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Characteristics of Tapioca-Glucomannan Based Foam Biocomposites with Variations in Microcrystalline Cellulose Concentration and Gelatinization Stirring Time

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Abstract. *Biocomposites are materials composed of a combination of polymer matrices and natural reinforcing agents that are environmentally friendly and have the potential to replace non-biodegradable synthetic polymers. The development of biodegradable foam biocomposites represents an innovation in lightweight materials that can be applied as sustainable packaging. This study aimed to examine the effect of microcrystalline cellulose (MCC) concentration on the characteristics of foam biocomposites and to determine the optimal concentration to produce the best quality foam. The research employed a Randomized Block Design (RBD) with three MCC concentration treatments (1.5%, 3.5%, and 5.5%) across three gelatinization times (1 minute, 2 minutes, and 3 minutes). The observed variables included tensile strength, density, tear resistance, compression set, thickness, swelling, elongation at break, and biodegradation time. The data were analyzed using Analysis of Variance (ANOVA) followed by the Honestly Significant Difference (HSD) test. The results showed that MCC concentration and gelatinization time significantly affected tensile strength, density, tear resistance, compression set, thickness, swelling, elongation at break, and biodegradation time. The best foam biocomposite was obtained at 5.5% microcrystalline cellulose concentration and 1 minute of gelatinization time, with tensile strength of 5.04 N/cm², density of 0.38 g/cm³, tear resistance of 3.60 N/cm², compression set of 19.99%, thickness of 15.11 mm, thickness swelling of 1.22%, elongation at break of 3.02%, and biodegradation time of 13 days.*

Keywords: *Biocomposite foam; tapioca, glucomannan; polyvinyl alcohol; microcrystalline cellulose; gelatinization time.*

Type of the Paper: Regular Article.

1. Introduction

Plastic packaging is widely used by the public because it is relatively affordable and possesses strong, lightweight, inert, corrosion-resistant, and thermoplastic (heat-sealable) properties, and can also be colored [1]. Plastic packaging is used to provide effective protection against weather, light, temperature changes, impact, stacking pressure, dirt, insects, and bacteria [2]. One type of plastic commonly used for packaging is styrofoam. Long-term use of styrofoam poses potential health risks due to the possible migration of monomer substances from the styrofoam material into food [3].

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Natural and biodegradable packaging materials as alternatives to plastic packaging, such as biocomposite foam, have begun to be developed to address plastic waste problems [4]. Starch, glucomannan, and PVA are potential matrix-forming materials for biocomposite foam [5]. According to previous research Admadi et al. [6], the manufacturing process of biocomposite foam is influenced by several factors, one of which is the presence of filler materials. The function of fillers in the production of biocomposite foam is to help regulate the density and porosity of the foam [7]. Microcrystalline cellulose is an important additive in the pharmaceutical field, commonly used as a binder in tablet production by the direct compression method [8]. According to previous research Hendri et al. [9] reported that sago starch-based bioplastic with 12% microcrystalline cellulose and 10% glycerol achieved a tensile strength of 14.21 MPa, elongation of 1.026%, water uptake of 36.91%, and biodegradation time of 34.43 days. According to previous research Pujawati et al. [10] temperature and gelatinization stirring time influence the production of taro–carrageenan composites. The best results were obtained at 85 °C for 5 minutes, producing a tensile strength of 11.19 MPa, elongation of 4.38%, elasticity of 255.35 MPa, swelling of 84.35%, vapor transmission of 0.55 g/h·m², and degradation within 7 days.

This study aims to determine the effect of microcrystalline cellulose concentration and gelatinization stirring time on the characteristics of biocomposite foam made from tapioca and glucomannan, as well as to determine the appropriate microcrystalline cellulose concentration and gelatinization stirring time to obtain the best characteristics of tapioca- and glucomannan-based biocomposite foam.

2. Experimental

2.1. Materials and Equipment

The materials used in this study were tapioca, glucomannan, polyvinyl alcohol (PVA), sorbitol, toluene diisocyanate, acetic acid, distilled water (aquades), and microcrystalline cellulose. The equipment used included an analytical balance, beakers, stirring rod, hotplate stirrer, stopwatch, thermometer, scissors, spoon, molding trays, aluminum foil, baking paper, tissue, oven, hot press molding machine, a mechanical testing instrument (ASTM D695-90), a thickness tester (micrometer screw gauge), a tear resistance tester (Haida HD-B609A), and a compression set tester (Haida HD-F750-1).

2.2. Methods

The preparation of biocomposite foam was carried out with modifications based on the study of Intandiana et al. (2019) regarding microcrystalline cellulose concentration and Pujawati et al. (2021) concerning gelatinization stirring time, as follows: First, the materials were weighed: tapioca (4.5 g), polyvinyl alcohol (5 g), glucomannan (1.5 g), and microcrystalline cellulose

according to the treatment levels (1.5%; 3.5%; and 5.5%). Polyol and toluene diisocyanate (1:1) were added at 17.5% of the total 100 g formulation.Three beakers were prepared. The first beaker was filled with tapioca (4.5 g), the second with glucomannan (1.5 g), and the third with PVA (5 g). A total of 47 mL of 1% acetic acid solution was added to the beakers containing tapioca and glucomannan. Each mixture was stirred for 1 minute until homogeneous. Microcrystalline cellulose was then added according to the treatment levels (1.5%, 3.5%, and 5.5%) into the combined mixture of the three components in a 1000 mL beaker.

The mixture was heated to a temperature of 75 ± 2 °C. Once the temperature stabilized, the mixture was stirred at 90 rpm until a gel was formed, with gelatinization times according to the treatments (1, 2, and 3 minutes). After gel formation, polyol (sorbitol) and TDI 80 were added and mixed using a magnetic stirrer for 1 minute until homogeneous. The homogeneous mixture was then poured into a mold measuring 12 cm × 12 cm × 3 cm and evenly spread. The mixture was allowed to expand for 1 hour at room temperature, then dried in an oven at 80 °C for 4 hours. The dried product was subsequently subjected to testing.

3. Results and Discussion

3.1 Tensile Streangth

Tensile strength is defined as the maximum stress or pulling force that a biocomposite foam can withstand before breaking or tearing [11]. Tensile strength testing is conducted to determine the magnitude of force required to reach maximum tension over a specific cross-sectional area of the biocomposite foam [9].

Analysis of variance showed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had a highly significant effect ($p \leq 0.01$) on the tensile strength of tapioca- and glucomannan-based biocomposite foam. The resulting tensile strength values ranged from 2.08 ± 0.14 to 5.04 ± 0.61 N/cm², as presented in Table 1.

Table 1. The average tensile strength values of tapioca- and glucomannan-based biocomposite foam at various microcrystalline cellulose concentrations and gelatinization stirring times.

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	2,19 ± 0,32 ^{c}	2,24 ± 0,07 ^{c}	5,04 ± 0,61 ^{a}
W2 (2 mnt)	2,37 ± 0,12 ^{c}	2,55 ± 0,08 ^{c}	2,82 ± 0,11 ^{c}
W3 (3 mnt)	3,92 ± 0,15 ^{b}	2,45 ± 0,07 ^{c}	2,08 ± 0,14 ^{c}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 1 shows that a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 1 minute produced the highest tensile strength value of tapioca- and glucomannan-based biocomposite foam, reaching 5.04 N/cm², which was significantly different from the other

treatments.Meanwhile, the lowest tensile strength value at the same microcrystalline cellulose concentration (5.5%) with a gelatinization stirring time of 3 minutes was 2.08 N/cm², which was not significantly different from almost all treatments except for the 5.5% microcrystalline cellulose concentration with 1 minute of stirring time and the 1.5% microcrystalline cellulose concentration with 3 minutes of stirring time.

This is attributed to the role of microcrystalline cellulose in forming a matrix with materials such as tapioca and glucomannan, resulting in a stronger composite polymer bonding structure. According to previous research Baru et al. [13] stated that the addition of cellulose can enhance the tensile strength of films at certain variations. Cellulose has long and linear polymer chains, which contribute to improving the mechanical strength of the biocomposite. Based on the results of this study, the tensile strength values obtained have met the Indonesian National Standard for plastic foam (SNI 06-1004-1989), which requires a minimum value of 0.70 N/cm².

3.2 Density

Analysis of variance showed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had a highly significant effect ($p \leq 0.01$) on the density of tapioca- and glucomannan-based biocomposite foam. The resulting density values ranged from 0.22 ± 0.01 to 0.38 ± 0.33 g/cm³, as presented in Table 2.

Table 2. The average density values (g/cm³) of tapioca- and glucomannan-based biocomposite foam at various microcrystalline cellulose concentrations and gelatinization stirring times.

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	0,27 ± 0,02 ^{b}	0,26 ± 0,01 ^{b}	0,25 ± 0,02 ^{b}
W2 (2 mnt)	0,27 ± 0,03 ^{b}	0,23 ± 0,02 ^{b}	0,25 ± 0,01 ^{b}
W3 (3 mnt)	0,22 ± 0,01 ^{b}	0,29 ± 0,11^{ab}	0,38 ± 0,33 ^{a}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 2 shows that a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 3 minutes produced the highest density of tapioca and glucomannan based biocomposite foam, with a value of 0.38 g/cm³, which was not significantly different from the treatment with 3.5% microcrystalline cellulose and 3 minutes of stirring time. Meanwhile, the lowest density value of 0.22 g/cm³ was obtained at a microcrystalline cellulose concentration of 1.5% with a gelatinization stirring time of 3 minutes, which was not significantly different from almost all treatments except for the 5.5% microcrystalline cellulose concentration with 3 minutes of stirring time. The differences in density values were influenced by the formation of air cavities due to CO_2, which significantly reduced the mass per unit volume of the resulting foam. In natural and synthetic rubber composite systems, cell size and number are directly related to density. According to previous research Ariff et al. (2008), the smaller the cell size formed, the higher the

material density. A decrease in density occurs when more CO_2 gas is trapped within the structure. Ferdiansyah et al. [14] also emphasized that crosslinking phenomena resulting from raw material interactions play an important role in determining the final density value. Based on the results of this study, the density values obtained have not yet met the Indonesian National Standard for plastic foam (SNI 06-1004-1989), which specifies a range of 12–15 kg/cm³.

3.3 Tear Resistance.

The analysis of diversity shows that the treatment of microcrystalline cellulose concentration with gelatinization stirring time and their interaction has a very significant effect ($p \leq 0.01$) on the tear resistance value of tapioca and glucomannan foam biocomposites. The resulting tear resistance value ranges from 1.49 ± 0.09 – 3.60 ± 0.43 N/cm² as seen in Table 3.

Table 3. The average tear resistance values of tapioca and glucomannan foam biocomposites at various concentrations of microcrystalline cellulose and different gelatinization stirring times.

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	1,57 ± 0,23 ^{c}	1,60 ± 0,05 ^{c}	3,60 ± 0,43 ^{a}
W2 (2 mnt)	1,70 ± 0,08 ^{c}	1,82 ± 0,05 ^{c}	2,01 ± 0,08 ^{c}
W3 (3 mnt)	2,80 ± 0,10 ^{b}	1,75 ± 0,05 ^{c}	1,49 ± 0,09 ^{c}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 3 shows that the highest average tear resistance of tapioca–glucomannan foam biocomposites was obtained at a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 1 minute, with a value of 3.60 N/cm², which was significantly different from the other treatments. Meanwhile, the lowest average tear resistance was observed in the tapioca–glucomannan foam biocomposites with a microcrystalline cellulose concentration of 5.5% and a stirring time of 3 minutes, with a value of 1.49 N/cm². This value was not significantly different from the tear resistance values of all treatments except for the treatment with a microcrystalline cellulose concentration of 5.5% and a gelatinization stirring time of 1 minute and the treatment with a microcrystalline cellulose concentration of 1.5% and a gelatinization stirring time of 3 minutes. According to previous research Sumardiono et al. [15] the addition of cellulose has been proven to influence the tear resistance of foam biocomposites. This may occur because cellulose fibers undergo decomposition and form long fiber structures that are interconnected. A higher cellulose content facilitates the formation of a strong inter-fiber network, thereby increasing the material's resistance to tearing forces. In contrast, excessively long gelatinization processes cause the viscosity of the mixture to decrease drastically due to the excessive rupture of starch granules, resulting in unstable molecular interactions, a more fragile foam structure, and reduced mechanical strength of the material. Tear resistance greatly affects the durability of foam biocomposites when used for extended periods. The higher the tear resistance

value, the more durable the foam biocomposite will be in use. Based on the results of this study, the tear resistance values have met the Indonesian National Standard (SNI) for foam plastics 06-1004-1989, which specifies a minimum value of 0.50 N/cm².”

3.4 Compression Set

The analysis of variance showed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had a highly significant effect ($p \leq 0.01$) on the compression set value of tapioca–glucomannan foam biocomposites. The resulting compression set values ranged from 9.82 ± 0.27% to 19.99 ± 0.65%, as shown in Table 4.

Table 4. The average compression set values of tapioca–glucomannan foam biocomposites at different microcrystalline cellulose concentrations and gelatinization stirring times.

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	19,99 ± 0,65 [a]	17,00 ± 0,80 [ab]	9,82 ± 0,27 [c]
W2 (2 mnt)	17,2 ± 0,96 [ab]	17,01 ± 2,04 [ab]	17,29 ± 1,92 [ab]
W3 (3 mnt)	10,34 ± 0,68 [c]	15,95 ± 0,70 [b]	16,23 ± 0,47 [b]

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 4 shows that a microcrystalline cellulose concentration of 1.5% with a gelatinization stirring time of 1 minute produced the highest compression set value of tapioca–glucomannan foam biocomposites, reaching 19.99%. This value was not significantly different from the compression set values obtained from treatments with a microcrystalline cellulose concentration of 1.5% and a gelatinization stirring time of 2 minutes, a microcrystalline cellulose concentration of 3.5% with stirring times of 1 and 2 minutes, and a microcrystalline cellulose concentration of 5.5% with a stirring time of 2 minutes. Meanwhile, the lowest compression set value was 9.82%, which was significantly different from the compression set values of treatments with microcrystalline cellulose concentrations of 1.5% and 3.5% with a gelatinization stirring time of 1 minute. According to previous research Pratami et al. [16], when the amount of cellulose exceeds the optimum limit, cellulose particles tend to agglomerate, which can reduce compressive strength. This statement is consistent with the findings of Berutu et al. [17] who reported that the addition of cellulose could reduce the compressive strength of foam biocomposites. Based on the results of this study, the compression set values obtained have not met the Indonesian National Standard (SNI) for foam plastics 06-1004-1989, which specifies a maximum value of 10%.

3.5 Thickness

The analysis of variance showed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had a highly significant effect ($p \leq 0.01$) on the thickness of tapioca–glucomannan foam biocomposites. The average thickness values obtained ranged from 5.24 ± 0.01 mm to 15.11 ± 4.01 mm, as presented in Table 5.

Table 5. The average thickness of tapioca–glucomannan foam biocomposites at different

microcrystalline cellulose concentrations and gelatinization stirring times

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	5,24 ± 0,01 ^{b}	6,42 ± 0,39 ^{b}	9,84 ± 0,03 ^{ab}
W2 (2 mnt)	6,80 ± 0,64 ^{b}	6,24 ± 0,14 ^{b}	7,42 ± 0,21 ^{b}
W3 (3 mnt)	15,11 ± 4,01^{a}	7,83 ± 0,01 ^{b}	9,00 ± 1,01 ^{b}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 5 shows that a microcrystalline cellulose concentration of 1.5% with a gelatinization stirring time of 3 minutes produced the highest thickness value of 15.11 mm, which was not significantly different from the thickness obtained at a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 1 minute. Meanwhile, the lowest thickness value was observed at a microcrystalline cellulose concentration of 1.5% with a gelatinization stirring time of 1 minute, with a value of 5.24 mm. This value was not significantly different from the thickness values of all treatments except for the treatment with a microcrystalline cellulose concentration of 1.5% and a gelatinization stirring time of 3 minutes.

In this study, microcrystalline cellulose was able to function optimally in the formation of the foam structure by assisting the binding process and the formation of foam cell walls, allowing the structure to expand and increase in thickness. However, the stirring time of 1 minute showed a decrease in thickness due to the uneven molding process of the foam biocomposite, which was carried out manually. According to Anandito et al. [18], excessively low dough viscosity can cause excessive expansion, resulting in a more fragile foam biocomposite. Thickness measurement is important because it serves as a packaging parameter that helps maintain the quality of the product [19].

3.6 Swelling

The analysis of varianc eshowed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had no significant effect on the swelling value of tapioca–glucomannan foam biocomposites. The swelling values obtained ranged from 0.64 ± 0.16% to 1.22 ± 0.16%, as presented in Table 6.

Table 6. The average swelling values of tapioca–glucomannan foam biocomposites at different microcrystalline cellulose concentrations and gelatinization stirring times

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	0,77 ± 0,10 ^{ab}	0,71 ± 0,08 ^{b}	0,65 ± 0,04 ^{b}
W2 (2 mnt)	0,84 ± 0,14 ^{ab}	0,64 ± 0,16 ^{b}	0,72 ± 0,06 ^{b}
W3 (3 mnt)	1,22 ± 0,16 ^{a}	0,76 ± 0,03 ^{ab}	0,83 ± 0,18^{ab}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 6 shows that a microcrystalline cellulose concentration of 1.5% with a gelatinization stirring time of 3 minutes produced the highest swelling value of 1.22%. This value was not significantly different from the swelling values obtained from treatments with a microcrystalline

cellulose concentration of 1.5% with gelatinization stirring times of 1 and 2 minutes, a microcrystalline cellulose concentration of 3.5% with a gelatinization stirring time of 3 minutes, and a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 3 minutes. Meanwhile, the lowest swelling value of 0.64% in the tapioca–glucomannan foam biocomposite was observed at a microcrystalline cellulose concentration of 3.5% with a gelatinization stirring time of 2 minutes. This value was not significantly different from the swelling values of all treatments except for the treatment with a microcrystalline cellulose concentration of 1.5% and a gelatinization stirring time of 3 minutes.

An increase in microcrystalline cellulose concentration tended to reduce the swelling value at the same stirring time. This decrease was caused by the role of microcrystalline cellulose as a filler or reinforcing agent that can increase the density of the matrix. Microcrystalline cellulose contains hydroxyl groups that can form hydrogen bonds with gelatin, thereby reducing the number of free hydrophilic groups that can interact with water. As a result, water penetration into the material structure becomes limited and the swelling capacity decreases. This finding is consistent with the study of previous research [19] which reported that the addition of microcrystalline cellulose as a filler in a polymer matrix can reduce water absorption due to the formation of a more compact and dense structure. Based on the results of this study, the swelling values obtained have met the Indonesian National Standard (SNI) for foam plastics 06-1004-1989, which specifies a maximum value of 1.44%.

3.7 Elongation at Break

The analysis of variance showed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had no significant effect on the elongation at break of tapioca–glucomannan foam biocomposites. The elongation at break values obtained ranged from 1.51 ± 0.69% to 3.02 ± 0.02%, as presented in Table 7.

Table 7. The average elongation at break of tapioca–glucomannan foam biocomposites at different microcrystalline cellulose concentrations and gelatinization stirring times.

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	2,48 ± 0,68 ^{ab}	2,51 ± 0,01^{ab}	3,02 ± 0,02 ^{a}
W2 (2 mnt)	2,54 ± 0,02 ^{ab}	2,01 ± 0,01 ^{ab}	1,51 ± 0,69 ^{b}
W3 (3 mnt)	2,54 ± 0,05 ^{ab}	2,51 ± 0,01 ^{ab}	2,06 ± 0,03 ^{ab}

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

Table 7 shows that a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 1 minute produced the highest elongation at break value of tapioca–glucomannan foam biocomposites, reaching 3.02%. This value was not significantly different from the elongation at break values of all treatments except for the treatment with a microcrystalline cellulose concentration of 5.5% and a gelatinization stirring time of 2 minutes. Meanwhile, the

lowest elongation at break value of 1.51% was obtained at a microcrystalline cellulose concentration of 5.5% with a gelatinization stirring time of 2 minutes. This value was not significantly different from the elongation at break values of all treatments except for the treatment with a microcrystalline cellulose concentration of 5.5% and a gelatinization stirring time of 1 minute.

The difference in elongation at break values was influenced by the concentration of microcrystalline cellulose, which acts as a filler that occupies the voids within the tapioca–glucomannan matrix, thereby increasing the ability of the matrix to stretch before breaking. However, at a microcrystalline cellulose concentration of 5.5% with gelatinization stirring times of 2 and 3 minutes, a significant decrease was observed, reaching the lowest value of 1.51 ± 0.69%. This decrease indicates that excessive cellulose addition combined with non-optimal stirring duration may increase the stiffness of the foam biocomposite. Gelatinization time plays an important role in determining the homogeneity of the polymer mixture. However, excessive gelatinization time may cause the foam structure to become too dense or may damage the foam cell walls, thereby reducing the elasticity of the foam biocomposite. According to the Indonesian National Standard (SNI) for foam plastics 06-1004-1989, the minimum elongation at break value required is 160%. The elongation at break values obtained in this study have not yet met the requirements of the Indonesian National Standard (SNI) for foam plastics 06-1004-1989.

3.8 Biodegradation

The analysis of varianceshowed that the treatment of microcrystalline cellulose concentration, gelatinization stirring time, and their interaction had no significant effect on the biodegradation of tapioca–glucomannan foam biocomposites. The biodegradation time obtained ranged from 10 ± 0.00 to 13 ± 1.41 days, as shown in Table 8.

Table 8. The average biodegradation time of tapioca–glucomannan foam biocomposites at different microcrystalline cellulose concentrations and gelatinization stirring times

Strirring Time	Microcrystalline Cellulose Concentration		
	K1 (1,5%)	K2 (3,5%)	K3 (5,5%)
W1 (1 mnt)	11 ± 1,41 [a]	11 ± 1,41 [a]	12 ± 2,83 [a]
W2 (2 mnt)	10 ± 0,00 [a]	13 ± 1,41 [a]	12 ± 0,00 [a]
W3 (3 mnt)	11 ± 1,14 [a]	11 ± 1,41 [a]	13 ± 1,41 [a]

Note: Different letters following the mean values indicate a significant difference at the 5% significance level.

The biodegradation test aims to determine the extent and rate at which the foam biocomposite samples can be decomposed by microorganisms in the soil. The results presented in Table 8 show that the tapioca–glucomannan foam biocomposite decomposed most rapidly at a microcrystalline cellulose concentration of 1,5% with a gelatinization stirring time of 1 minute; however, this result was not significantly different from the other treatments. In the other treatments, the biodegradation time was also relatively similar, with the foam biocomposites

decomposing between 11 and 13 days.

The results indicate that increasing the concentration of microcrystalline cellulose and the gelatinization stirring time tends to increase the biodegradation time. Cellulose-based materials have good biodegradability because their polysaccharide structure can be easily degraded by microorganisms. The biodegradation process occurs at different rates depending on environmental conditions and material properties, such as moisture, temperature, pH, types of microorganisms, as well as the type and thickness of the polymer. In addition, environmental parameters such as pH, temperature, nutrient availability, minerals, oxygen, and moisture must be properly regulated according to the characteristics of the microorganisms involved in the degradation process. Based on the results of this study, the biodegradation time has met the Indonesian National Standard (SNI) for foam plastics 06-1004-1989, which specifies a maximum biodegradation period of 60 days.

4. Conclusions

Tapioca and glucomannan biocomposite foam reinforced with microcrystalline cellulose (MCC) as a filler was successfully prepared through a gelatinization and foaming process. The concentration of microcrystalline cellulose and the gelatinization stirring time, as well as their interaction, significantly affected the tensile strength, tear resistance, density, compression set, thickness, swelling, and elongation at break of the biocomposite foam, while no significant effect was observed on biodegradation.

The best characteristics were obtained at 5.5% microcrystalline cellulose concentration with 1 minute of gelatinization stirring time. This treatment produced a tensile strength of 5.04 N/cm² and tear resistance of 3.60 N/cm², meeting the requirements of SNI 06-1004-1989 for plastic foam. The thickness swelling value of 1.22% complied with EN 317 standards, and the biodegradation time of 13 days fulfilled ASTM D5988 standards. These results indicate that the developed biocomposite foam has good mechanical properties and is environmentally friendly, demonstrating its potential as a biodegradable alternative to conventional plastic foam packaging.

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