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Original Paper

The Effects of Modifying Agents on the Production of Bioplastic from Sago

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***Abstract*—This study aims to develop sago starch-based bioplastics with the addition of modifying agents such as acetic acid, chitosan, and glycerin to improve mechanical properties, elongation, and biodegradability. The results showed that the optimal combination was reached at 4% acetic acid and 2% chitosan concentration, resulting in the highest tensile strength of 8 MPa, elongation at break of 26%, and degradation rate of 70%. At this condition, the bioplastic matrix has an optimal balance between strength, flexibility, and degradability. Increasing the acetic acid concentration to 6% caused a decrease in tensile strength to 4.2 MPa and elongation at break to 14%, indicating degradation of the matrix structure due to excess acid. Chitosan also affected the mechanical properties, where increasing its concentration from 2% to 4% tended to decrease the elongation at break. The degradation rate tended to increase with higher concentrations of acetic acid, reaching 82% at 6% acetic acid concentration with 2% chitosan, while higher concentrations of chitosan (4%) slowed down the degradation due to a denser and stronger matrix structure. Overall, the combination of sago starch, acetic acid, chitosan, and glycerin produced bioplastics that have improved mechanical properties, water resistance, and environmental friendliness, making them a potential alternative to replace conventional plastics in various industrial applications. These findings support the development of environmentally friendly materials that can reduce the negative impacts to the environment in general and in Papua as the local producer of Sago.**

***Keywords*—Biodegradable Plastic, Modifying Agents, Sago Starch, Environmentally Adapted, Papua**

I. INTRODUCTION

Synthetic plastics have become an integral part of everyday life, mainly due to their versatility, durability and relatively low production cost. However, the environmental impact caused by the accumulation of non-biodegradable plastic waste is a global concern. Synthetic plastics take hundreds of years to degrade, and their overuse causes pollution that damages ecosystems [1-2]. This has led to the development of more environmentally friendly plastic alternatives, one of which is bioplastic. Bioplastics are polymeric materials derived from renewable natural resources, such as starch, cellulose, and protein [1-4]. One of the potential raw materials for bioplastic production is sago starch, which is widely available in Southeast Asia, including Indonesia. Sago has the advantage of containing a high concentration of starch, which can be used as a base material for the manufacture of bioplastics [2-3], [5-6].

Sago (Metroxylon sagu) is one of the world's largest starch-producing crops, with a distribution spanning the tropics, particularly in Indonesia and Papua New Guinea. Sago starch has unique characteristics, including gelling ability, which makes it suitable for applications in bioplastic production. In addition, sago is a renewable and abundant resource, so it can be used as an alternative to starch from other sources that often compete with food needs, such as corn or potato starch. However, sago starch has some intrinsic limitations, such as low mechanical properties and water instability [7]. Therefore, in order to improve the quality of sago starch-based bioplastics, modifications need to be made, either through the addition of a number of modifying agents such as plasticizers, chitosan, or certain organic acids [6,8-10]. An interesting modification

model to investigate is the addition of acetic acid, chitosan and glycerin in the production process of bioplastics from sago.

Acetic acid, with the chemical formula CH_3COOH, is a simple carboxylic acid that is widely used in various industries. In the context of bioplastic production, acetic acid acts as a modifying agent that can affect the physical and chemical properties of bioplastics. The addition of acetic acid to sago starch can improve the film-forming ability and mechanical strength of bioplastics, while reducing their brittle properties. Acetic acid works by breaking the bonds between starch molecules, thus facilitating the formation of a more homogeneous polymer. Other than acetic acid, glycerin can also act as a plasticizing agent, which can improve the flexibility and elasticity of the final product. Glycerin is used in many industrial applications and now due to its characteristic, it is possible to be adopted for the use of bioplastic production. Moreover, for maintaining the structure stability of bioplastics, chitosan has been used.

The mechanical properties of bioplastics, such as tensile strength and elongation, are crucial to determine their application in commercial products. Good biodegradability is one of the main advantages of bioplastics [11-12], and the addition of modifier agents are not expected to reduce the ability of bioplastics to biodegrade. The results of this research are expected to contribute to the development of more efficient and environmentally friendly bioplastics, while utilizing local natural resources, such as sago, as an alternative raw material in the production of renewable plastics.

II. Material And Methods

A. Material

This research aims to produce bioplastics from sago starch by modifying its mechanical and physical properties through the addition of acetic acid, chitosan, and glycerin and mixed well in deionized water. Sago starch that serves as a source of starch to form bioplastics. Sago starch was obtained from local supplier in Jayapura, Papua. While three modifying agents of Acetic acid, Chitosan and Glycerin were ordered from Chemical supplier in Jakarta. Other than material, the following are the tools used in the research of making sago-based bioplastics such as Hot Plate and Stirrer, Beaker Glass, Thermometer, Analytical Balance, Aluminum Foil or Glass Plate, Oven, Aluminum dish, Drop Pipette, Spatula, Tongs, Stopwatch and Physics characterization.

B. Methods

The methods used includes several main stages, namely material preparation, preparation of sago starch solution, addition of modifying agents, bioplastic film formation, and testing the properties of the resulting bioplastics. To proceed the experiment, deionized water was used as a solvent.

1) Stage 1

The first step in the bioplastic manufacturing process is to prepare the sago starch solution. Sago starch as much as 8% (by weight) or 4 gr was dissolved in 50 ml of distilled water, then heated at 75-90°C while stirring until a homogeneous solution was formed. The heating process is done to activate starch gelatinization, so that the starch can dissolve completely and form a thick paste. This solution will be the basis for making bioplastic films.

2) Stage 2

After the sago starch solution is homogeneous, acetic acid is added with varying concentrations (2%, 4% and 6% v/v) to modify the molecular structure of starch and improve the mechanical properties of bioplastics. Acetic acid was added gradually while stirring continuously to ensure even distribution. Acetic acid will help break some of the bonds between starch molecules, improving the film-forming ability and tensile strength of the resulting bioplastics.

3) Stage 3

The addition of chitosan was carried out at certain concentrations (2% and 4% w/w) to determine its effect on the mechanical strength of bioplastics.

4) Stage 4

After the acetic acid and chitosan are well mixed, glycerin is added as a plasticizer. The addition of glycerin aims to increase the flexibility of bioplastics and prevent bioplastics from becoming too brittle. The concentration of glycerin used is constant at 3%. Glycerin will function to disrupt the interaction between starch molecules, so that the polymer chains become more mobile, which results in a more elastic material.

5) Stage 5

The well-mixed solution of sago starch, acetic acid, chitosan, and glycerin can be added with dye and stirred until it produces a homogeneous color. After that, it is poured into a flat mold. This solution is leveled so that it forms an even thin layer. The mold is then dried in an oven at 50-60°C for 24 hours or until the bioplastic film is completely dry. After drying, the bioplastic film was released from the mold and stored in a humidity-controlled room for further testing.

6) Stage 6

After the bioplastics were formed, a series of tests were conducted to evaluate their physical, mechanical, and biodegradability properties. The tests carried out include: First, Tensile strength test is adapted to measure the mechanical strength of bioplastics, such as maximum tensile. Second test was Elongation test in which a mechanical test conducted to measure the ability of a material to stretch or extend until it reaches its breaking point when given a tensile load. Another important test was Biodegradability test where Bioplastics are tested by placing them in soil or compost to see the rate of degradation of the material in a natural environment.

III. Result And Discussion

This study aims to evaluate the effect of the addition of modifying agents namely acetic acid, chitosan, and glycerin on the physical and mechanical properties of sago starch-based bioplastics.

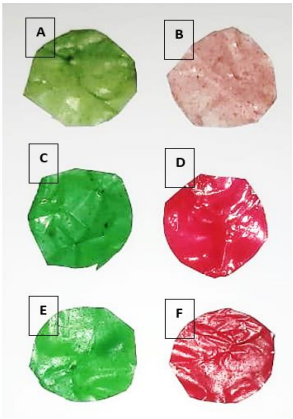

Fig. 1. 6 Samples ID Bioplastic from Sago

Based on the test results, data on tensile strength, elongation at break, and degradation of bioplastics in the soil environment were obtained. There are 6 samples of bioplastic were produced shown in figure 1 with the same ID as presented at tables 1,2 and 3 below.

A. Effect of Adding Modifying Agents on Tensile Strength

Acetic acid acts as a solvent to dissolve chitosan, which allows the formation of a homogeneous polymer matrix. The table 1 below shows the effect of modifying agents in the form of acetic acid, chitosan, and glycerin on the tensile strength of sago-based bioplastics.

TABLE I. TENSILE STRENGTH OF BIOPLASTIC FROM SAGO

Sample ID	Acetic acid (%)	Chitosan (%)	Glycerin (%)	Tensile strength (MPa)
A	2	2	3	6.2
B	2	4	3	6
C	4	2	3	8
D	4	4	3	6.5
E	6	2	3	5.8
F	6	4	3	4.2

At 4% acetic acid concentration, the tensile strength reached the highest value of 8 MPa with 2% chitosan, indicating that acetic acid in the optimal concentration can dissolve chitosan well without causing matrix degradation. In contrast, at higher acetic acid concentration (6%), the tensile strength decreased, both in 2% (5.8 MPa) and 4% (4.2 MPa) chitosan. This occurs because excess acetic acid can cause partial degradation of the polymer, weakening the interaction between molecules in the bioplastic matrix. Chitosan, as the main filler, increases the strength of the matrix through the formation of hydrogen bonds with sago starch. However, at too high concentration, such as at 4% chitosan, the tensile strength tends to decrease. For instance, at 4% acetic acid, the tensile strength dropped from 8 MPa (2% chitosan) to 6.5 MPa (4% chitosan). This shows that excess chitosan can make the matrix more rigid, reduce flexibility, and weaken the ability to withstand pressure. Meanwhile, glycerin as a plasticizer is used at a constant concentration (3%) in this table, so its direct effect on tensile strength cannot be analyzed separately. However, the role of glycerin in improving elasticity remains important to reduce matrix stiffness due to the interaction between chitosan and starch. The most optimal combination was found at 4% acetic acid and 2% chitosan concentration, resulting in bioplastics with the highest tensile strength. Conversely, too high concentrations of acetic acid and chitosan resulted in a less optimal matrix, both due to degradation and stiffness, thus reducing the tensile strength of the bioplastics.

When compared with other studies, similar trends were also found in sago, corn and cassava starch-based bioplastics [3,12-13]. Research on cassava starch-based bioplastics, for example, shows that increasing cross-linking agents such as acetic acid can increase tensile strength to a certain extent before stabilizing or decreasing at too high a concentration [14]. In a similar study with cassava-based bioplastics, the use of glycerol in appropriate concentrations was also shown to increase mechanical strength through the formation of a more rigid and stable matrix [15]. However, the advantage of sago-based bioplastics lies in the more economical and environmentally friendly nature of the material due to its abundant raw materials, especially in tropical regions such as Indonesia. On the other hand, the use of glycerin as a plasticizer in this table also provides a stabilizing effect, preventing the material from becoming too brittle as the acetic acid content increases [15]. When comparing the texture, it is clearly seen that the present of chitosan affected the stiffness of bioplastic. The more chitosan added the more stiffness observed from the bioplastic product. Overall, this study shows the importance of optimizing the concentration of additives such as acetic acid and chitosan to achieve a balance between mechanical strength and flexibility, as required by bioplastic applications.

B. Effect of Adding Modifying Agents on Degradation Rate

Elongation at break reflects the flexibility of bioplastics. The table 2 below shows the effect of modifying agents such as acetic acid, chitosan, and glycerin on the elongation at break of sago-based bioplastics. In the table, glycerin was used at a constant concentration of 3%, so the main factors came from the variation of acetic acid and chitosan.

TABLE II. ELONGATION AT BREAK OF BIOPLASTIC FROM SAGO

Sample ID	Acetic Acid (%)	Chitosan (%)	Glycerin (%)	Elongation at break (%)
A	2	2	3	20 %
B	2	4	3	18%
C	4	2	3	26 %
D	4	4	3	22 %
E	6	2	3	18 %
F	6	4	3	14%

Acetic acid affects the homogeneity of the bioplastic matrix by solubilizing chitosan. At 4% acetic acid concentration with 2% chitosan, elongation at break reached the highest value of 26%, indicating that the bioplastic matrix was more elastic in this combination. In contrast, at 6% acetic acid concentration, elongation at break decreased dramatically, both in 2% chitosan (18%) and 4% chitosan (14%). This decrease was likely due to the degradation of the matrix structure due to excess acetic acid, which resulted in a more brittle bioplastic. Chitosan acts as a filler that increases structural strength, but tends to decrease elongation at break when the concentration is high. For example, at 4% acetic acid concentration, the elongation at break decreased from 26% (2% chitosan) to 22% (4% chitosan). This indicates that higher chitosan

concentration makes the matrix stiffer, thus reducing flexibility. Overall, the best combination was seen at 4% acetic acid and 2% chitosan concentration, resulting in high elongation at break due to the balance between matrix strength and flexibility. However, too high a concentration of acetic acid and chitosan tends to decrease elasticity, resulting in a stiffer and less flexible bioplastic. Glycerin helps maintain the elasticity of the matrix [16], although in this table the concentration is not varied.

When compared with several previous studies, the trends shown in this table are consistent with results found in other starch-based bioplastics, such as corn starch and cassava starch [. In the cassava starch-based study, for example, it was found that increasing cross-linking agents such as acetic acid reduced elongation at break, but increased tensile strength. This is similar to what happened with sago-based bioplastics, where high concentrations of acetic acid resulted in a stiffer but less elastic material. On the other hand, the use of glycerin as a plasticizer was shown to maintain the flexibility of the material to a certain extent [16-17], although its role was not significant enough to counter the negative influence of increasing acetic acid concentration. However, the weakness in terms of elongation at break at high concentrations of acetic acid needs to be further addressed through formula modification or the addition of additional plasticizers to improve flexibility without compromising material strength. Thus, this study provides important insights for the development of sago-based bioplastics with mechanical performance that can be customized according to specific application needs, both for flexible packaging and long-term use and in line with previous studies reported [6,18-22].

C. Effect of Adding Modifying Agents on Degradation Rate

The table 3 below shows the effect of modifying agents such as acetic acid, chitosan and glycerin on the degradation rate of sago-based bioplastics. The degradation rate increased as the concentration of these agents changed, which affected the structure and porosity of the bioplastic matrix.

TABLE III. ELONGATION AT BREAK OF BIOPLASTIC FROM SAGO

Sample ID	Acetic Acid (%)	Chitosan (%)	Glycerin (%)	Degradation rate (%)
A	2	2	3	50 %
B	2	4	3	45%
C	4	2	3	70 %
D	4	4	3	62 %
E	6	2	3	82 %
F	6	4	3	74 %

Acetic acid has a significant effect because it plays a role in dissolving chitosan and forming the bioplastic matrix. At a higher concentration of acetic acid (6%), the degradation rate increased, reaching 82% (2% chitosan) and 74% (4% chitosan). This is due to the weaker matrix structure resulting from partial degradation of the polymer during the manufacturing process, making it easier to be degraded by microorganisms. In contrast, at 2% acetic acid concentration, the degradation rate was lower (50% in 2% chitosan and 45% in 4% chitosan) due to the denser and more homogeneous bioplastic structure. Chitosan plays a role in strengthening the matrix through hydrogen bonding with starch, thereby increasing resistance to degradation. At higher chitosan concentration (4%), the degradation rate tends to be lower than that of 2% chitosan, as seen at 4% acetic acid concentration (62% for 4% chitosan, compared to 70% for 2% chitosan). Glycerin, used at a constant concentration of 3%, increases the solubility of the matrix in water, thereby facilitating the access of microorganisms and accelerating degradation. The right combination of agents is required to optimize the degradation rate as needed, with a balanced concentration of acetic acid and chitosan to obtain a durable yet biodegradable bioplastic.

These results are in line with several other studies on bioplastics from natural sources [10-11]. For example, in a study of corn starch-based bioplastics, it was found that increasing the concentration of cross-linking agent also reduced the degradation rate due to the formation of a denser material structure [12]. Another study was found to reach higher degradable rate of 82.8% of bioplastic from sago when glycerol was used [10]. Sago-based research offers an additional advantage as sago is more accessible in many tropical regions, and has good solubility and film-forming properties. A significant difference with other studies may lie in the feedstock, where sago provides a smoother material texture than cassava starch [14], and has a higher biodegradability rate than synthetic polymer-based bioplastics. Overall, this table not only illustrates the importance of material concentration, but also contributes to ongoing research to create environmentally friendly bioplastics with performance that can be customized for specific application needs, whether in packaging, medical, or agricultural industries [19-22].

IV. CONCLUSIONS

This study demonstrated that modifying agents such as acetic acid, chitosan, and glycerin significantly influence the mechanical, physical, and biodegradability properties of sago starch-based bioplastics. The optimal formulation of 4% acetic acid and 2% chitosan provided a balance of high tensile strength, improved flexibility, and favorable degradation rates, making it a promising alternative to conventional plastics. However, excessive acetic acid weakened the polymer structure, while increased chitosan content enhanced mechanical strength but reduced flexibility, emphasizing the importance of optimizing these components for practical applications. The results highlight the potential of sago starch-based bioplastics in sustainable packaging, disposable products, and biodegradable films, offering an eco-friendly solution to plastic pollution. Future research should focus on refining the formulation by incorporating alternative natural plasticizers such as sorbitol or citric acid to enhance flexibility without compromising mechanical integrity. Additionally, reinforcing the bioplastic with biodegradable nanofibers or polymer composites could improve durability and expand industrial applications.

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