradation performance of bioplastics was assessed through weight loss percentages, as illustrated in Figure 7. Sample F5 demonstrated the greatest degradation at 49.16%, whereas F4 exhibited the least degradation at 41.76%. Weight loss indicates microbial degradation activity in the soil. Samples F3 and F4 exhibited decreased degradation rates of 43.49% and 41.76%, respectively, which can be attributed to the presence of chitosan, a hydrophobic compound (Mustapa et al., 2017). The incorporation of hydrophilic components such as starch and glycerol enhanced microbial accessibility and degradation. Chitosan degradation occurs through enzymatic hydrolysis, initiating with the cleavage of β-1,4 glycosidic bonds, followed by deacetylation, which leads to a reduction in molecular weight (Wrońska et al., 2023). Enzymes including chitinase, lysozyme, and protease facilitate the conversion of chitosan into monomers such as glucosamine, which can be assimilated by microorganisms (Wrońska et al., 2023).

F5, consisting of PVA and chitosan, demonstrated greater degradation compared to F2, likely attributable to enhanced amorphism and porosity. PVA, despite being semicrystalline, exhibits predominant amorphous regions. This characteristic, in conjunction with the amorphous nature of chitosan, increases microbial accessibility (Sumartono et al., 2015). Manual mixing contributed to surface heterogeneity and the presence of air bubbles, which in turn increased porosity and the degradation rate. All samples exhibited degradation ranging from 41.79% to 49.16% over a period of 12 days; however, they failed to satisfy the 60% degradation criterion

established by SNI 7188.7:2016. Higher starch and glycerol content facilitates hydrolysis and enhances degradation via interactions with hydroxyl groups (Nissa et al., 2019). In contrast to traditional plastics, which take approximately 100 years to decompose (Ratnawati, 2017), bioplastics demonstrate significant environmental benefits.

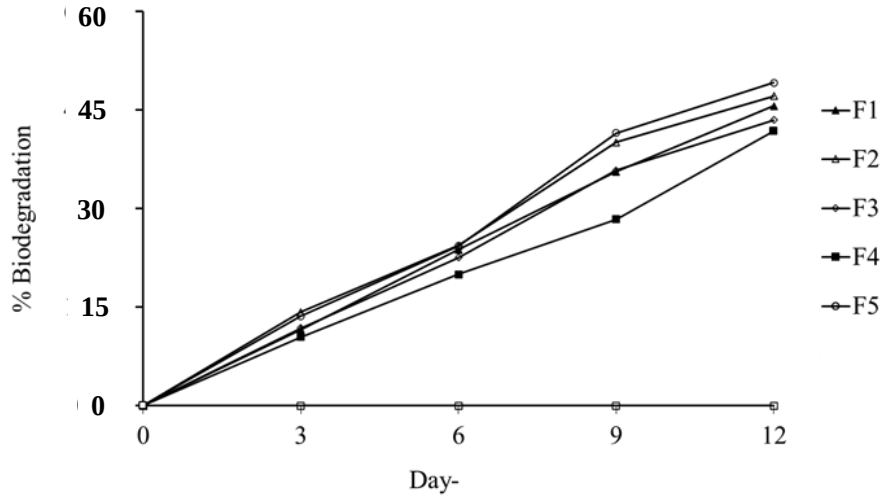


Figure 7. Biodegradation percentage of bioplastic samples

CONCLUSION

The present study demonstrates that cassava peel starch, when combined with chitosan and PVA, can be developed into bioplastics exhibiting enhanced mechanical properties and regulated biodegradation rates. The findings also enhance the value of agro-industrial waste and contribute to the creation of more sustainable materials, which may decrease dependence on traditional plastics in packaging applications. The novelty of this research introduces the dual incorporation of chitosan and PVA into cassava peel starch-based bioplastics, demonstrating their combined effect on improving tensile strength, flexibility, and biodegradability. The interaction of matrix components, particularly through hydrogen bonding, significantly affects tensile strength, flexibility, and degradation behavior. Increasing the concentration of polymers, particularly PVA and chitosan, results in enhanced tensile strength, accompanied by a reduction in elongation and biodegradation rates.

Among the formulations tested, sample F5, which incorporates both PVA and chitosan, exhibited the most balanced performance. The material demonstrated a thickness of 0.25 mm, a tensile strength of 11.95 MPa, an elongation at break of 17.83%, and a biodegradation rate of 49.16% over 12 days. Future research should prioritize the scaling of the production process and the evaluation of the bioplastic's performance in actual packaging settings, encompassing interactions with food and exposure to diverse humidity and temperature conditions. Further research on natural plasticizers, crosslinking agents, or nanofillers could enhance biodegradation rates to comply with international standards. Policymakers and industry stakeholders should consider cassava peel–based bioplastics as a viable approach for waste valorization and sustainable packaging innovation.

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BIBLIOGRAPHY

Abdo, S. M., & Ali, G. H. (2019). Analysis of polyhydroxybutrate and bioplastic production from microalgae. *Bulletin of the National Research Centre*, 43(1). https://doi.org/10.1186/s42269-019-0135-5

Abdullah Al Balushi, K. S., Devi, G., Rashid Khamis Al Gharibi, A. S., Adeeb, M. A. S., Al Hudaifi, A. S. M., & Khalfan Al Shabibi, S. S. (2021). Extraction of bio polymers from crustacean shells and its application in refinery wastewater treatment. *Walailak Journal of Science and Technology*, 18(5), 1–11. https://doi.org/10.48048/wjst.2021.11543

Abral, H., Atmajaya, A., Mahardika, M., Hafizulhaq, F., Kadriadi, Handayani, D., Sapuan, S. M., & Ilyas, R. A. (2020). Effect of ultrasonication duration of polyvinyl alcohol (PVA) gel on characterizations of PVA film. *Journal of Materials Research and Technology*, 9(2), 2477–2486. https://doi.org/10.1016/j.jmrt.2019.12.078

Al-kayyis, H. K., & Susanti, H. (2016). Perbandingan metode somogyi-nelson dan anthrone-sulfat pada penetapan kadar gula pereduksi dalam umbi cilembu (*Ipomea batatas L.*). *Jurnal Pharmascience Community*, 13(02), 81–89. https://doi.org/10.24071/jpsc.2016.130206

Alauhdin, M., Eden, W. T., & Alighiri, D. (2015). Aplikasi spektroskopi inframerah untuk analisis tanaman dan obat herbal. *Jurnal Inovasi Sains dan Kesehatan*, 84–118.

Alfian, A., Wahyuningtyas, D., Sukmawati, P. D., Kimia, J. T., Teknologi, F., Ist, I., Yogyakarta, A., & Lingkungan, J. T. (2020). Pembuatan edible film dari pati kulit singkong menggunakan plasticizer sorbitol dengan asam sitrat sebagai crosslingking agent (variasi penambahan karagenan dan penambahan asam sitrat). *J Inov Proses*, 5(2), 46–56.

Anisa, S., Dalimunthe, G. I., Lubis, M. S., & Yuniarti, R. (2023). Isolasi amilopektin dari pati jagung (*Zea mays L*) yang berpotensi sebagai film coated pada tablet. *Jurnal Farmasainkes*, 3(1), 51–57.

Aripin, S., Saing, B., & Kustiyah, E. (2017). Studi pembuatan bahan alternatif plastik biodegradable dari pati ubi jalar dengan plasticizer gliserol dengan metode melt intercalation. *Jurnal Teknik Mesin*, 6(2), 18–25. https://doi.org/10.22441/jtm.v6i2.1185

Asngad, A., Marudin, E. J., & Cahyo, D. S. (2020). Kualitas bioplastik dari umbi singkong karet dengan penambahan kombinasi plasticizer gliserol dengan sorbitol dan kitosan. *Bioeksperimen: Jurnal Penelitian Biologi*, 6(1), 36–44. https://doi.org/10.23917/bioeksperimen.v6i1.10431

ASTM D882-12. (2012). *Standard Test Method for Tensile Properties of Thin Plastic Testing*. ASTM.

Badan Pusat Statistik Kabupaten Bogor. (2020). Produksi Tanaman Palawija berdasarkan Kecamatan (Ton). Badan Pusat Statistik.

Bidari, R., Abdillah, A. A., Alfredo, R., Ponce, B., & Charles, A. L. (2023). Characterization of biodegradable films made from taro peel. *Polymer*, 15(338), 1–17.

Bracciale, M. P., De Gioannis, G., Falzarano, M., Muntoni, A., Polettini, A., Pomi, R., Rossi, A., Sarasini, F., Tirillò, J., & Zonfa, T. (2024). Disposable Mater-Bi® bioplastic

tableware: Characterization and assessment of anaerobic biodegradability. *Fuel*, 355. https://doi.org/10.1016/j.fuel.2023.129361

Chabbi, J., Jennah, O., Katir, N., Lahcini, M., Bousmina, M., & Kadib, A. E. (2017). Aldehyde-functionalized chitosan-montmorillonite films as dynamically-assembled, switchable-chemical release bioplastics. *Carbohydr Polym*, 11(2), 21–25. https://doi.org/10.1016/j.carbpol.2017.12.036

Charerntanom, W., Buddhakala, M., & Buddhakala, N. (2025). Mechanical Properties, Morphology and Biodegradability of Biopolymer Composites Prepared from Thermoplastic Starch and Polybutylene Succinate Reinforced with Rice Straw Fiber. *Trends in Sciences*, 22(6). https://doi.org/10.48048/tis.2025.9767

Chen, X., Yao, W., Gao, F., Zheng, D., Wang, Q., Cao, J., Tan, H., & Zhang, Y. (2021). Physicochemical properties comparative analysis of corn starch and cassava starch, and comparative analysis as adhesive. *Journal Renew Mater*, 9(5), 789–992. https://doi.org/10.32604/jrm.2021.014751

Cho, B. G., Joshi, S. R., Lee, S., Kim, S. K., Park, Y. B., & Kim, G. H. (2021). Enhanced mechanical and antibacterial properties of nanocomposites based on poly(Vinyl alcohol) and biopolymer-derived reduced graphene oxide. *Polymers (Basel)*, 13(4), 1–17. https://doi.org/10.3390/polym13040615

Crema, A., Dinelli, E., Fabbri, E., Galletti, P., Greggio, N., Lastella, V., Parodi, A., Pasteris, A., Pedrizzi, M., & Samorì, C. (2024). Additives in bioplastics: Chemical characterization, migration in water and effects on photosynthetic organisms. Science of the Total Environment, 955. https://doi.org/10.1016/j.scitotenv.2024.177205

Deliana, P., Khairat, & Bahruddin. (2019). Pembuatan komposit pati sagu/polivinil alkohol (PVA) dengan penambahan kitosan sebagai filler dan gliserol sebagai plasticizer. *JOM Fak. Tek*, 6(1), 1–8.

Dian, N. S. F., & Astili, R. (2018). Kandungan asam sianida dendeng dari limbah kulit singkong. *J Dunia Gizi*, 1(1), 20–29.

Fadjria, N., Zulfisa, Z., Arfiandi, A., & Yolandari, I. (2019). Penentuan kadar karbohidrat pada biji cempedak hutan (*Artocarpus champeden Lour*.) dengan metoda tembaga-iodometri. *J Ris Kim*, 10(2), 93–97. https://doi.org/10.25077/jrk.v10i2.327

Fadlilah, N., & Udjiana, S. (2022). Pembuatan plastik biodegradable dengan variasi jenis filler dan plasticizer. *J Distil*, 8(3), 548–558.

Fikriyah, Y. U., & Nasution, R. S. (2021). Analisis kadar air dan kadar abu pada teh hitam yang dijual di pasaran dengan menggunakan metode gravimetri. *Amina*, 3(2), 50–54.

Fitria, A., Nilandita, W., & Hakim, A. (2023). Karakteristik fisik dan mekanik bioplastik berbahan dasar pati limbah kulit pisang raja bulu (Musa paradisiaca L.var sapientum) dengan variasi jenis plasticizer dan kitosan. *DAMPAK: Jurnal Teknik Lingkungan Universitas Andalas*, 1, 26–32. https://doi.org/https://doi.org/10.25077/dampak.20.1.26-32.2023

Fitriani, S., Yusmarini, Y., Riftyan, E., Saputra, E., & Rohmah, M. C. (2023). Karakteristik dan profil pasta pati sagu modifikasi pragelatinisasi pada suhu yang berbeda. *J Teknol Has Pertan*, 16(2), 10–24. https://doi.org/10.20961/jthp.v16i2.56057

Gea, S., Pasaribu, K. M., Sarumaha, A. A., & Rahayu, S. (2022). Cassava starch/bacterial cellulose-based bioplastics with Zanthoxylum acanthopodium. *Biodiversitas*, 23(5), 2601–2608. https://doi.org/10.13057/biodiv/d230542

Guntarti, A., Ahda, M., Kusbandari, A., & Atmadja, D. (2020). Aplikasi metode FTIR kombinasi kemometrika untuk analisis lemak daging tikus pada nugget ayam. *J Halal Sci Res*, 1(1), 1–8. https://doi.org/10.12928/jhsr.v1i1.1837

Gurunathan, M. K., Navasingh, R. J. H., Selvam, J. D. R., & Čep, R. (2025). Development and characterization of starch bioplastics as a sustainable alternative for packaging. *Scientific Reports*, 15(1). https://doi.org/10.1038/s41598-025-00221-0

Hernández-Jaimes, C., Meraz, M., Lara, V. H., González-Blanco, G., & Buendía-González, L. (2017). Acid hydrolysis of composites based on corn starch and trimethylene glycol as plasticizer. *Rev Mex Ing Quim*, 16(1), 169–178. https://doi.org/10.24275/rmiq/alim764

Jiang, T., Duan, Q., Zhu, J., Liu, H., & Yu, L. (2020). Advanced industrial and engineering polymer research starch-based biodegradable materials: Challenges and opportunities. *Adc Ind Eng Polym Res*, 3(1), 8–18. https://doi.org/10.1016/j.aiepr.2019.11.003

JIS-Z-1707. (1997). *General Rules of Plastic Films for Food Packaging*. Japanese Industrial Standard.

Kemal, N., Siahaan, M., Gustiani, S., & Tekstil, B. B. (2021). Studi pembuatan biokomposit dari limbah tepung manihot. *J Arena Tekst*, 36(2), 67–72.

Kementerian Lingkungan Hidup dan Kehutanan. (2020). *Sistem Informasi Pengelolaan Sampah Nasional*. Kementerian Lingkungan Hidup dan Kehutanan.

Kusumah, A. M., Christian, W., Siregar, T. M., Cornelia, M., & Natania, K. (2023). Pembuatan kemasan biokomposit berbasis pva (polyvinyl alcohol) dan limbah kulit kopi. *Teknotan*, 17(3), 235–242. https://doi.org/10.24198/jt.vol17n3.10

Limbong, S. F., Harsojuwono, B. A., & Hartiati, A. (2022). Pengaruh konsentrasi polivinil alkohol dan lama pengadukan pada proses pemanasan terhadap karakteristik komposit biotermoplastik maizena dan glukomanan. *J Ilm Teknol Pertan Agrotechno*, 7(1), 37–46. https://doi.org/10.24843/jitpa.2022.v07.i01.p05

Maharsih, I. K., Pusfitasari, M. D., Ernawati, L., & Saraswati, C. A. (2022). Formulasi edible coating berbasis limbah pertanian untuk menjaga kualitas nanas. *J Keteknikan Pertan*, 10(2), 145–161.

Maharsih, I. K., Pusfitasari, M. D., Putri, C. A. S., & Hidayat, M. T. (2021). Performance evaluation of cassava peels starch-based edible coating incorporated with chitosan on the shelf-life of fresh-cut pineapples (*Ananas comosus*). *IOP Conference Series: Earth and Environmental Science*, 733(1), 012017. https://doi.org/10.1088/1755-1315/733/1/012017

Maladi, I. (2019). Pembuatan Bioplastik Berbahan Dasar Pati Kulit Singkong (*Manihot utilissima*) dengan Penguat Selulosa Jerami Padi, Polivinil Alkohol dan Bio-Compatible Zink Oksida PVA, Selulosa, dan ZnO Gliserol [Skripsi, Universitas Islam Negeri Syarif Hidayatullah Jakarta].

Maneking, E., Sangian, H. F., & Tongkukut, S. H. J. (2020). Pembuatan dan karakterisasi bioplastik berbahan dasar biomassa dengan plasticizer gliserol. *J MIPA*, 9(1), 23–31. https://doi.org/10.35799/jmuo.9.1.2020.27420

Marsa, Y., Susanto, A. B., & Pramesti, R. (2023). Bioplastik dari karagenan kappaphycus alvarezii dengan penambahan carboxymethyl chitosan dan gliserol. *Bul Oseanografi Mar*, 12(1), 1–8. https://doi.org/10.14710/buloma.v12i1.42859

Maruni, E., Nurlina, N., & Wahyuni, N. (2022). Isoterm adsorpsi Pb(ii) pada karbon aktif tempurung kelapa dengan variasi konsentrasi aktivator natrium bikarbonat. *Indones. J Pure Appl Chem*, 5(2), 73–78. https://doi.org/10.26418/indonesian.v5i2.52987

Melani, A., Herawati, N., & Kurniawan, A. F. (2018). Bioplastik pati umbi talas melalui proses melt intercalation. *J Distilasi*, 2(2), 53–67. https://doi.org/10.32502/jd.v2i2.1204

Mohammed, A. A. B. A., Hasan, Z., Borhana Omran, A. A., Elfaghi, A. M., Ali, Y. H., Akeel, N. A. A., Ilyas, R. A., & Sapuan, S. M. (2023). Effect of sugar palm fibers on the properties of blended wheat starch/polyvinyl alcohol (PVA)-based biocomposite films. *J Mater Res Technol*, 24(2), 1043–1055. https://doi.org/10.1016/j.jmrt.2023.02.027

Mohd-asharuddin, S., Othman, N., Shaylinda, N., & Zin, M. (2017). A Chemical and morphological study of cassava peel : a potential waste as coagulant aid. MATEC Web of Conferences, 6(12), 1–8. https://doi.org/10.1051/matecconf/20171030

Mudaffar, R. A. (2021). Karakteristik edible film dari limbah kulit singkong dengan penambahan kombinasi plasticizer serta aplikasinya pada buah nanas terolah minimal. *Jurnal TABARO Agri Science*, 4(2), 473–483. https://doi.org/10.35914/tabaro.v4i2.669

Muhlis, H., Pradana, A. D., & Leoanggraini, U. (2021). Pemurnian kitosan hasil fermentasi limbah cangkang kepiting menggunakan pelarut asam asetat. *Fluida*, 14(2), 57–64. https://doi.org/10.35313/fluida.v14i2.3097

Mustapa, R., Restuhadi, F., & Efendi, R. (2017). Pemanfaatan kitosan sebagai bahan dasar pembuatan edible film dari pati ubi jalar kuning. *JOM FAPERTA*, 4(2), 1–12.

Nathan, K. G., Genasan, K., & Kamarul, T. (2023). Polyvinyl Alcohol-chitosan scaffold for tissue engineering and regenerative medicine application: A review. *Mar Drugs*, 21(5), 1–18. https://doi.org/10.3390/md21050304

Nisah, K. (2018). Study pengaruh kandungan amilosa dan amilopektin umbi-umbian terhadap karakteristik fisik plastik biodegradable dengan plastizicer gliserol. *Biot J Ilm Biol Teknol dan Kependidikan*, 5(2), 10–26. https://doi.org/10.22373/biotik.v5i2.3018

Nissa, R. C., Fikriyyah, A. K., Abdullah, A. H. D., & Pudjiraharti, S. (2019). Preliminary study of biodegradability of starch-based bioplastics using ASTM G21-70, dip-hanging, and Soil Burial Test methods. *IOP Conference Series: Earth and Environmental Science*, 277(1), 012007. https://doi.org/10.1088/1755-1315/277/1/012007

Nofiandi, D., Yahdian, R., Zaunit, M. M., & Pratiwi, M. (2021). Formulasi dan karakterisasi edible film dari poliblen pati umbi talas kimpul – polivinil alkohol. *J Katalisator*, 6(1), 88–99.

Nugroho, F. (2012). Studi aplikasi membran komposit kitosan–selulosa terhadap rejeksi logam besi (Fe) dan mangan (Mn) pada sumber air minum [Skripsi, Universitas Brawijaya].

Nurrahmi, S., Nuraisyah, S., & Hernawati, H. (2020). Pengaruh penambahan pati dan plasticizer gliserol terhadap sifat mekanik plastik biodegradable. *J Fis dan Ter*, 7(2), 128–138. https://doi.org/10.24252/jft.v7i2.18267

Pamela, Y. V., Syarief, R., Iriani, S. E., & Suyatma, E. N. (2016). Karakteristik mekanik, termal dan morfologi film polivinil alkohol dengan penambahan nanopartikel zno dan asam stearat untuk kemasan multilayer. *J Penelit Pascapanen Pertan*, 13(2), 63–73.

Pongmassangka, L. N., Harsojuwono, A. B., & Mulyani, S. (2021). Optimasi suhu dan lama pengeringan pada pembuatan komposit bioplastik campuran maizena dan glukomanan. *J Rekayasa dan Manaj Agroindustri*, 8, 329–337. https://doi.org/10.24843/JRMA.2020.v08.i03.p02

Prasetya, A., & Apriyani, S. (2019). Pemanfaatan pati kulit ubi kayu sebagai bahan baku edible coating dengan penambahan kitosan untuk memperpanjang umur simpan jeruk rimau gerga lebong (RGL) Bengkulu. *Prosiding Seminar Nasional Teknologi Informasi Komputasi dan Sains*, (2), 247–256.

Purnavita, S., Subandriyo, D. Y., & Anggraeni, A. (2020). Penambahan gliserol terhadap karakteristik bioplastik dari komposit pati aren dan glukomanan. METANA: Media Komunikasi Rekayasa Proses dan Teknologi Cepat Guna, 16(1), 19–25.

Putra, D. P., Harsojuwono, B. A., & Hartiati, A. (2019). Studi suhu dan ph gelatinisasi pada pembuatan bioplastik dari pati kulit singkong. *J Rekayasa Dan Manaj Agroindustri*, 7(3), 441–449. https://doi.org/10.24843/jrma.2019.v07.i03.p11

Qadri, O. R. J., Hamzah, F. H., & Ayu, D. F. (2023). Variasi konsentrasi kitosan dalam pembuatan bioplastik berbahan baku jerami nangka. *Agrointek Jurnal Teknologi Industri Pertanian*, 17(1), 106–113. https://doi.org/10.21107/agrointek.v17i1.14376

Rahim, E. A., Ridhay, A., Halizah, S. N., Sosidi, H., Inda, N. I., Mirzan, M., & Amar, A. A. (2024). Sintesis dan Karakterisasi Polivinil Alkohol (PVA) terlapis polieugenol. *KOVALEN: Jurnal Riset Kimia*, 10(1), 69–76.

Rahmawati, T. E., Cahyani, I. M., & Munisih, S. (2023). Karakterisasi pati bonggol pisang kepok kuning (*Musa paradisiaca L.*) sebagai bahan tambahan sediaan farmasi. *Jurnal Sains dan Kesehatan*, 5(2), 100–108. https://doi.org/10.25026/jsk.v5i2.1658

Rambe, M. S. (2014). Analisa pengaruh pati biji durian durian (durio zibethinus) sebagai bahan pengisi terhadap sifat mekanik dan biodegradasi komposit matrik polipropilena (PP). *Teori dan Aplikasi Fisika*, 02(02), 139–146.

Ratnawati, S. (2017). Processing of plastic waste into alternative fuels in the form pf grounded (pertalastic) through pirolysis process in science laboratory of MTSN 3 West Aceh. *Indonesian Journal of Chemical Science and Technology*, 6(1), 51–66.

Rinaldi, F. S., Gita, M. G., M., H. S. G., & Rosdanelli, H. (2014). Pengaruh penambahan gliserol terhadap sifat kekuatan tarik dan pemanjangan saat putus bioplastik dari pati umbi talas. *J Tek Kim USU*, 3(2), 19–24. https://doi.org/10.32734/jtk.v3i2.1608

Rosmainar, L., Tukan, D. N., & Deviyanti, M. (2021). Perbandingan plastik dari material-material bioplastik. *Jejaring Matematika dan Sains*, 03(01), 19–28.

Salmahaminati, S. (2022). Sintesis kitosan dari cangkang kepiting dengan metode pemanasan microwave selama 2 menit. Indones J Chem Res, 7(1), 27–36. https://doi.org/10.20885/ijcr.vol7.iss1.art4

Saputra, M. R. B., & Supriyo, E. (2020). Pembuatan plastik biodegradable menggunakan pati dengan penambahan katalis zno dan stabilizer gliserol. *Pentana*, 1(1), 41–51.

Saraswati, E., Syahbanu, I., Kimia, A. J., Matematika, F., Ilmu, D., Alam, P., & Tanjungpura, U. (2023). Pengaruh penambahan pati umbi talas (*colocasia esculenta (l.) schott*) terhadap karakteristik plastik biodegradable dengan polimer pva dan filler kalsium karbonat ($CaCO_3$). *Jurnal Ilmu Dasar*, 24(1), 83–90.

Sari, A. R., Martono, Y., & Rondonuwu, F. S. (2020). Identifikasi kualitas beras putih (*Oryza sativa L.*) berdasarkan kandungan amilosa dan amilopektin di pasar tradisional dan "selepan" kota salatiga. *Titian Ilmu J Ilm Multi Sci*, 12(1), 24–30. https://doi.org/10.30599/jti.v12i1.599

Sari, N., Mairisya, M., Kurniasari, R., & Purnavita, S. (2019). Bioplastik berbasis galaktomanan hasil ekstraski ampas kelapa dengan campuran polyvinyl alkohol. *Metana: Media Komunikasi Rekayasa Proses dan Teknologi Tepat Guna*, 15(2), 71–78.

Shi, S., Peng, X., Liu, T., Chen, Y. N., He, C., & Wang, H. (2017). Facile preparation of hydrogen-bonded supramolecular polyvinyl alcohol-glycerol gels with excellent thermoplasticity and mechanical properties. *Polymer(Guildf)*, 111, 168–176. https://doi.org/10.1016/j.polymer.2017.01.051

Simarmata, R., Hartiati, A., & Antara, N. S. (2023). Pengaruh pemlastis dan penguat polivinil alkohol terhadap karakteristik komposit bioplastik pati talas (*Colocasia esculenta L*) dan karagenan. *J Ilm Teknol Pertan AGROTECHNO*, 8(2), 77–89.

Standar Nasional Indonesia. (2016). *Kriteria Ekolabel, Bagian 7: Kategori produk tas belanja plastik dan bioplastik mudah terurai*. Badan Standar Nasional.

Standar Nasional Indonesia. (1992). *Penentuan Karbohidrat dalam Bahan Makanan (Metode Luff Schoorl)*. Badan Standar Nasional.

Standar Nasional Indonesia. (1992). *Tepung Singkong*. Badan Standar Nasional.

Steven, Mardiyati, M., Dyota, A., & Widyanto, B. (2018). Pembuatan dan karakterisasi bioplastik pati-kitosan dengan menggunakan metode dialisis-solution casting. *Mesin*, 27(1), 32–42. https://doi.org/10.5614/mesin.2018.27.1.4

Subamia, I. D. P., Nyoman, N., Ayu, I. G., Sri, N., Lilik, P., & Kristiyanti, P. (2023). Optimasi kinerja alat fourier transform infrared (FTIR) melaui studi perbandingan komposisi dan ketebalan sampel-KBr. *Jurnal Pengelolaan Laboratorium Pendidikan*, 5(2), 58–69.

Sulistyani, M. (2017). Optimasi pengukuran spektrum vibrasi sampel protein menggunakan spektrofotometer fourier transform infra red (Ftir). *Indones J Chem Sci*, 6(2), 173–180.

Sumartono, N. W., Handayani, F., Desiriana, R., Novitasari, W., & Hulfa, D. S. (2015). Sintesis dan karakterisasi bioplastik berbasis alang-alang (imperata cylindrica(l.))dengan penambahan kitosan, gliserol, dan asam oleat. *Pelita: Jurnal Penelitian Mahasiswa UNY*, 10(2), 13–25.

Suryanegara, L., Fatriasari, W., Zulfiana, D., Anita, S. H., Masruchin, N., Gutari, S., & Kemala, T. (2021). Novel antimicrobial bioplastic based on pla-chitosan by addition of TiO_2 and ZnO. *Journal of Environmental Health Science & Engineering*, 19(1), 415–425. https://doi.org/10.1007/s40201-021-00614-z

Suryanto, H. (2019). Biokomposist Starch-Nanoclay: Sintesis dan Karakterisasi [Skripsi, Universitas Negeri Malang].

Syafutri, M. I. (2022). Pengaruh heat moisture treatment terhadap sifat fisikokimia tepung beras merah termodifikasi. *Jurnal Pangan*, 30(3), 175–186. https://doi.org/10.33964/jp.v30i3.530

Syiami, D., Handayani, R., & Najihudin, A. (2021). Pengaruh plastisizer terhadap elastisitas dan kelenturan edible film. *Jurnal Kesehatan Madani Medika*, 12(02), 152–158.

Syuhada, M., Sofa, S. A., & Sedyadi, E. (2020). The effect of cassava peel starch addition to bioplastic biodegradation based on chitosan on soil and river water media. *BioMed Natural Product Chemistry*, 9(1), 7–13. https://doi.org/10.14421/biomedich.2020.91.7-13

Tur-Ridha, N. K. (2019). Potensi hidrogel dari pati kulit singkong sebagai absorben zat warna metanil kuning [Skripsi, UIN Alaudin Makassar].

Utomo, W. A., Argo, D. B., & Hermanto, B. M. (2013). Karakteristik fisikokimiawi plastik biodegradable dari komposit pati lidah buaya (*aloe vera*). *Jurnal Bioproses Komoditas Tropis*, 1(1), 73–79.

Wahyudi, B., & Muljani, S. (2021). Synthesis and characterization edible films from taro strach (*xanthosoma sagittifolium*). *Chemical Sciences Journal*, 15(5), 49–55. https://doi.org/10.9790/2402-1505014955

Warsiki, E., Setiawan, I., & Hoerudin. (2020). Sintesa komposit bioplastik pati kulit singkong-. *Jurnal Kimia dan Kemasan*, 42(2), 37–45.

Wasistha, A. W., Dika, M. R. S., Aulia, A. S., Samudra, N. M., & Putri, D. N. (2021). Physical and mechanical characteristics of edible film based on cassava peel starch. *AGRISAINTIFIKA: Jurnal Ilmu-Ilmu Pertanian*, 5(2), 149–158. https://doi.org/10.32585/ags.v5i2.1877

Weligama Thuppahige, V. T., Moghaddam, L., Welsh, Z. G., Wang, T., & Karim, A. (2023). Investigation of critical properties of cassava (*Manihot esculenta*) peel and bagasse as starch-rich fibrous agro-industrial wastes for biodegradable food packaging. *Food Chemistry*, 422, 136200. https://doi.org/10.1016/j.foodchem.2023.136200

Wening, D. N., & Amalia, R. (2023). Optimasi kondisi operasi pembuatan plastik biodegradable dari selulosa tongkol jagung dan pati kulit singkong dengan penambahan pva dan tio2 sebagai smart packaging. *Rekayasa Proses*, 17(1), 1–9. https://doi.org/10.22146/jrekpros.77598

Widhiantara, I. G., Gde, I. M., & Sandhika, S. (2023). Polimer alam sebagai bahan plastik ramah lingkungan. *Kesehatan Terpadu*, 7(2), 58–63.

Widyaningrum, B. A., Kusumaningrum, W. B., Aulya, F., Pramasari, D. A., Kusuma, S. S., Akbar, F., & Cahyaningtyas, A. A. (2020). PVA dengan penambahan pulp tandan kosong kelapa sawit dan asam sitrat teraktivasi. *Jurnal Kimia dan Kemasan*, 42(2), 46–56.

Wolayan, F. R., Kumajas, N. J., & Rumerung, S. N. (2023). Pemanfaatan kulit umbi ubi kayu terfermentasi dengan Rizhopus oligosporus dalam ransum terhadap efisiensi ransum broiler. *Zootec*, 43(2), 168–176.

Wrońska, N., Katir, N., Nowak-Lange, M., & Kadib, A. E. (2023). Biodegradable chitosan-based films as an alternative to plastic packaging. *Br Food J*, 60(3), 2–12. https://doi.org/10.1108/eb011552

Yuliana, N., & Huzairi, N. (2021). Karakteristik fisik komposit plastik polyethylene terephthalate (pet) berbasis serat alam daun pandan laut (Pandanus tectorius) dan aplikasinya sebagai bahan baku casing pada produk elektronik. *Bul Profesi Ins*, 4(2), 58–61.

Yustinah, Y., AB, S., Solekhah, P. P., Novitasari, G. P., Nuryani, F., Djaeni, M., & Buchori, L. (2023). Pengaruh jumlah kitosan dalam pembuatan plastik biodegradabel dari selulosa sabut kelapa dengan pemplastik gliserol. *Jurnal Riset Sains dan Teknologi*, 7(2), 149–155. https://doi.org/10.30595/jrst.v7i2.15598

Zahiruddin, W., & Ariesta, A. (2018). Karakteristik mutu dan kelarutan kitosan dari ampas silase kepala udang windu (Penaeus monodon). *Buletin Hasil Perikanan*, 9(2), 140–151.