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Research Paper

Manufacturing and Characterization of Bioplastic from Chitosan and Rambutan Seed (*Nephelium lappaceum* L.) Starch with the Addition of Sorbitol as Plasticizer

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Abstract
A bioplastic formulated from chitosan and rambutan seed starch (*Nephelium lappaceum* L.), with sorbitol added as a plasticizer, presents a promising innovation to reduce the reliance on conventional plastics, which contribute to an annual waste accumulation of 381 million tons. This study aims to produce bioplastic from chitosan and rambutan seed starch, to analyze its physical and mechanical properties, and to determine the optimal composition. The bioplastic was fabricated using the solution casting method, with heating at 85-95°C and drying in an oven at 60°C for approximately 24 hours. The resulting bioplastic exhibited favorable tensile strength and elongation, as well as rapid biodegradability in soil. FTIR analysis revealed functional groups including O−H, C−H, N−H, C−O, and C−C, indicating the presence of corresponding components. The best composition was achieved with a starch-to-chitosan ratio of 40:60% and 20% sorbitol, resulting in a thickness of 0.21 mm, density of 0.80 g/cm^3, water absorption of 41.17%, tensile strength of 52.53 N/mm^2, elongation of 22.64%, and biodegradability of 36.67%. TGA analysis showed three degradation stages i.e. water dehydration, starch degradation, and chitosan degradation.

Keywords
Bioplastic, Chitosan, *Nephelium lappaceum*, Plasticizer, Sorbitol, Starch

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1. INTRODUCTION

Every year, the world produces around 380 million tons of plastic waste, most of which comes from synthetic materials with high durability. This resilience, although beneficial in the short term, results in the accumulation of large amounts of plastic waste in landfills and waters (Okunola et al., 2019), triggering a global environmental crisis that is difficult to address. One solution that is attracting increasing attention is bioplastics (Rahmatullah et al., 2022), namely biodegradable plastics that can be broken down by microorganisms. However, although bioplastics from renewable biopolymers such as cellulose, starch, protein, and lactic acid have decomposition rates 10 to 20 times faster than conventional plastics (Ncube et al., 2020), their widespread application is still constrained by several factors, including mechanical properties, production costs, and environmental resistance. To address these challenges, developing starch-based bioplastics as a more environmentally friendly and economical alternative is highly desirable.

There has been a notable shift in the history of food packaging development, particularly with the switch from hazardous to renewable resources (Istiqomah et al., 2024). Rambutan seeds offer potential as a raw material for starch production, leveraging their high carbohydrate content. Rambutan seeds are frequently discarded as waste in the rambutan canning industry, generating around 94,500 tons per year in countries like Thailand, Indonesia, and Malaysia. Incorrect management in the direct consumption and industrial processes of these seeds and husks can lead to environmental impact and loss in finances (Azzatul et al., 2020). However, the rambutan seeds constitute important components, including carbohydrates at 48.1%, protein at 12.4%, and fat at 38.9% (Jahurul et al., 2020). Thus, the utilization of rambutan starch as a precursor in the synthesis of bioplastics is needed and can solve this issue quite efficiently.

Starch is one of the natural polymers with properties close to synthetic polymers, affordable price, sufficient availability, and good novelty (Kusumawati et al., 2025). Starch has

been widely researched in the realm of bioplastics because it is easy to mix due to its polysaccharide constitution, which comfortably allows itself to be mixed with plasticizers and water. Starch is made up of two main components, amylose and amylopectin. Amylose is a linear polysaccharide of molecular weight 105-106 g mol-1 with α-(1-4)-D-glucose linkages, while amylopectin is a larger branched polymer of molecular weight 107–109 g mol-1 with α-(1-6)-D-glucose bonds. The structures of amylose and amylopectin can be seen in Figure 1.

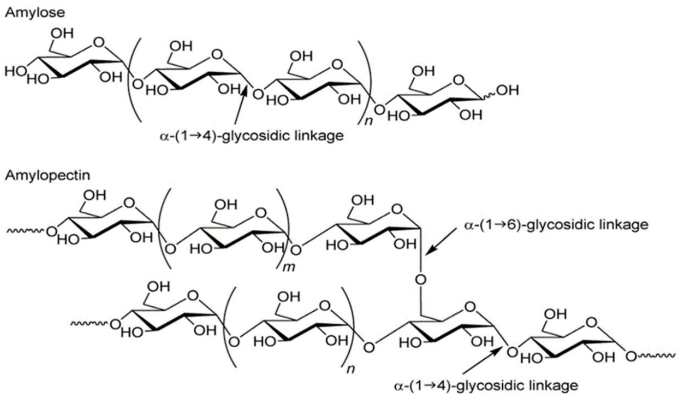


Figure 1. The Structures of Amylose and Amylopectin

Another disadvantage of starch-based bioplastics is that they are highly hydrophilic, and generally, such formulations have low mechanical performance. To a larger extent, improving the interaction of the biopolymer, chitosan, reduces these drawbacks by reducing the water absorption of the matrix. Chitosan is a biopolymer obtained from chitin, the exoskeleton of arthropods and insects, and fungi and bacteria (Brigode et al., 2020), made up 2-acetamido-2-deoxy-β-D-glucopyranose and β-D-glucopyranose-2-amino-2-deoxy linked through β-1-4-bonds (Grzybek et al., 2022). Advantages of chitosan are its biodegradability, non-toxicity, cheapness, and ample availability in nature. Furthermore, it improves the tensile strength of bioplastics (Khajavian et al., 2022). A lot of research has been done on starch/chitosan films in recent years. Starch/-chitosan film is seen as a potential option because of its biocompatible, easily modifiable, and environmentally beneficial qualities (Kusumaningsih et al., 2023), utilising the complementary qualities of Ch and starch to create biodegradable films with improved barriers for a range of uses. This innovation has the potential to significantly reduce environmental effects while improving the functionality of packaged products' preservation and protection (Istiqomah et al., 2025).

Since starch and water-based bioplastics are generally brittle and rigid in nature, plasticizers need to be incorporated to enhance their elasticity. Plasticized systems are used to increase flexibility and, therefore, depend heavily on the nature and percentage composition of the plasticizer, so suitable plasticizers need to be selected, enabling consideration between molecular weight and polarity in order to achieve stability over long periods (Aguilar et al., 2020). Commonly known plasticizers are glycerol, sorbitol, and polyethylene glycol. In acrylic films, sorbitol is preferred due to its stability as well as low toxicity (Lim et al., 2020). Sorbitol has the chemical formula $C_6H_{14}O_6$. It is synthesized as D-glucose by catalytic hydrogenation; its structure is similar to that of hexane (C_6H_{14}) (Gunawan et al., 2021). The higher the concentration of the plasticizer, the lower the tensile pressure on the film, and the higher the tension.

Based on the previous introduction, the purpose of this study is to develop and characterize bioplastics from a combination of chitosan, rambutan seed starch (*Nephelium lappaceum* L.), and sorbitol plasticizer, with a focus on evaluating the structural integration and functional group composition through FTIR analysis. In this study, sorbitol was utilized at concentrations of 20%, 40%, and 60% (v/v). Furthermore, to optimize and characterize the formulation of bioplastics made from chitosan and rambutan seed starch (*Nephelium lappaceum* L.) with sorbitol as a plasticizer, with a focus on mechanical properties, water absorption, biodegradation, and thermal degradation behavior.

2. EXPERIMENTAL SECTION

2.1 Chemicals

Rambutan seed starch, chitosan (medium molecular weight Sigma Aldrich), sorbitol (20%,40%,60%) (v/v), CH_3COOH Merck p.a, Na_2CO_3 Merck p.a, HCl Merck p.a, $Na_2S_2O_3$ Merck p.a, $NaHCO_3$ Merck p.a, KI Merck p.a, and water.

2.2 Instrumentations

Hotplate stirrer (Thermo Scientific), Analytical balance (Fujitsu), Drying oven (Memmert), Universal Testing Machine (Zwick Roell 20), FTIR (Agilent Cary 630), TG-DTA (Linseis PT1600) equipped with nitrogen flow to temperature with a heating rate of 10°C/minute.

2.3 Procedure

2.3.1 Starch Extraction

The preparation process involved peeling and cleaning 1.950 kg of rambutan seeds, which were then ground and dried in the sunlight for 6 hours. The dried seeds were blended with water in a 1:5 (w/v) ratio and allowed to macerate for 48 hours. The wet starch was oven-dried at 50°C for approximately 24 hours, ground to a fine powder, and passed through a 100-mesh sieve for further processing.

2.3.2 Starch Characterization

Rambutan seed starch was characterized by moisture content testing (SNI-01-2891-1992), carbohydrate content analysis via the Luff-Schoorl method, and evaluation of the gelatinization profile using a Rapid Visco Analyzer (RVA). The RVA process included both heating and cooling phases. The RVA procedure included continuous stirring at 160 rpm, where the starch suspension was heated from 50°C to 95°C at a rate of 6°C per minute and held at 95°C for 5 minutes. The cooling phase then decreased the temperature to 50°C at 6°C per minute, holding it for 2 minutes.

2.3.3 Bioplastic Manufacturing

Bioplastic was manufactured using the solution casting technique, where starch and chitosan were measured in various ratios: 30%:70%, 40%:60%, 50%:50%, and 60%:40%. A starch solution was prepared by dissolving starch in distilled water in a 1:20 (w/v) ratio, while the chitosan solution was made by dissolving chitosan in a 1% (v/v) CH_3COOH solution at a ratio of 1:40 (w/v). Sorbitol, used as a plasticizer, was prepared at concentrations of 20%, 40%, and 60% (v/w). An illustration of the solution casting method can be seen in Figure 2.

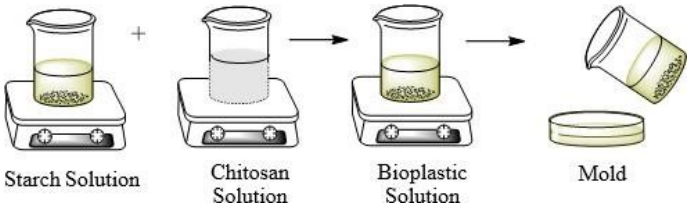


Figure 2. Solution Casting Method

These solutions were homogenized using a magnetic stirrer at 400 rpm for around 25 minutes at a gelatinization temperature of 85–95°C. A total of 50 mL of the mixture was poured into a 20 × 20 cm mold and dried in an oven at 60°C for about 24 hours. The final product was placed in a desiccator for 24 hours before analysis.

2.3.4 Bioplastic Characterization

The characterization of bioplastics began with thickness measurement, followed by assessments of water absorption and biodegradation. Water absorption testing was performed to determine how much water the material can retain. Biodegradation was assessed using a soil burial test, where 2 cm × 2 cm bioplastic samples were buried in humus soil for 7 days, and residual weights were recorded on the 3rd, 5th, and 7th days to track microbial degradation.

Following the thickness analysis, mechanical properties such as tensile strength and elongation at break were evaluated. The bioplastic films were cut to dimensions of 1 cm × 10 cm and had a thickness of 7 mm. These samples were tested using a Universal Testing Machine (UTM) with a load of 10 kg, following ASTM D882 specifications. The films with the highest tensile strength and elongation were selected for Fourier Transform Infrared (FTIR) and Thermogravimetric Analysis (TGA).

The FTIR analysis provided a spectrum of wavenumbers and transmittance, which was used to identify functional groups in the bioplastic. For TGA, the sample was analyzed using a Shimadzu TA 50 instrument. A 12 mg sample was heated from room temperature to 600°C at a rate of 10°C per minute, with weight changes being monitored throughout the process. The decomposition peaks were determined from the resulting thermogram.

3. RESULTS AND DISCUSSION

3.1 Starch Characteristic

Rambutan seed starch exhibits a fine solid texture similar to flour, with a white to pale yellow hue attributed to the oven drying process, and carries a distinct aroma reminiscent of rambutan seeds. This study used 1,950 g of seeds, yielding 512.20 g of starch, which corresponds to a 26.26% yield. The extraction was performed via maceration with water, an environmentally friendly method.

Water Content: The water content is a vital characteristic that affects a product's appearance, texture, and shelf life. It also influences the material's freshness and durability; a higher water content can promote the proliferation of bacteria, molds, and fungi, thus impacting the material's resistance (Donmez et al., 2021). The experiment revealed that the water content of rambutan seed starch was 13.81%, in accordance with the SNI-01-2891-1992 standard, which sets the maximum permissible water content for flour or starch at 14%.

Carbohydrate Content: The carbohydrate content of rambutan seed starch was analyzed using the Luff-Schoorl method, which is based on the interaction between monosaccharides and a copper solution. This method is founded on the reduction of cupric oxide (Cu^{2+}) to cuprous oxide (Cu^{+}). Monosaccharides reduce CuO present in the Luff solution to Cu_2O, while any excess CuO reacts with excess potassium iodide (KI) to release iodine (I_2). The released iodine is then titrated with a sodium thiosulfate ($Na_2S_2O_3$) solution. This method employs iodometric titration, a redox titration that involves measuring the iodine produced in the reaction against a standard sodium thiosulfate solution (Boshagh, 2021). The carbohydrate content in the rambutan seed starch sample is calculated as the difference between the titration volumes of the blank and the sample, using established tables for reference. The experimental results indicated an average carbohydrate content of 58.33% in rambutan seed starch, compared to a literature value of 56.56% for carbohydrate content in rambutan seeds (Diez et al., 2020).

Gelatinization Profile: The purpose of the RVA analysis is to determine the gelatinization profile of the rambutan seed starch displayed on Figure 3.

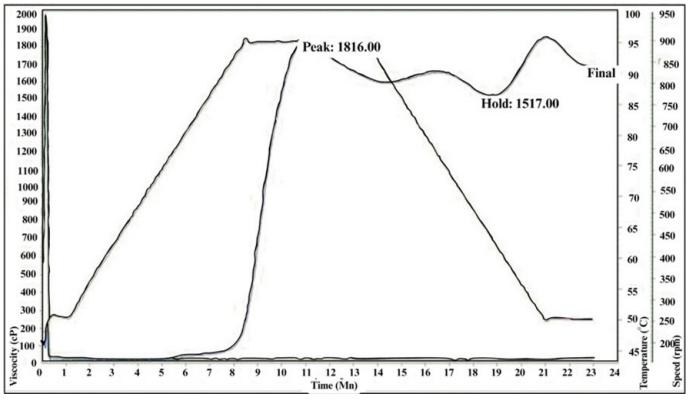


Figure 3. Rambutan Seed Starch Gelatinization Profile

According to the RVA test results, the pasting temperature at which starch begins to gelatinize was determined to be 93.55°C. The maximum viscosity observed during the heating phase was 1816 cP. The viscosity of the hot paste, maintained at 95°C, was measured, resulting in a breakdown viscosity of 299 cP, calculated as the difference from the maximum viscosity. The cold paste viscosity, recorded at 50°C, was found to be 1680 cP, leading to a setback viscosity of 163 cP when comparing cold and hot paste viscosities. Additionally, the peak time was recorded at 10.73 seconds. These results differ from those documented in the literature, likely due to variations in the rambutan varieties used.

3.2 Bioplastic Characteristic

The results of mixing chitosan, rambutan seed starch, and plasticizers produce transparent bioplastics that tend to be yellow with speckled surfaces. The estimation of hydrogen interactions between amylose and amylopectin molecules in starch, chitosan, and plasticizers can be seen in Figure 4.

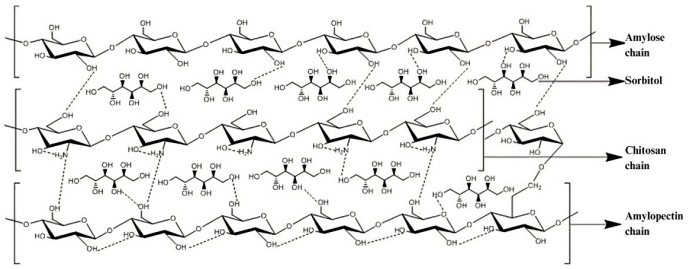


Figure 4. Hydrogen Interaction in Bioplastic

By interfering with the hydrogen bonds between neighboring polymer molecules, sorbitol reduces the strength of the intermolecular attractions that exist within the polymer chains.

3.2.1 Thickness

Thickness analysis aims to ascertain the thickness of bioplastics, impacting their physical properties. The bioplastic film's thickness was measured in five different spots using a Digital Thickness Gauge, allowing for the calculation of an average value from these measurements. This gauge has an accuracy of 0.01 mm. The thickness of the bioplastic is shown in Figure 5.

Figure 5 demonstrates that the bioplastic film thickness ranges from a maximum of 0.27 mm to a minimum of 0.20 mm. The findings suggest that the thickness of the bioplastic films produced is largely uniform, showing little difference across the samples.

3.2.2 Water Absorption Ability

Water absorption analysis is conducted to evaluate how much water the material can absorb. Chitosan has the potential to reduce the water absorption capability of bioplastics. In contrast, increasing the amounts of starch and plasticizer will lead

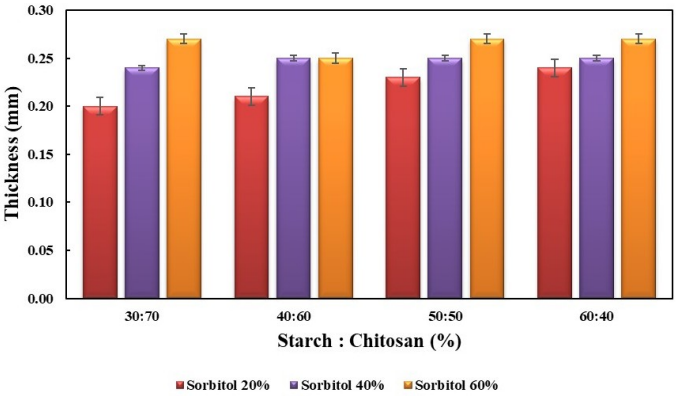


Figure 5. Thickness of Bioplastic at Varying Sorbitol Concentrations

to greater water absorption. The hydrophilic properties of plasticizers, due to their hydroxyl groups that can form hydrogen bonds with water, contribute to this phenomenon (Pradeep et al., 2022). The water absorption of bioplastic is shown in Figure 6.

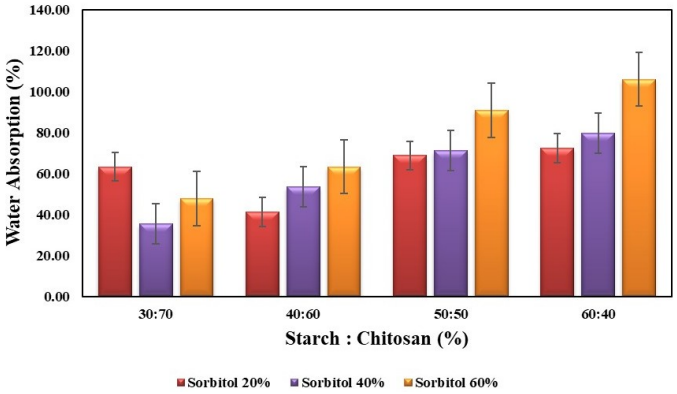


Figure 6. Water Absorption of Bioplastic

The addition of varying amounts of starch and chitosan in the production of bioplastics impacts their water absorption characteristics. Figure 6 demonstrates that as the amount of chitosan increases, the water absorption decreases, resulting in bioplastics that are more resistant to water. A higher chitosan composition leads to a lower percentage of water absorption in the film. Conversely, increased starch content creates more pores in the bioplastic film, enhancing its water absorption capability. This increased water absorption can impair the mechanical properties of the bioplastic film, as it interferes with molecular chain interactions, increases diffusivity, and allows for greater absorption of water vapor from the atmosphere (Sariningsih et al., 2019).

3.2.3 Biodegradability

Biodegradability analysis is used to find out how quickly bioplastics can be degraded by microorganisms in the soil. The

biodegradability of bioplastic is shown in Figure 7.

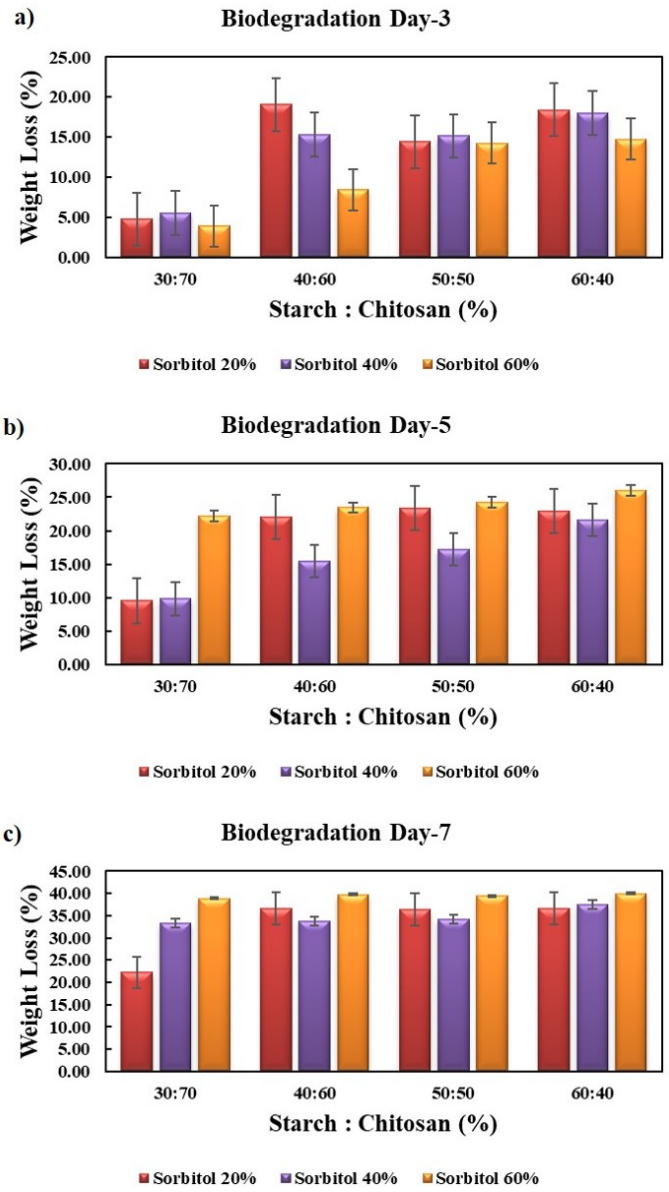


Figure 7. Weight Loss (%) of Bioplastics on Day-3 (a), Day-5 (b), and Day-7 (c)

Bioplastics from chitosan and rambutan seed starch with the addition of sorbitol plasticizer can be easily degraded in the soil because they contain hydroxyl (OH) and carbonyl (CO) groups derived from starch, which are hydrophilic, so they have good water absorption ability. Water molecules cause microorganisms in the soil to enter the plastic matrix. Bacteria prefer aqueous nutrients (Webb et al., 2013). Table 1 shows the documentation of the biodegradation test before and after being buried in the soil on day 7.

Increasing the amount of chitosan leads to a decrease in the weight loss percentage. Chitosan is biodegradable and provides sufficient mechanical strength and elasticity in film applications, yet it also exhibits antioxidant and antimicrobial properties that may hinder the biodegradation process (Oberlintner et al., 2022). The structure of chitosan consists of D-glucosamine and N-acetyl-D-glucosamine units linked by glycosidic bonds in a random arrangement. The presence of hydrophobic N-acetyl-D-glucosamine units in the main chain reduces water-binding capacity, which in turn lowers its biodegradability (Huang et al., 2022). On the other hand, higher concentrations of sorbitol plasticizers lead to an increase in weight loss percentage, as plasticizers are typically hydrophilic (Ballesteros-Mártinez et al., 2020).

3.2.4 Tensile Strength and Elongation at Break

Tensile strength analysis is conducted to determine the maximum force that bioplastic can withstand before breaking. This property is vital for bioplastic films, as high tensile strength ensures adequate protection for packaged items against mechanical disturbances. In contrast, elongation at break is defined as the percentage increase in the length of the bioplastic material upon breaking. The purpose of the elongation test is to measure the elasticity of the bioplastic (Gabriel et al., 2021). The tensile strength and elongation at break of bioplastic can be seen in Figure 8.

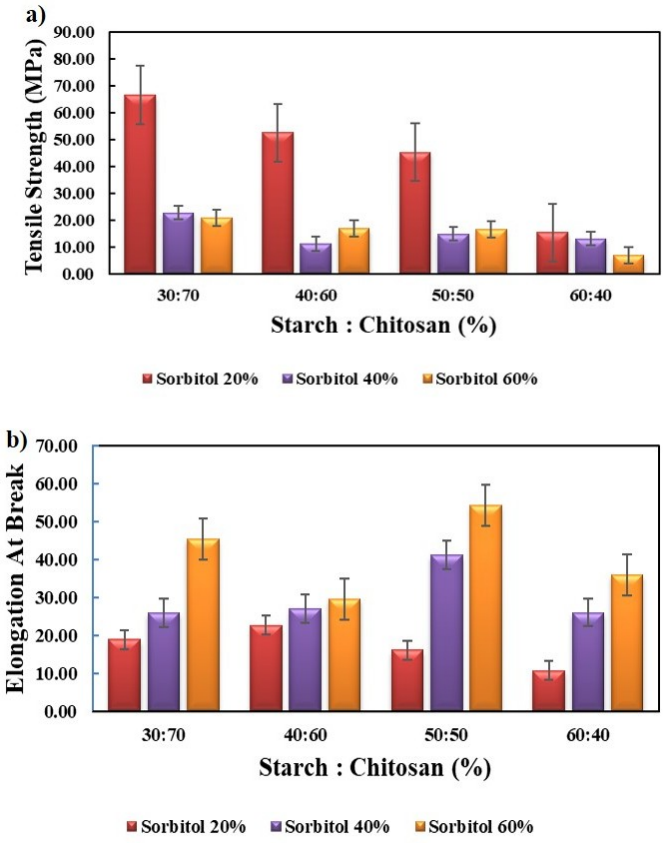
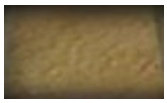


Figure 8. Tensile Strength of Bioplastic (a) and Elongation at Break of Bioplastic (b)

Table 1. Biodegradation Test Results Before and After Being Buried in the Soil on the 7th Day

Starch : Chitosan (%)	Sorbitol (%)	Before	After
30 : 70	20		
40 : 60	20		
50 : 50	20		
60 : 40	20		
30 : 70	40		
40 : 60	40		
50 : 50	40		
60 : 40	40		
30 : 70	60		
40 : 60	60		
50 : 50	60		
60 : 60	60		

Bioplastics derived from rambutan seed starch exhibit favorable tensile strength and elongation at break properties. An increase in chitosan content enhances the tensile strength while decreasing the elongation at break. The incorporation of chitosan into the starch matrix promotes the formation of intermolecular hydrogen bonds, resulting in stronger molecular connections (Suryanegara et al., 2021). In contrast, the addition of sorbitol plasticizer results in a reduction of tensile strength but an increase in elongation at break. This effect is attributed to the ability of plasticizers to weaken internal hydrogen bonds and diminish the intermolecular forces between neighboring polymer chains (Ibrahim et al., 2019).

The incorporation of rambutan seed starch yields bioplastics with commendable tensile strength properties. Hydroxyl groups play a crucial role in facilitating intermolecular and intramolecular hydrogen bonding, leading to enhanced cross-

linking between the filler and matrix. This mechanism promotes compactness among the components of the bioplastic, which contributes to their stiffness (Oluwasina et al., 2021). Rambutan seed starch is primarily composed of two elements: the linear chains of amylose and the branched chains of amylopectin. Amylose generally forms hard gels and durable films, while amylopectin is more prone to dispersion in water, producing soft gels and weaker films. Additionally, the linear arrangement of chitosan enhances the compactness of the overall structure (Istiqomah et al., 2022a).

3.2.5 Fourier Transform InfraRed (FTIR)

The characterization of bioplastics was performed using FTIR spectroscopy to examine the interactions between the various components of the bioplastic films. The analysis included three samples: rambutan seed starch, chitosan, and the bioplastic film. The results of FTIR identification are shown in Figure 9.

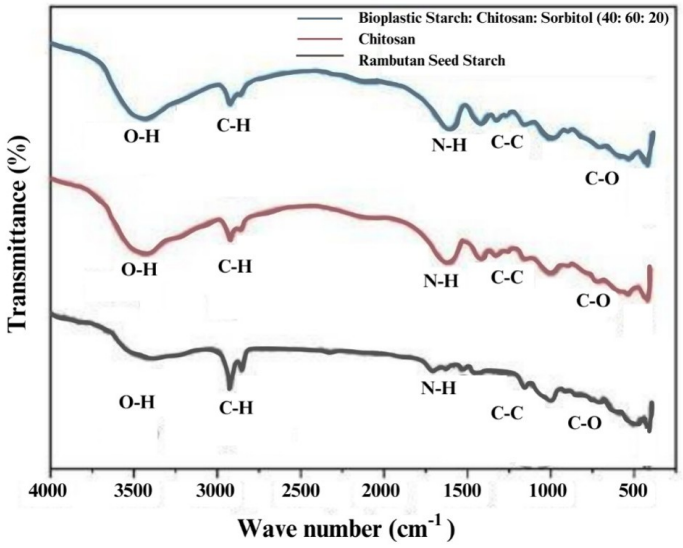


Figure 9. FTIR Spectra of Bioplastic

Rambutan seed starch features a primary structure formed by amylose and amylopectin, as evidenced by the presence of O−H, C−H, and C−O groups. The absorption peak observed at a wavenumber of 3402.58 cm^{-1} confirms the presence of hydroxyl groups in rambutan seed starch. Additional absorption peaks at 2923.25 cm^{-1} and 2854.77 cm^{-1} indicate C−H groups, while peaks at 1154.45 cm^{-1}, 1076.33 cm^{-1}, and 999.17 cm^{-1} point to the presence of C−O−C, C−C, and C−O groups (Awolu et al., 2020).

The results of the FTIR analysis of chitosan indicate an absorption peak at 3430.55 cm^{-1}, reflecting the N−H and O−H stretching vibrations (Istiqomah et al., 2022b). Peaks at 2858.63 cm^{-1} and 2922.28 cm^{-1} are associated with C−H stretching vibrations. A symmetrical N−H functional group is confirmed by an absorption peak at 1616.42 cm^{-1}. Additionally, stretching vibrations for the C−O−C bridge and C−O groups appear at 1159.27 cm^{-1} and 998.21 cm^{-1}, respectively (Fatoni et al., 2018).

The FTIR analysis of the bioplastic film revealed absorption peaks around 3000 cm^{-1}, specifically between 3431.51 cm^{-1} and 3501.92 cm^{-1}, indicating the presence of O−H groups. The peaks at 2921.32 cm^{-1} to 2981.11 cm^{-1} correspond to C−H groups, while the range of 1612.56 cm^{-1} to 1716.72 cm^{-1} in the bioplastic spectra signifies the presence of N−H groups. The shifts observed in the wavenumbers of the O−H and N-H groups suggest interactions through hydrogen bonding between the polysaccharide and chitosan molecules within the film. Furthermore, an absorption peak at 1160.23 cm^{-1} indicates the presence of C−C groups, and another peak at 1003.03 cm^{-1} suggests C−O groups. Consequently, it can be concluded that the bioplastic is formed through the physical mixing of the raw materials, specifically starch and chitosan.

3.2.6 Thermo Gravimetric Analysis (TGA)

TGA analysis aims to assess the thermal stability of bioplastics derived from starch and chitosan, focusing on their environmental sustainability. This thermal properties assessment can provide valuable information regarding the physical changes that occur within the bioplastics. The results of the thermal analysis are illustrated as a curve called a thermogram. The results of the thermogravimetric analysis of bioplastics can be seen in Figure 10.

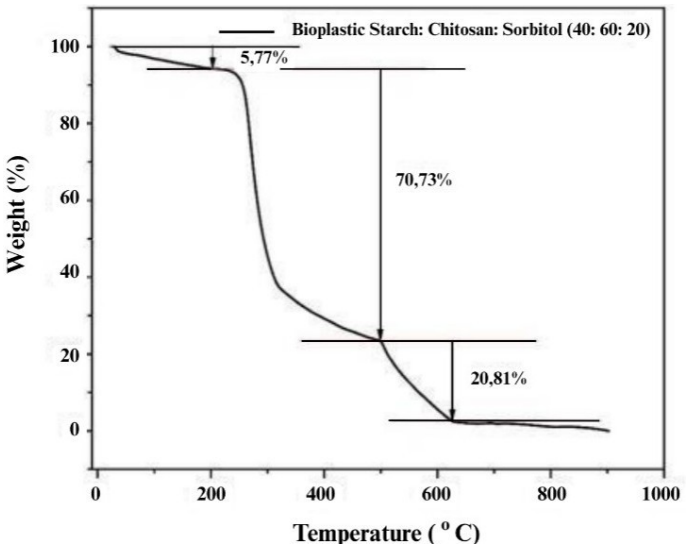


Figure 10. Thermogravimetric Graph of Bioplastic

The TGA results for bioplastics formulated with a 40:60% starch-to-chitosan ratio and 20% sorbitol plasticizer demonstrated distinct phases of the decomposition process. The first phase occurs between 30.528°C and 216.593°C, where a weight loss of 5.77% is recorded. This phase is characterized by the dehydration of water, leading to the loss of volatile compounds and thermal decomposition through water evaporation (Neelam et al., 2018). The need for high temperatures to evaporate water indicates that the water in the bioplastic is bound

to other components, rather than being free water. The second degradation phase occurs from 216.593°C to 487.170°C, with a weight loss of 70.73%, which corresponds to the degradation of starch derived from rambutan seeds (Istiqomah et al., 2022b). Finally, the third degradation phase occurs between 487.170°C and 628.101°C, leading to a weight loss of 20.81%, attributed to the degradation of chitosan (Pradeep et al., 2022).

4. CONCLUSIONS

The combination of chitosan, rambutan seed starch, and sorbitol plasticizer has succeeded in producing bioplastics with dimensions of 20 cm × 20 cm, which are transparent with a yellowish hue and a spotted surface. The results of FTIR analysis showed the presence of functional groups corresponding to the raw materials, which confirmed the successful integration of these components in the bioplastic structure. The optimal bioplastics formulation was obtained with a starch to chitosan mass ratio of 40:60%, with the addition of 20% sorbitol as a plasticizer. Further characterization shows that this bioplastic has a water absorption capacity of 41.17%, a tensile strength of 52.53 N/mm^2, an elongation of up to 22.64%, and a biodegradation rate of 36.67%. TGA revealed the presence of three main degradation phases: water dehydration, starch breakdown, and chitosan decomposition, confirming the thermal stability and biodegradability of the bioplastics under the tested conditions. These results confirm that the combination of materials used is not only capable of creating bioplastics with good mechanical and thermal properties, but also shows significant potential as an environmentally friendly alternative for bioplastic applications. Further research is needed to understand the degradation mechanisms in more detail and optimize formulations for specific applications.

5. ACKNOWLEDGMENT

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