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Characteristics of Foam Biocomposites from Tapioca, Chitosan, Polyvinyl Alcohol in Variations of Concentration and Mixed Ratio of Sorbitol/Toluene Diisocyanate

[1] Angelia Noventa Cahyani, [2] Bambang Admadi Harsojuwono, [3] Lutfi Suhendra
[1, 2, 3] Agricultural Industrial Technology, Faculty of Agricultural Technology, Udayana University, Jimbaran, South Kuta, Badung (80361), Bali, Indonesia

Corresponding Author: **Bambang Admadi Harsojuwono**

Abstract
Biocomposite foam is a foam-shaped material formed from a mixture of natural materials that can form a gel matrix with the help of a foam former. This study aimed to examine the effect of sorbitol and toluene diisocyanate (TDI-80) concentration and mixture ratio on the characteristics of tapioca, chitosan, and polyvinyl alcohol biocomposite foam and to determine the optimal concentration and mixture ratio of sorbitol/TDI-80. The experiment was designed using a Randomized Block Design (RBD) with three concentration treatments (15%, 17.5%, and 20%) and three ratio treatments (4:6, 5:5, and 6:4) in two groups of biocomposite foam production times. The variables observed included tensile strength, compression set, density, thickness expansion, thickness, tear strength, and biodegradation time. Sorbitol and toluene diisocyanate concentration of 17.5% with a sorbitol and toluene diisocyanate ratio 6:4 produced the best biocomposite foam with a tensile strength of 15.8 N/cm2, compression set of 8.8%, density of 0.3 kg/m3, thickness expansion of 1.1%, thickness of 9.7 mm, tear strength of 11.3 N/cm2, and biodegradation time of 12.0 days.

Keywords: Biocomposite Foam, Chitosan, Polyvinyl Alcohol, Tapioca, Sorbitol/Toluene Diisocyanate

1. Introduction

Styrofoam is a type of synthetic plastic often used as disposable food and beverage packaging. Styrofoam is used for food and beverage packaging due to its lightweight, practical, heat-resistant, waterproof, and affordable nature (Azis, 2017) [1].

The rapid development of the food, beverage, and culinary industries has increased the use of Styrofoam as disposable packaging, resulting in increased Styrofoam waste, a type of waste that is difficult to decompose and thus pollutes the environment (Abdullah *et al*., 2022) [2]. Furthermore, substances contained in Styrofoam, such as styrene and benzene, have the potential to migrate into food or beverages, posing a danger to consumers (Dinanti *et al*., 2024) [4]. Given the various negative impacts of Styrofoam packaging, it is necessary to find alternative packaging that is similar but biodegradable, one of which is biocomposite foam packaging or biodegradable foam.

Biocomposite foam is a foam-like material formed from a mixture of natural materials that can form a gel matrix with the aid of a foam former (Sitanggang *et al*., 2023) [15]. Potential natural materials include tapioca, chitosan, polyvinyl alcohol (PVA) (Harsojuwono *et al*., 2022; Marichelvam *et al*., 2022) [7, 11], and sorbitol, both as a plasticizer and foam former, along with TDI-80.

Taro leaves contain bioactive compounds such as flavonoids, tannins, and lignocellulose fibers, which have the potential to act as reinforcing materials (fillers) in the manufacture of biopolymer materials. According to research (Ulfah *et al*., 2019) [16], taro leaf powder was mixed with PVA in various ratios, but the optimal composition was 45:55 (taro leaf powder: PVA). The cellulose fiber content in taro leaves can improve the mechanical properties and thermal stability of natural-based biofoam.

The success of foam biocomposite formation is greatly influenced by many factors, including the type and concentration of matrix material, concentration and ratio of foam-forming materials used (Harsojuwono & Arnata, 2017) [6]. Several studies of foam biocomposites have been reported, but not all of their characteristics meet the established standards. Reviandi *et al* (2022) [13] reported that the best characteristics of cornstarch-glucomannan foam biocomposite were obtained using 17.5%

foam-forming material (sorbitol: TDI-80 = 7: 3) which had a mass density of 0.09 g/mL, hardness of 6.14 kg, rebound springiness of 19.93%, breaking stress of 0.21 N/mm², elongation at break of 6.53%, tear resistance of 0.15 N/cm², constant compression of 4.90% and degraded in an average of 7.25 days. Meanwhile, Ferdiansyah *et al*. (2021) demonstrated that the best tapioca-glucomannan biocomposite foam used a 17.25% sorbitol/TDI-80 mixture in a 1:1 ratio, resulting in a tensile strength of 0.69 N/cm2, tear resistance of 0.49 N/cm2, density of 0.20 g/ml, a constant compressibility of 7.61%, a thickness of 10.27 mm, a swelling of 0.55%, and a degradation time of 13.67 days.

The above description indicates that there is no information available regarding the concentration and ratio of the sorbitol/TDI-80 mixture in the production of biocomposite foam from tapioca, chitosan, and PVA. Therefore, research is needed on the concentration and ratio of the sorbitol/TDI-80 mixture in the production of biocomposite foam from tapioca, chitosan, and PVA, with the hope of obtaining a biocomposite foam with characteristics that meet the Indonesian National Standard (SNI).

This study aims to determine the effect of the concentration and ratio of the sorbitol/toluene diisocyanate mixture on the characteristics of tapioca, chitosan, and PVA foam biocomposites. The results of this study are expected to produce foam biocomposites with characteristics that meet the Indonesian National Standard (SNI).

2. Material and Methods

Material

The materials used in this study were the main matrix material tapioca from CV. Nura Jaya, chitosan from Chimultiguna, and taro leaves obtained from Br. Umadiwang, Batannyuh Village, Marga District, Tabanan Regency. The chemicals used were glycerol, acetic acid, PVA from Saba Kimia, polyol compounds (sorbitol) and toluene diisocyanate from UD. Hasil Kasih.

Method

Research Design

This research was conducted using a Randomized Block Design (RBD) with two factors: sorbitol/toluene diisocyanate concentration (15%, 17.5%, and 20%) and ratio (4:6, 5:5, and 6:4), resulting in nine treatment combinations were divided into two groups based on production time, resulting in 18 experimental units.

Research Implementation

The study will be conducted in two stages: the first stage, producing taro leaf powder, and the second stage, producing biocomposite foam, as described below.

Taro Leaf Powder Production

The taro (Colocasia esculenta) leaves selected were mature and bright green. The taro leaves were then washed under running water until clean and soaked for 24 hours. Afterward, the taro leaves were dried in an oven at 60°C for 3 hours. Once dried, the taro leaves are blended and sieved using a 100-mesh sieve (Ulfah *et al*., 2019) [16].

Biocomposite Foam Production

The biocomposite foam preparation begins by weighing 4.5 g of tapioca, 1.5 g of chitosan, 5 g of PVA, 2 g of taro leaf powder, and sorbitol/TDI-80 according to the treatment. Then, a 1% acetic acid solution is added to the mixture until the material weighs 100 g. Next, three beakers are prepared: the first beaker is filled with 4.5 g of tapioca, the second with 1.5 g of chitosan, and the third with 5 g of PVA. Then, a 1% acetic acid solution was added in equal amounts to each beaker. Afterward, beakers 1, 2, and 3 were stirred until evenly distributed. The following three mixtures were combined in a larger beaker, then heated to 75°C and stirred thoroughly until a gel formed.

The resulting gel was gradually added with sorbitol/TDI-80, then stirred until evenly distributed. The smooth mixture was transferred to a 10 x 10 cm baking pan and allowed to stand for 30 minutes at room temperature until it expanded. It was then dried in an oven at 50°C for 8 hours until it expanded and formed a foam (modified by Prihastuti, 2008). The mold and the formed biocomposite foam were then cooled at room temperature for 1 hour, after which the biocomposite foam was removed from the mold and ready for testing.

Data Analysis

The observed data were analyzed using analysis of variance (ANOVA) to determine the effect of the concentration and ratio of the sorbitol/toluene diisosinate mixture, as well as their interaction, on the characteristics of the resulting biocomposite foam. This was followed by an Honestly Significant Difference (HSD) test at a 5% significance level to determine differences between treatments.

The best treatment was determined by comparing all observed parameters against applicable quality standards, namely the Indonesian National Standard (SNI) and International Standards, to obtain the treatment combination that yielded the most optimal biocomposite foam characteristics. All data analysis was performed using Microsoft Excel software.

3. Results and Discussion

Tensile Strength

The results of the analysis of variance in the tensile strength test showed that the concentration and ratio of sorbitol/TDI-80, as well as their interaction, had a highly significant effect ($P<0.01$) on the tensile strength of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams. The average tensile strength of tapioca, chitosan, and PVA-based biocomposite foams ranged from 3.50 to 15.80 N/cm2, as shown in Table 1.

Table 1: Average tensile strength value (N/cm2) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at sorbitol/TDI-80 concentration and ratio

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio		
	4:6	5:5	6:4
15	10.4±0.44^{c}	3.5±0.02^{d}	9.9±0.88^{c}
17.5	13.2±0.63^{b}	5.3±0.94^{d}	15.8±0.37^{a}
20	3.5±0.28^{d}	3.6±0.11^{d}	3.6±0.47^{d}

Note: Different letters after the average value indicate significant differences at a 5% error level.

Table 1 shows that the highest tensile strength was obtained at 17.5% concentration with a sorbitol/TDI-80 ratio of 6:4, at 15.8 N/cm2. The lowest value was found at 15% concentration with a 5:5 ratio, at 3.5 N/cm2. This was not significantly different from the tensile strength at 17.5% concentration with a sorbitol/TDI-80 ratio of 5:5, and at

20% concentration with ratios of 4:6, 5:5, and 6:4. When compared to the foam tensile strength standard based on SNI 06-1004-1995, which is a minimum of 0.70 N/cm2, all treatments in this study met this standard. The resulting foam biocomposites demonstrated good tensile strength before failure. Increasing the concentration from 15% to 17.5% resulted in a significant increase in tensile strength. However, at a concentration of 20%, the tensile strength decreased. This is because the excessive addition of plasticizer to biofoam can reduce the biofoam's ability to withstand tensile loads due to the increased flexibility of the polymer network in the biofoam (Zhang *et al*., 2023) [17].

Permanent Compression

Permanent compression indicates the foam material's ability to return to its original shape after being subjected to pressure for a certain period of time. The lower the permanent compression value (%), the better the foam quality, as it indicates the material's ability to return to its original shape after being compressed. The results of the analysis of variance in the permanent compression value test showed that the concentration and sorbitol/TDI-80 ratio, as well as their interaction, had a highly significant effect (P<0.01) on the permanent compression value of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams. The average tensile strength values for tapioca, chitosan, and PVA foam biocomposites ranged from 8.8 to 36.3%, as shown in Table 2.

Table 2: Average constant compression value (%) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at different sorbitol/TDI-80 concentrations and ratios

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio		
	4:6	5:5	6:4
15	10.0±0.04^{d}	21.9±1.42^{c}	9.8±0.02^{d}
17.5	8.9±0.03^{d}	22.9±1.43^{c}	8.8±0.05^{d}
20	29.4±0.72^{b}	33.3±3.58^{ab}	36.3±0.74^{a}

Note: Different letters after the average value indicate significant differences at a 5% error level.

Table 2 shows that the highest permanent compression value of the tapioca, chitosan, and polyvinyl alcohol foam biocomposite was achieved at a concentration of 20% with a sorbitol/TDI-80 ratio of 6:4, at 36.3%. This was not significantly different from the permanent compression value at the 20% concentration with a sorbitol/TDI-80 ratio of 5:5. Meanwhile, the lowest permanent compression value was achieved at a concentration of 17.5% with a sorbitol/TDI-80 ratio of 6:4, at 8.8%. This was not significantly different from the permanent compression values at the 15% and 17.5% concentrations with sorbitol/TDI-80 ratios of 4:6 and 6:4. A lower permanent compression value indicates the foam's ability to return to its original shape after experiencing pressure.

Based on SNI 06-1004-1989, the maximum permanent compression value is 10%. Therefore, only a few treatments in this study met this standard: the 15% 4:6 ratio, the 15% 6:4 ratio, the 17.5% 4:6 ratio, and the 17.5% 6:4 ratio. The other treatments had permanent compression values above the standard and therefore did not meet the SNI foam quality criteria. An increase in the permanent compression value was seen in treatments with higher sorbitol and TDI concentrations, particularly at 20%, where the permanent compression value increased to more than 30%. This condition indicates that the addition of high amounts of plasticizer causes a decrease in the structural density of the foam by increasing the mobility of the polymer chain and reducing the material modulus, so that the matrix becomes soft, easily undergoes permanent deformation under pressure, and has the potential to cause or coalesce cells (Litauszki & Kmetty, 2021) [8].

Density

Density testing is an important variable in foam characterization because it is related to the level of cell structure density and the number of air cavities formed within the material. The results of the density test variance analysis showed that the concentration and ratio of sorbitol/TDI-80, as well as their interaction, had a highly significant effect (P<0.01) on the density of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams. The average density values of tapioca, chitosan, and PVA biocomposite foams ranged from 0.2 to 0.4 kg/m3, as shown in Table 3.

Table 3: Average density value (kg/m3) of biocomposites from tapioca, chitosan, and polyvinyl alcohol at a concentration and ratio of sorbitol/TDI 80

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio		
	4:6	5:5	6:4
15	0.20±0.01^{d}	0.28±0.01^{c}	0.32±0.02^{b}
17.5	0.32±0.01^{b}	0.32±0.02^{b}	0.32±0.02^{b}
20	0.32±0.02^{b}	0.32±0.02^{b}	0.40±0.02^{a}

Note: Different letters after the average value indicate significant differences at a 5% error level.

Table 3 shows that the highest density was obtained at 20% concentration with a sorbitol/TDI-80 ratio of 6:4, at 0.4 kg/m3, significantly different from the other treatments. The lowest density was obtained at 15% concentration with a sorbitol/TDI-80 ratio of 4:6, at 0.2 kg/m3, significantly different from the other treatments.

Table 3 shows a tendency for density to increase with increasing concentration and sorbitol/TDI-80 ratio. This suggests that the higher the amount of solids in the biopolymer system, the denser the foam structure becomes, reducing the space for air cells to form. This phenomenon was reported in a study (Cuadra-Rodríguez *et al*., 2023) [3], which stated that increasing the solids content can create a denser polymer network, thus promoting foam cell formation and growth, which can increase biofoam density. Based on foam quality standards according to SNI 06-1004-1989, the required density is in the range of 12-15 kg/m3. Compared with the research results, all treatments in this study did not fall within this standard range.

Thickness Swelling

Thickness swelling is a variable that indicates a material's ability to absorb water, which can cause dimensional changes in the foam. The lower the thickness swelling value, the better the material's dimensional stability against water. The results of the analysis of variance in the thickness swelling test showed that the concentration and ratio of sorbitol/TDI-80 had a highly significant effect (P<0.01), while the interaction between the two had no significant effect on the thickness swelling values of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams. The average thickness swelling values for tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams ranged from 0.6 to 2.1%, as shown in Table 4.

Table 4: Average thickness swelling values (%) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at sorbitol/TDI 80 concentrations and ratios

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio			
	4:6	5:5	6:4	Average
15	2.1±0.21	1.8±0.12	1.7±0.10	1.8±0.14[a]
17.5	1.7±0.07	1.4±0.06	1.1±0.15	1.4±0.09[b]
20	1.1±0.07	0.7±0.04	0.6±0.10	0.8±0.07[c]
Average	1.6±0.11[a]	1.3±0.07[b]	1.1±0.11[b]	

Note: Different letters after the average value indicate significant differences at a 5% error level

Table 4 shows the thickness swelling of the biocomposite foam made from tapioca, chitosan, and polyvinyl alcohol. The highest swelling value was obtained at the 15% concentration, with a value of 1.8%, significantly different from the other treatments. The lowest value was obtained at the 20% concentration, with a value of 0.6%, significantly different from the other treatments. The effect of the sorbitol/TDI-80 ratio shows that the highest thickness swelling was at a ratio of 4:6, at 1.6%, significantly different from the other treatments. The lowest was at a ratio of 6:4, with a thickness swelling value of 1.1%, not significantly different from the thickness swelling at a sorbitol/TDI-80 mixture ratio of 5:5.

Based on foam quality standards according to International Standard (SI) (EN 317), the required thickness swelling is a maximum of 1.44%. The decrease in thickness swelling value that occurs with increasing sorbitol/TDI-80 concentration indicates that the foam matrix structure becomes denser and more stable. Furthermore, the interaction between starch, chitosan, and polyvinyl alcohol in the biopolymer matrix can form a stronger network, thereby increasing the material's resistance to water absorption. A denser polymer network can increase resistance to water infiltration and material dimensional changes (Lohtander *et al*., 2023) [10].

Thickness

Thickness is a physical variable that indicates the degree of foam expansion during the forming process. The results of the analysis of variance in the thickness test showed that the sorbitol/TDI-80 ratio had a highly significant effect ($P<0.01$), while the concentration and interaction of the two had no significant effect on the thickness of the tapioca-, chitosan-, and polyvinyl alcohol-based biocomposite foam. The average thickness values ranged from 7.3 to 9.8 mm, as shown in Table 5.

Table 5: Average thickness values (mm) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at sorbitol/TDI-80 concentrations and ratios

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio			
	4:6	5:5	6:4	Average
15	2.1±0.21	1.8±0.12	1.7±0.10	1.8±0.14[a]
17.5	1.7±0.07	1.4±0.06	1.1±0.15	1.4±0.09[b]
20	1.1±0.07	0.7±0.04	0.6±0.10	0.8±0.07[c]
Average	1.6±0.11[a]	1.3±0.07[b]	1.1±0.11[b]	

Note: Different letters after the average value indicate significant differences at a 5% error level

Table 5 shows that the highest thickness value for the biocomposite foam made from tapioca, chitosan, and polyvinyl alcohol was obtained in the sorbitol/TDI-80 ratio of 6:4, with a value of 9.4 mm, significantly different from the other treatments. The lowest thickness was obtained in the sorbitol/TDI-80 ratios of 4:6 and 5:5, with a value of 9.0 mm, significantly different from the other treatments. Based on foam quality standards according to SNI 06-1004-1989, the thickness variable does not have a specific value limit because foam thickness is generally influenced by mold size and the material forming process. Therefore, thickness measurements in this study focused more on observing the effect of variations in sorbitol/TDI-80 concentration on the resulting foam shape.

This increase in thickness is thought to occur because a higher amount of polymer matrix material increases the system's ability to form cellular or pore structures during the foam formation process. The resulting cell structure increases the material volume, resulting in greater foam thickness. Furthermore, according to Liu *et al*. (2022) [9], the presence of sorbitol as a plasticizer can increase the mobility of the polymer chains, thus facilitating the foam expansion process during the material formation reaction.

Tear Resistance

Tear resistance is a critical variable in determining the foam material's ability to withstand tearing forces or mechanical damage when subjected to a tensile load at a specific point. The results of the tear resistance test variance analysis showed that the concentration and ratio of sorbitol/TDI-80, as well as their interaction, had a highly significant effect ($P<0.01$) on the tear resistance of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams. The average tear resistance values of tapioca, chitosan, and polyvinyl alcohol biocomposite foams ranged from 2.5 N/cm2 to 11.3 N/cm2, as shown in Table 6.

Table 6: Average tear resistance (N/cm2) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at sorbitol/TDI-80 concentrations and ratios

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio		
	4:6	5:5	6:4
15	7.4±0.31[c]	2.5±0.01[d]	7.1±0.63[c]
17.5	9.4±0.45[b]	3.8±0.67[d]	11.3±0.26[a]
20	2.5±0.20[d]	2.6±0.08[d]	2.6±0.33[d]

Note: Different letters after the average value indicate significant differences at a 5% error level

Table 6 shows that the highest tear resistance value for the biocomposite foam made from tapioca, chitosan, and polyvinyl alcohol was 11.3 N/cm2 at a concentration of 17.5% with a sorbitol/TDI-80 ratio of 6:4. This value was significantly different from the other treatments. The lowest tear resistance value was 2.5 N/cm2, which was not significantly different from the tear resistance values at concentrations of 15, 17.5, and 20% with a sorbitol/TDI-80 ratio of 5:5, and the 20% concentration with a sorbitol/TDI-80 ratio of 4:6, and 6:4.

Based on foam quality standards according to SNI 06-1004-1989, the minimum required tear resistance value is 0.50 N/cm2. In this study, all treatments met this standard, as the tear resistance values were well above the specified minimum limit. Differences in tear resistance values between treatments indicate that varying sorbitol/TDI-80 concentrations affects the strength of the foam structure formed. At a concentration of 17.5%, tear resistance values tended to be higher than at other concentrations, indicating that this composition produced a stronger and more stable polymer matrix structure. Conversely, at a concentration of 20%, tear resistance values decreased due to the increased amount of plasticizer, which softened the polymer structure, thus reducing tear resistance. This is consistent with research (Masahid *et al*., 2023) [12], which explains that the mechanical properties of starch-based materials are strongly influenced by the material composition and the presence of plasticizers, which can increase flexibility but potentially reduce mechanical strength if used in excessive amounts.

Biodegradability

Permanent compression indicates the foam material's ability to return to its original shape after being subjected to pressure for a certain period of time. The lower the permanent compression value (%), the better the foam quality, as it indicates the material's ability to return to its original shape after being compressed. The results of the analysis of diversity in the permanent compression value test showed that the treatment of sorbitol/TDI-80 concentration and ratio as well as the interaction of the two had a very significant effect ($P<0.01$) on the permanent compression value of tapioca, chitosan, and polyvinyl alcohol-based foam biocomposites. The average tensile strength value of tapioca, chitosan, and PVA foam biocomposites ranged from 8.8 to 36.3% as shown in Table 7.

Table 7: Average biodegradation time (days) of tapioca, chitosan, and polyvinyl alcohol foam biocomposites at different concentrations and ratios of sorbitol/TDI-80

Sorbitol/TDI-80 mixture concentration (%)	Sorbitol/TDI-80 Ratio			
	4:6	5:5	6:4	Average
15	21.5±0.70	170±1.41	14.5±0.70	17.6±0.93^a
17.5	18.0±1.41	12.0±1.41	12.0±1.41	14.0±1.41^b
20	23.0±1.41	19.5±2.12	16.5±0.70	19.6±1.41^a
Mean	20.8±1.17^a	16.1±1.64^b	14.3±0.93^c	

Note: Different letters after the average value indicate significant differences at a 5% error level

Table 7 shows that the fastest biodegradation time for the tapioca starch, chitosan, and polyvinyl alcohol-based biocomposite foam occurred at a concentration of 17.5%, with a value of 14 days. The longest biodegradation time was 19.6 days for the 20% sorbitol/TDI-80 mixture, which was not significantly different from the biodegradation time at a concentration of 15%. Meanwhile, considering the sorbitol/TDI-80 ratio, the fastest biodegradation time (14.3 days) was found in the 6:4 ratio, significantly different from the other treatments. The 4:6 ratio showed a slower biodegradation time (20.8 days).

These results indicate that the composition of the foam ingredients influences the biodegradation rate. Starch-based biopolymers are known to be readily degradable due to their chemical structure containing hydroxyl groups that are readily decomposed by soil microorganisms, thus accelerating the decomposition process (Shahrim *et al*., 2022) [14]. Soil biodegradation testing methods generally adhere to the International Standard (ASTM D5988) with a maximum standard of 60 days.

Best Treatment

A biocomposite of tapioca, chitosan, and polyvinyl alcohol foam with a sorbitol/TDI-80 concentration of 17.5% and a sorbitol/TDI-80 ratio of 6:4 produced the best foam biocomposite with a tensile strength of 15.8 N/cm2, a constant compressive strength of 8.8%, a density of 0.3 kg/m3, a thickness swelling of 1.1%, a thickness of 9.7 mm, a tear resistance of 11.3 N/cm2, and a biodegradation time of 12.0 days. The results are shown in Table 8.

Table 8: Perbandingan variabel yang diamati dengan variabel yang ditetapkan pada standar

Variable	Standard	Standard value	Research result	Discription
Tensile strength (N/cm^2)	SNI 06-104-1989	Minimum 0.70	15.8	Compliant
Permanent compression (%)	SNI 06-104-1989	Maximum 10%	8.8	Compliant
Density (kg/m^3)	SNI 06-104-1989	12 - 15	0.3	Not compliant
Swelling (%)	EN 317	Maximum 1.44%	1.1	Compliant
Thickness	SNI 06-104-1989	SNI 06-104-1989	9.7	Compliant
Tear resistance (N/cm^2)	SNI 06-104-1989	Minimum 0.50	11.3	Compliant
Biodegradation (day)	ASTM D5988	Maximum 60 days	12.0	Compliant

4. Conclusion

Based on the results of the study on the effect of the concentration and ratio of the sorbitol/toluene diisocyanate (TDI-80) mixture on the characteristics of tapioca, chitosan, and polyvinyl alcohol-based biocomposite foams, the following conclusions can be drawn:

1. The concentration and ratio of the sorbitol/toluene diisocyanate mixture influence the characteristics of the resulting biocomposite foam, including tensile strength, compressive strength, density, thickness swelling, tear resistance, and biodegradation time. The ratio of the sorbitol/toluene diisocyanate mixture influences thickness. The resulting tensile strength values ranged from 3.5–15.8 N/cm^2, constant compression 8.8–36.3%, density 0.3–0.4 kg/m^3, thickness swelling 0.6–2.1%, thickness 7.3–9.8 mm, tear resistance 2.5–11.3 N/cm^2, and biodegradation time 12–23 days.
2. The concentration and ratio of the sorbitol/toluene diisocyanate mixture that produced the best characteristics was a concentration of 17.5% with a sorbitol:toluene diisocyanate ratio of 6:4. This treatment produced biofoam with a tensile strength of 15.8 N/cm^2, a constant compressibility of 8.8%, a density of 8.8 kg/m^3, a thickness expansion of 1.1%, a thickness of 9.7 mm, a tear resistance of 11.3 N/cm^2, and a biodegradation time of 12 days. This treatment demonstrated the best performance because most of the resulting variables met or approached the foam quality standards based on SNI 06-1004-1989 and international standards.

5. Conflict of interest

There is no conflict of interest between the authors or any other parties.

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