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Original Paper

Synthesis Of Biofoam Based On Glucomannan Porang and Polyvinyl Alcohol (PVA) with The Addition of Seaweed Dregs

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***Abstract*— Biofoam (Biodegradable foam) is an alternative packaging to Styrofoam made from natural raw materials that can be biodegraded in the soil. Biofoam is generally made from 3 constituent materials in the form of main ingredients in the form of starch or other similar materials, plasticizers such as PVA and also fillers in the form of fibers containing cellulose. The purpose of this study was to determine the effect of the combination of porang glucomannan, PVA and seaweed pulp on biofoam and to determine the best formulation and characteristics of the biofoam samples made. The technique of making biofoam was done using baking technique with 9 different treatments. Each treatment was repeated 3x and observations were made on biofoam structure, mechanical properties testing (tensile strength, elongation and young modulus), water absorption test, and biodegradation test. The results showed that Polyvinyl Alcohol plays a role in the formation of a hollow biofoam structure. The thickness parameter value for each treatment was 0.628-1.939 mm. The tensile strength value of each treatment has a value ranging from 15.989-35.265 N/mm². The elongation value for each treatment ranged from 25.719-76.427%. The young modulus value for each treatment ranged from 0.343-0.896 N/mm². The water absorption value of each treatment obtained values ranging from 35.81-77.12%. And the value of testing biodegradation parameters obtained values ranging from 8.68-32.18%. So that the best treatment obtained using the multiple attribute method is the A3B1 treatment (PVA 15% and the ratio of seaweed pulp concentration to glucomannan 1: 2).**

***Keywords*—Baking process, Biofoam, Glucomannan porang, PVA, Seaweed Dregs, Styrofoam.**

I. INTRODUCTION

Waste has been a serious issue for humans and the environment for a long time. Currently, waste is dominated by plastic waste which cannot be separated from human life because most of the equipment supporting all human activities is made of plastic materials which are easily available at low prices, are lightweight, easy to shape, flexible and have good strength. Based on the National Waste Management Information System (SIPSN) data obtained from the Ministry of Environment and Forestry (KLKH), it is known that the total amount of Indonesian waste generation in 2023 reached 28.01 million tons where most types of waste came from food waste as much as 41.7%, plastic waste as much as 18.7%, paper/carton waste as much as 10.7% and the rest comes from other types of waste. Based on this data, it is known that plastic waste has become the second largest contributing factor that causes an increase in the amount of waste that can result in environmental damage. Plastic waste that is non-biodegradable or difficult to decompose in nature causes a buildup of waste which results in environmental pollution not only on land but also in the oceans [5].

Styrofoam is one type of plastic that has been massively used by the public lately as a food packaging material. Styrofoam is a food packaging material made from styrene granules which are processed using benzene [3]. Styrofoam is widely used as a food and goods wrapper because styrofoam has practical, heat-resistant, waterproof and oil-resistant properties and is very light. Behind its advantages, the continuous use of styrofoam can result in the accumulation of waste and can also cause disease due to its use as food packaging due to the migration of carcinogenic substances, namely styrene, which can interfere with the nervous system and brain, and can have an impact on genetics, lungs, liver and immunity [22]. Starting from the problems that have been mentioned, an alternative is needed to replace styrofoam which is not friendly to humans and the environment. One of them is the use of biofoam as an alternative to styrofoam made from natural materials that are easily degraded naturally, safe for health and also for the environment.

Biofoam (Biodegradable foam) is an alternative packaging to styrofoam made from polymers that can be regenerated and are composed of 3 main components, namely binding material (matrix), plasticizer and also reinforcing material (filler). Biofoam is formed from starch and fiber with the addition of plasticizers to improve its properties [20]. However, the development of starch-based biofoam has weaknesses in the form of low mechanical strength and high water absorption. Based on the research of Zulmanwardi & Sofia, (2023) regarding the manufacture of biofoam with raw materials in the form of uwi tuber starch, rice straw waste and polyvinyl alcohol as a plasticizer produced biofoam with a water absorption value of 12.02-339.87%, the tensile strength of 0.0058 N/mm²-0.6217 N/mm² and the degradation time for 14 days. From the results of this study, it is known that the water absorption value of biofoam

is quite good but the tensile strength value is still far from the standard, which means that biofoam still has low mechanical strength. So it is necessary to review the constituent materials of biofoam to improve existing deficiencies.

Porang glucomannan is a potential material that can be used as a bonding agent in making biofoam compared to starch, because starch-based biofoam has weaknesses such as water sensitivity, low mechanical properties and low material flexibility [17]. Glucomannan has properties between cellulose and galactomannan which when dissolved in water can form a transparent viscous solution in the form of a gel and if dried can form a thin layer that is impermeable to water. The constituent components used for the manufacture of other biofoams are plasticizers and fibers (cellulose). PVA is a synthetic polymer that is non-toxic and naturally degradable. PVA has high tensile strength, good flexibility, and good oxygen barrier properties [19]. Biofoam made from glucomannan and PVA both have properties that are easily soluble in water (hydrophilic) so that which can affect the mechanical strength of biofoam. To improve these shortcomings, it is necessary to add fiber (cellulose) so that the resulting biofoam properties are even better. Seaweed dregs are residual waste from the agar industry that can be used as a source of fiber with a cellulose content of 20.17% and its hydrophobic properties to help reduce its water absorption to improve the mechanical properties of biofoam [9]. This research aims to determine the effect of the combination of porang glucomannan, PVA and seaweed pulp as an ingredient in making biofoam. As well as to determine the biofoam formulation that produces the best characteristics that are expected to be utilized as an alternative packaging to replace styrofoam in the future.

II. Material and Methods

A. Time and Place

This research was conducted from January to March 2024 and was carried out in the laboratory of Agro-industrial technology and management of agricultural industry technology and the laboratory of agricultural product process engineering, faculty of agicultural technology, University of Jember.

B. Materials

The tools used in this research include Hot plate magnetic stirrer, Oven (LabTech), Universal Testing Machine (Shimadzu), Microscope, Stopwatch (Oppo A31), Thickness gauge (Mitutoyo Absolute), 80 mesh sieve, Beaker glass (Pyrex), Spatula, Plastic mold, Digital balance, Mortal and pestle, Plastic bowl, Scissors, Alumunium foil, SPSS software 16, and Microsoft Excel 2019.

And the materials used are porang tuber glucomannan flour (Ikarie), Polyvinyl alcohol (PVA), Seaweed dregs from the agar processing industry, Aquadest, and Humus soil.

C. Research

This research used a Completely Randomized Design (RAL) with 2 factors. The first factor is variation of polyvinyl alcohol (PVA) namely A1 (5%), A2 (10%), and A3 (15%) in 100 ml aquadest. The second factor in the variation of comparison between concentration of porang tuber glucomannan flour and seaweed dreg (g:g) namely B1 (2:1), B2 (1:1), and B3 (1:2). The treats and code used in table 1:

TABLE I. Combination of factor 1 and factor 2

Glucomannan: Seaweed dreg (g:g) (B)	PVA Concentration (A)		
	A1 (5%)	**A2 (10%)**	**A3 (15%)**
B1 (2:1)	A1B1	A2B1	A3B1
B2 (1:1)	A1B2	A2B2	A3B2
B3 (1:2)	A1B3	A2B3	A3B3

D. Research Stage

Biofoam manufacturing proess

The manufacture of biofoam in this study uses a baking technique at an oven temperature of 60 ºC. Before making biofoam, seaweed pulp is sieved using an 80 mesh sieve so that the particle size is uniform and separates the dirt. Making biofoam starts with weighing porang tuber glucomannan flour, PVA and also seaweed pulp using a digital balance according to the treatment. Furthermore, PVA that has been weighed according to the variation (5%, 10% and 15%) of each treatment is dissolved in 100 ml of aquadest at a speed of 150 rpm for 5 minutes. The next step, porang glucomannan flour was added and continued with the addition of seaweed pulp (g: g) according to variations (1:2, 1:1, and 2:1) into the PVA solution. The mixture of the three ingredients is then homogenized again using a hot plate magnetic stirrer with a temperature of 65ºC for 30 minutes at 100-120 rpm until the gel forms and the dough expands well. After 30 minutes, the thickened biofoam dough is poured into plastic molds and cooled. Biofoam that has been molded is baked in the oven at 60ºC for 8-10 hours until the biofoam dough dries. And the last step is to test the biofoam sample.

E. Analysis Procedure for Parameters Assesment

1. Observation of Biofoam Structure

Structural observations were made using a light microscope with an objective lens magnification of 4x.

2. Thickness Analysis

Biofoam thickness measurements were taken at 3 different point using a thickness gauge [12].

3. Mechanical Strength Analysis

Mechanical strength analysis on the sample consists of 3 tests, namely the tensile strength test, elongation test and young modulus test. Analysis of the mechanical strength of biofoam is carried out using ASTM D638-94 standards, whereas in the testing process is carried out using a Universal Testing Machine (UTM). The test is carried out using a Universal Testing Machine (UTM) which will automatically issue a tensile strength value and elongation on each sample tested. Each biofoam sample is cut to a size of 10 mm wide and 80 mm long

before being tested on the tool [12]. The sample testing model is in Figure 1.

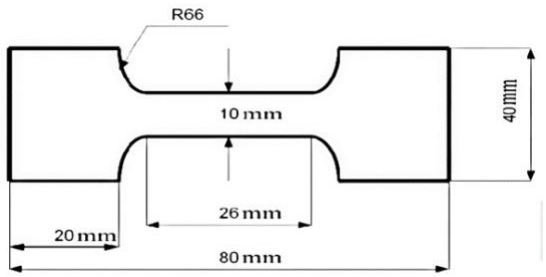


Fig. 1. Biofoam mechanical strength testing model

Meanwhile, the young modulus test value is obtained by comparing the tensile strength value with the elongation value of each sample. Young modulus testing formula as follows:

$$E = \frac{Tensile\ strength\ (\sigma)}{Elongation\ (\varepsilon)} \quad (1)$$

4. Water Absorption Analysis

Water absorption analysis was carried out by cutting the sample by 2 x 2 cm and then weighing the initial weight (W_o) of each biofoam sample that has been cut using a digital balance sheet. Cut using a digital balance. Furthermore, the sample that has been weighed, soaked in distilled water as much as 30 ml for 1 minute. The sample is then lifted and dried the remaining water using tissue and weighed to determine the final weight of the sample. weighing to determine the final weight of the sample (W_1) [8]. The water absorption analysis was calculated as follows:

$$\text{Swelling (\%)} = \frac{w_1 - w_0}{w_0} X100\% \quad (2)$$

5. Biodegradation Analysis

The biodegradation test was carried out by cutting samples with a size of 3 x 1.5 cm which were buried using humus soil 10 cm deep during 7 days of observation [23].

$$\text{(\%) Biodegradation} = \frac{m_0 - m_1}{m_0} X100\% \quad (3)$$

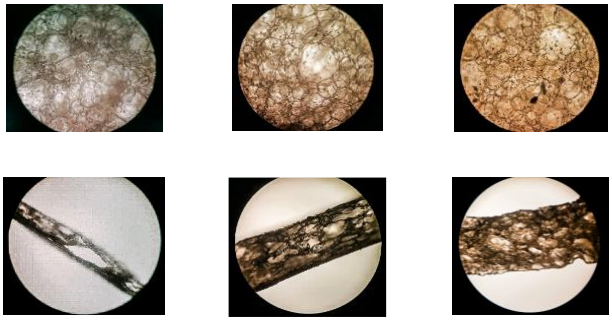
The initial weight is the weight of the sample before burial (m_0) while the final weight is the weight of the sample after burial (m_1).

F. Data Analysis

The research results were analyzed statistically using ANOVA analysis of variance with a significance level of 5% using the SPSS software. If there is a significant difference in treatment continue with Duncan's Multiple Range Test (DMRT) analysis at $P \leq 0.05$. The selection of the best treatment using the multiple attribute method [21].

III. Result and Discussion

A. Structure of Biofoam



(a) 5% PVA (b) 10% PVA (c) 15% PVA

Fig. 2. Biofoam sample structure

From the picture above, it is known that the biofoam structure is formed from air bubbles trapped in the thickened sample dough and results in many voids in the sample. Air bubbles formed in biofoam samples are the result of the interaction of PVA which expands and thickens when stirring and dissolving in distilled water through hydrogen bonding. Thus, the number of air bubbles is influenced by the concentration of PVA used. In addition, the stirring speed can also affect the number of air bubbles that exist due to the trapping of free air into the thickened sample. The higher PVA concentration and the faster the stirring is done, the more and denser the air bubbles formed in the sample. The longer and faster-stirring process in the heating process, increases in the homogeneity and compactness of the composite which causes the molecular structure in the composite to become tighter and stronger. The composite is getting tighter and stronger [11]. Besides that, PVA or Polyvinyl alcohol can make the mixture fluffy and porous [6].

The hollow structure of biofoam is formed due to the increasing viscosity of biofoam dough and the spaces in the sample are filled by glucomannan components as well as seaweed pulp. Glucomannan also has acetyl groups can form cross-links with hydroxyl found in PVA. Porang glucomannan can form a gel that is thin, elastic, transparent and very strong and can be degraded naturally [13]. Meanwhile, seaweed pulp containing cellulose, lignocellulose and lignin is suitable for use as additional material with the aim of strengthening the biofoam structure. Cellulose can increase the strength of a material by forming fibers and strengthening the bond between fibers of a material [2].

B. *Thinkness of Biofoam*

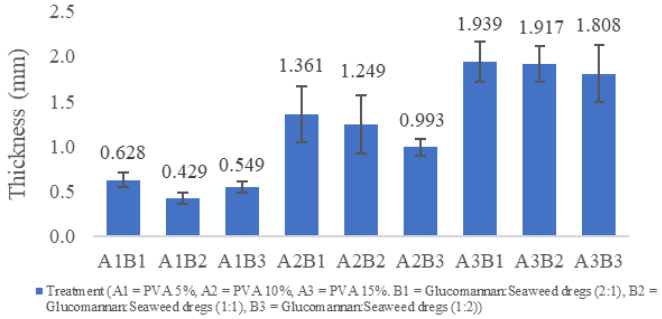
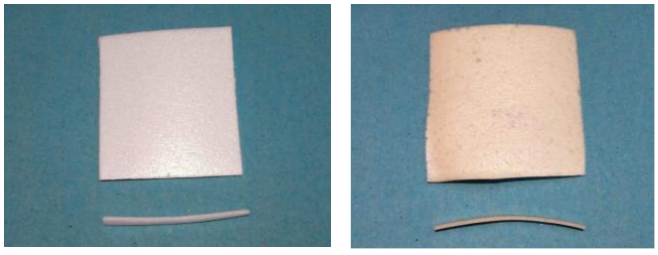


Fig. 3. The result of measuring thickness of Biofoam sample

The result of the research indicates that the thickness value of the biofoam sample increases with the addition of PVA concentration. PVA which has the property of expanding causes the level of thickness of the biofoam sample to increase with the use of higher PVA. ANOVA test results that have been carried out show that the treatment of PVA addition has a significant effect on biofoam thickness parameters (Sig. <0.05). While the treatment of the addition of porang glucomannan flour ratio does not significantly affect the thickness of biofoam.

The addition of higher PVA concentrations can form a denser and denser biofoam structure with air bubbles so that the thickness of the biofoam increases along with the increase in PVA concentration. Polyvinyl alcohol (PVA) has hydrophilic properties so that PVA membranes easily expand in water. The ability to easily expand is due to the presence of -OH groups that interact with water molecules through hydrogen bonds [1]. So that biofoam samples with higher PVA concentration tend to have a strong structure and large thickness. The results of the study can also be seen if the sample with a higher concentration of glucomannan compared to seaweed pulp has a higher thickness. This is due to the nature of the expansion in water from glucomannan which reaches 138-200% which can occur in a short time [18]. Comparison of the thickness of conventional styrofoam with biofoam can be seen in Figure 4.



a. Styrofoam *b. Biofoam*

Fig. 4. Comparison of the thickness of conventional styrofoam with biofoam

C. *Tensile Strength*

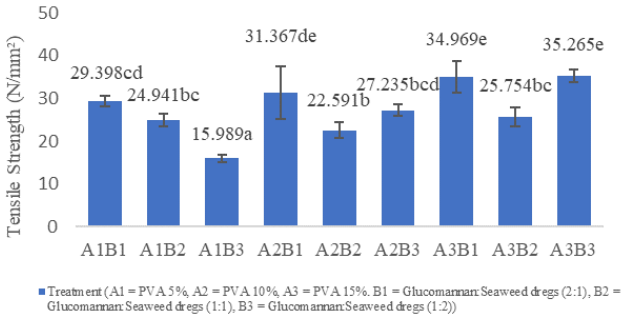


Fig. 5. The result of measuring tensile strength of Biofoam sample

The result of the research showed that the treatment of the comparison of the concentration of porang glucomannan flour with seaweed pulp and the treatment of the addition of PVA concentration and the interaction of the two in the ANOVA analysis on the tensile strength test had a significant effect (Sig. <0.05) on the synthesis of biofoam. In the tensile strength parameter, the biofoam sample has a value between 15.98 N/mm² the highest 35.26 N/mm².

The tensile strength value will increase in line with the increase in the amount of PVA (Polyvinyl alcohol) concentration because PVA has excellent elasticity and strength properties. PVA has hydroxyl groups that can bind freely with other molecules and is proven to increase the strength of a composite [16]. In addition, the addition of glucomannan flour and seaweed pulp also helps in increasing the tensile strength of biofoam. PVA and glucomannan porang that interact with each other produce hydrogen bonds that are stronger and denser, causing the biocomposite to have greater strength and require greater energy to break the bond [20].

Seaweed dregs with a high enough cellulose content are also able to increase the strength of biofoam synthesis in this study. This can be seen based on the test results it is known if the sample with the addition of seaweed dregs is higher than glucomannan porang flour has the highest tensile strength, namely sample A3B3. Seaweed dregs help increase the cohesiveness and viscosity of biofoam dough so that the sample becomes stronger. The addition of cellulose as a filler material in the manufacture of biofoam serves to strengthen the physical and mechanical properties of biofoam [24].

D. *Elongation*

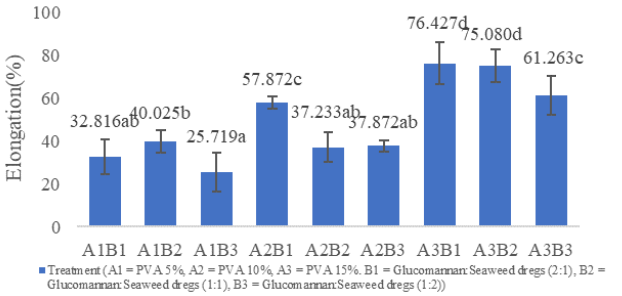


Fig. 6. The result of measuring elongation of Biofoam sample

The results of the research on elongation parameters showed that the treatment of the addition of concentration ratio between porang glucomannan flour and seaweed dregs and the treatment of the addition of PVA concentration and the interaction between the two factors based on ANOVA analysis had a significant effect on biofoam composites (Sig. <0.05). Figure 6 shows that the elongation value increases with the increase in PVA concentration and the sample with the highest elongation is produced by a sample with a PVA concentration of 15% and the addition of more glucomannan flour concentration than seaweed dregs. PVA, which acts as a plasticizer, can provide flexible properties to increase the percentage of elongation along with its use in high concentrations [11]. High elongation indicates the flexibility of the sample is not easily damaged when subjected to tensile forces.

Porang glucomannan flour as a constituent component of biofoam with seaweed dregs also helps increase the elongation value. Glucomannan is known to have high elastic properties. Glucomannan also has other advantages, namely that it can form a viscous mass that is sticky, able to form a thin transparent layer with good strength, high elasticity and easily soluble in water [15].

E. Young's Modulus

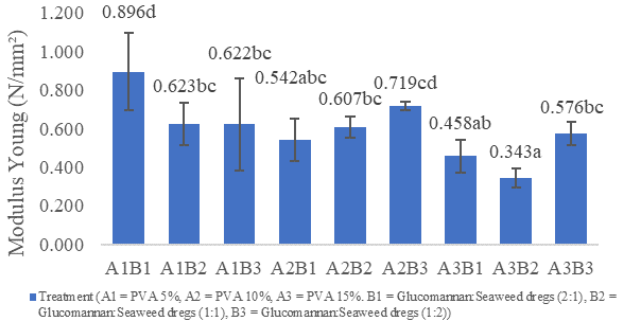


Fig. 7. The result of measuring modulus young of Biofoam sample

The results of the research on the young modulus or elasticity test of biofoam showed that the treatment of the addition of concentration ratio between porang glucomannan flour and seaweed dregs and the addition of PVA concentration, as well as the interaction between the two through ANOVA analysis gave a significant effect on biofoam synthesis (Sig. <0.05). The average value of the young modulus of biofoam samples is between 0.343 N/mm²-0.896 N/mm².

Figure 7 shows that the value of young's modulus or elasticity of biofoam tends to decrease as the concentration of PVA increases. The higher the level of plasticizer in the form of PVA used will provide a smaller young modulus value [10]. The lower the value of young's modulus indicates that the elasticity of a material is getting better and not rigid. the value of young's modulus of samples with PVA concentration of 5% tends to be higher than samples with PVA concentration of 10% and 15%. This is caused by PVA which is very elastic and very strong which is easily soluble in water [14]. so that it can increase the elasticity of biofoam.

In the level of elasticity of biofoam, apart from PVA, another influential ingredient is the addition of glucomannan. Glucomannan, which is elastic compared to starch, increases the elasticity value of the sample because it functions as a binder for polymer groups. Meanwhile, seaweed dregs, function to strengthen the structure of biofoam because they can improve the compactness of the biofoam sample, however, adding high amounts of fiber will cause the biofoam elasticity to decrease and become brittle [6].

F. Water Absorption

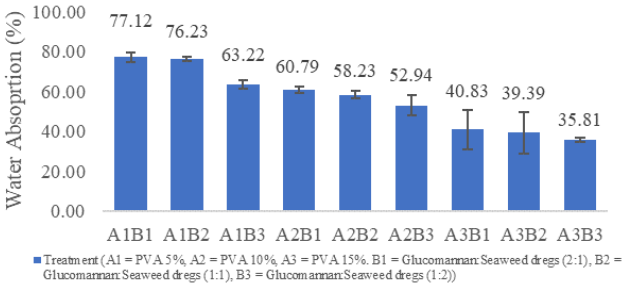


Fig. 8. The result of measuring water absorption of Biofoam sample

The results of research on testing biofoam water absorption parameters using ANOVA analysis showed that the treatment of adding a ratio of the concentration of porang glucomannan flour to seaweed dregs had no real effect (Sig.> 0.05). While the treatment of increasing PVA concentration has a real effect on the water absorption value of biofoam samples (Sig. < 0.05). The range of water absorption capacity values for biofoam samples is between 35.01%-77.12%. The water absorption capacity value is still quite high and does not comply with existing Indonesian national standards with a maximum figure of 26.12%.

Figure 8 shows that there is a decrease in the water absorption capacity of the biofoam sample as the PVA concentration used in each treatment increases. Increasingly higher PVA addition results in a thicker, denser dough with smaller voids compared to samples with low PVA concentration addition. Dilute biofoam dough will produce biofoam with larger cavities with thin walls. Larger and more numerous cavities and thin walls result in higher sample porosity resulting in a high value of water absorption of the biofoam sample [20].

Meanwhile, the added glucomannan porang and seaweed dregs help reduce the water absorption capacity of biofoam by filling the cavities in the foam together with PVA so that they become more compact and tight. In this case, cellulose which functions as a filler that contains fiber in the form of hydrophobic cellulose can block water from entering the sample. Cellulose has a larger crystalline region than starch and glucomannan which have a tighter microfibril structure so that it can increase the crystallinity of biofoam products [3]. Increasing the crystallinity of biofoam products will hinder the water absorption process and have an impact on the lower water absorption capacity of biofoam samples with more seaweed dregs.

G. Biodegradation

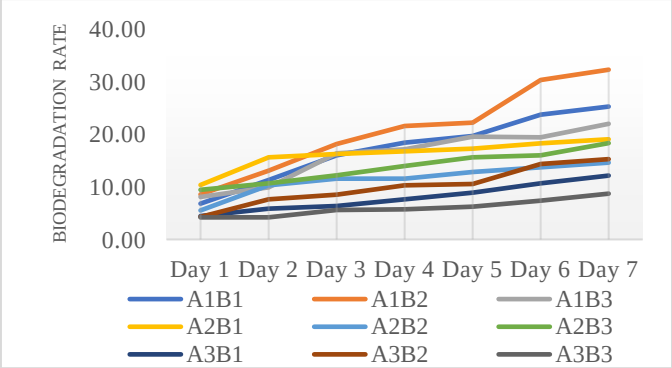


Fig. 9. The biodegradation rate of Biofoam sample

Biodegradation testing aims to determine the rate at which biofoam samples can decompose naturally in the soil by microorganisms. Based on the results of research on biodegradation parameters of biofoam samples, it is known that during 7 days, the rate of biofoam degradation process for each sample is different where the sample that has the fastest degradation rate is sample A1B2 and the slowest is sample A3B3. in this study, the biodegradation rate of biofoam samples ranged from 8.68%-32.18% for 7 days.

Based on ANOVA analysis of biodegradation parameters, it is known that the treatment of the addition of porang glucomannan flour concentration ratio with seaweed dregs and the treatment of the addition of PVA concentration and the interaction between the two has a significant effect on the degradation rate of biofoam samples (Sig.<0.05). Glucomannan tends to degrade more easily than cellulose in seaweed dregs because glucomannan is hydrophilic which facilitates the growth and development of microorganisms in the soil in the sample. Glucomannan bioplastics contain hydroxyl groups (OH) and carbonyl groups (CO) which have hydrophilic properties so that water molecules easily enter the plastic matrix resulting in the growth and development of bacteria [13]. Meanwhile, the addition of seaweed pulp as a source of cellulose is useful as a source of energy needed by decomposing microorganisms in the soil in the process of decomposing biofoam samples.

The addition of PVA with a higher concentration in the manufacture of biofoam resulted in a decrease in the level of decomposition of biofoam samples in the soil. This can be seen in the graphical image of the biofoam biodegradation rate which shows the biodegradation rate of the sample with the addition of PVA by 5% has a much higher biodegradation rate compared to the sample with the addition of PVA by 10% and 15%. biofoam that uses PVA as an ingredient can reduce the biodegradability of the sample. This is because PVA is a synthetic polymer produced from biodegradable petroleum, so microorganisms in the soil are more difficult and take longer to decompose the material than other organic materials [20]. Factors that can affect the speed of biodegradation of a composite include moisture, type of microorganism, temperature, pH, polymer type, and polymer thickness, as well as sunlight intensity [4].

H. Best Treastment

Based on the results of the calculation of the best treatment selection with the multiple attribute method, the best sample is the A3B1 sample. Sample A3B1 is a sample with the treatment of adding a concentration ratio of porang glucomannan flour with seaweed dregs of 2:1 and the addition of a PVA concentration of 15%. A3B1 sample has characteristics such as thickness of 1.939 mm, tensile strength of 34.968 N/mm², elongation of 76.427%, young modulus or elasticity of 0.463 N/mm², water absorption of 40.83%, and biodegradation of 12.10% within 7 days. The results of the best treatment assessment can be seen in Table 2.

TABLE II. BEST TREATMENT

Treatment	λ	L_1	L_2	$L\infty$	Total	The Best Treatment
A1B1	0.166	0.47	0.04	0.11	0.62	8
A1B2	0.166	0.42	0.04	0.13	0.59	7
A1B3	0.166	0.53	0.05	0.12	0.70	9
A2B1	0.166	0.31	0.02	0.07	0.39	4
A2B2	0.166	0.43	0.03	0.09	0.56	6
A2B3	0.166	0.42	0.03	0.09	0.53	5
A3B1	0.166	0.17	0.01	0.10	0.29	1
A3B2	0.166	0.18	0.04	0.09	0.31	2
A3B3	0.166	0.23	0.02	0.12	0.38	3

Sample A3B1 has the highest thickness among other samples so it is expected to protect the most optimal product that is close to the thickness of conventional styrofoam in the future. In addition, the A3B1 biofoam sample also has a good level of strength, and flexibility and is by existing standards compared to other samples, making it easier for biofoam to be produced in various desired shapes with qualified strength as food product packaging in the future. Biofoam is also has a lightweight like conventional styrofoam and can be degraded naturally in the environment. However, biofoam still has a fairly high level of water absorption so a review is needed so that these deficiencies can be overcome.

IV. CONCLUTION

From the results of research on the synthesis of biofoam based on porang glucomannan and polyvinyl alcohol (PVA)with the addition of seaweed pulp can be drawn conclusions include:

1. The variation of the addition of the ratio of porang glucomannan and seaweed dreg (g:g) with concentrations (2:1, 1:1, and 1:2) and the variation of the addition of polyvinyl alcohol (PVA) with concentrations (5%, 10%, and 15%) influenced the test values of tensile strength, elongation, young modulus, and the level of biodegradation of biofoam. while in the test values of water absorption and thickness only the variation of the addition of PVA effected on the biofoam samples.
2. The best sample obtained by the multiple attribute method is sample A3B1 with the addition of glucomannan flour

ratio with seaweed pulp of 2:1 and concentration of PVA addition of 15%. sample A3B1 has a thickness characteristic of 1.939 mm, tensile strength of 34.968 N/mm², elongation of 76.427%, young modulus or elasticity of 0.463 N/mm², and elasticity of 0.463 N/mm². of 76.427%, young modulus or elasticity of 0.463 N/mm², water absorption of 40.83%, and biodegradation of 12.10% in 7 days

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