KARAKTERISTIK *BIODEGRADABLE FOAM* BERBAHAN BAKU TANDAN KOSONG KELAPA SAWIT (TKKS)

Fatahillah Pringgo Adji[1*], Ngatirah[2] & Ir. Reni Astuti Widyowanti[3]

[1] Student of Department of Agricultural Product Technology, Faculty of Agricultural Technology

Institute of Agricultural Stiper Yogyakarta, Sleman, Yogyakarta, Indonesia

[2] Lecturer of Department of Agricultural Product Technology, Faculty of Agricultural Technology

Institute of Agricultural Stiper Yogyakarta, Sleman, Yogyakarta, Indonesia

**Corresponding author: goalkipperm2m@gmail.com*

Abstract

Biodegradable foam is an alternative packaging to replace Styrofoam from natural raw materials in the form of starch with additional fiber to strengthen its structure. The purpose of this study is to analyze the effect of the ratio of oil palm empty fruit bunch (TKKS) fiber to tapioca starch and the use of polyvinyl alcohol (PVA) on the characteristics of biodegradable foam and to determine the ratio of TKKS to tapioca starch and the use of PVA which produces biodegradable foam that meets Synbra Technology standards. The experimental design used the complete block design (RBL) method with 2 factors, namely the ratio of TKKS fiber to tapioca starch and the use of PVA, and was carried out 2 times. The test parameters used were water absorption analysis, density analysis, L* value brightness analysis, total color difference (ΔE) analysis, biodegradability analysis, thickness analysis, and scanning electron microscope

(SEM) analysis. The results of this study indicate that the ratio of TKKS fiber to tapioca starch affects the density, water absorption, color brightness level (L*) value, total color difference, biodegradability test, and biodegradable foam thickness test. the use of PVA affects the density, water absorption, color brightness level (L*) value, total color difference, biodegradability, and thickness of the biodegradable foam. the best biodegradable foam that is close to Synbra Technology standards is made with a combination of the ratio of TKKS fiber to tapioca starch 75: 25 and the amount of PVA 10%.

Keywords: biodegradable foam, fiber, PVA, starch

Abstrak

Buih terbiodegradasi adalah pembungkusan alternatif untuk menggantikan Styrofoam daripada bahan mentah semula jadi dalam bentuk kanji dengan serat tambahan untuk menguatkan strukturnya. Tujuan kajian ini adalah untuk menganalisis kesan perbandingan serat tandan minyak sawit kosong (TKKS) dengan kanji ubi kayu dan penggunaan alkohol polyvynil (PVA) terhadap ciri-ciri buih terbiodegradasi dan menentukan perbandingan EFB dengan kanji ubi kayu dan penggunaan PVA yang menghasilkan buih terbiodegradasi mengikut piawaian Teknologi Synbra. Reka bentuk eksperimen menggunakan kaedah reka bentuk blok lengkap (RBL) dengan 2 faktor, iaitu nisbah gentian TKKS dengan kanji ubi kayu dan penggunaan PVA dan melakukan 2 ulangan. Parameter ujian yang digunakan adalah analisis penyerapan air, analisis ketumpatan, analisis kecerahan nilai L*, analisis perbezaan warna keseluruhan (ΔE), analisis biodegrability, analisis ketebalan dan analisis mikroskop elektron imbasan (SEM). Hasil kajian ini menunjukkan bahawa nisbah serat TKKS dengan kanji ubi kayu mempengaruhi ketumpatan, penyerapan air, nilai tahap kecerahan warna (L*), perbezaan warna keseluruhan, ujian biodegrability dan ujian ketebalan buih terbiodegradasi. Penggunaan PVA menjejaskan ketumpatan, penyerapan air, nilai tahap kecerahan warna (L*), perbezaan warna keseluruhan,

biodegrability dan ketebalan buih terbiodegradasi. Buih terbiodegradasi terbaik yang hampir dengan piawaian Teknologi Synbra dibuat dengan gabungan nisbah gentian TKKS kepada kanji ubi kayu 75:25 dan jumlah PVA sebanyak 10%.

Kata kunci: buih terbiodegradasi, serat, PVA, kanji

Introduction

One type of plastic that is popular as a food and beverage packaging material is polystyrene foam or styrofoam. Styrofoam is widely used by food producers as a packaging material for disposable food or beverage products, both ready-to-eat, fresh, and ready-to-process food. However, the impact of using Styrofoam can have adverse effects on health and damage the environment (Irawan et al., 2018). According to the West Java Environment Agency, styrofoam takes about 500-1 million years to be decomposed by soil.

Biodegradable foam is an alternative packaging to styrofoam from natural raw materials in the form of starch with additional fiber to strengthen its structure. Thus biodegradable foam is not only biodegradable but also renewable. The process of making biodegradable foam does not use harmful chemicals such as benzene and styrene which are carcinogenic but utilizes the ability of starch to expand due to heat and pressure processes (Coniwati et al., 2018).

The most important components in the manufacture of biodegradable foam are starch and fibers that serve as structural reinforcement. Starch content is very important in determining the physicochemical characteristics of the biodegradable foam produced and also because starch has high biodegradability and is cheap. This biodegradable foam will decompose within 6 to 9 months. So that it can reduce the impact of using styrofoam plastic (Putri et al., 2021).

One of the potential starch sources in Indonesia is tapioca, which comes from the cassava plant (Manihot esculenta). Unlike other types of starch, tapioca has low fat, protein, ash, and amylose content. The very low protein and fat content distinguishes tapioca from cereal starch. Tapioca generally has almost the same amylose content for all types, which is around 17-20%. This is quite different from corn and rice, which have a large variation in amylose content (0-70%) for corn and (0-40%) for rice. Tapioca can contribute to the puffing and popping process when heated using a microwave. This ability is utilized to produce bio foam products through an extrusion process (Iriani, 2013).

Indonesia is the largest palm oil producer in the world. In the production process, it produces as much as 23% TKKS waste from every 1 tonne of fresh fruit bunch (FFB) processing. TKKS is a solid waste produced from palm oil processing that is usually only used for compost. Empty palm oil bunches have a high fiber content of 33.25% cellulose, 25.83% lignin, and 23.24% hemicellulose. Due to the high cellulose content, PKS has the potential to be used as raw material for biodegradable foam fillers. The high cellulose content in TKKS fiber can be used as raw material in the manufacture of biodegradable foam (Dewanti, 2018).

In making biodegradable foam, another ingredient that affects the properties of biodegradable foam is a plasticizer. One plasticizer that is safe to use is polyvinyl alcohol (PVA). PVA has the characteristics of high chemical resistance and hydrophilicity, making it a promising candidate as a food packaging material. PVA is widely used as an alternative packaging material due to its good properties in packaging formation, good resistance to oil and grease, has high tensile strength and flexibility (Maryam et al., 2019).

Other ingredients used in the manufacture of biodegradable foam are magnesium stearate and water. Magnesium stearate is a hydrophobic compound that serves to prevent the sticking of the foam formed on the mold. And the addition of water to the biodegradable foam serves as a blowing agent to increase the expansion of the dough to produce a hollow structure. A blowing agent is a substance that can produce cellular structures through a foaming process in materials that are hardened, for example, biodegradable foam (Putri et al., 2021).

The purpose of this study was to analyze the effect of the ratio of TKKS fiber to tapioca starch and the addition of PVA on the physical and mechanical characteristics of biodegradable foam.

Materials and Methods

Tools used in the manufacture of biodegradable foam are thermopressing tools, mixers, digital scales, and basins. While the tools used for the analysis of biodegradable foam properties are a ruler, cutter/scissors, analytical scales, vernier caliper, stopwatch, bowl/plate, oven, polybag containing fertile soil with a soil height of 10 cm, color analyzer (colorimetry, CS-10) and gester tensile strength test 013159.

The materials used in making biodegradable foam are TKKS powder, tapioca starch, polyvinyl alcohol (PVA), magnesium stearate, and water.

This study used the Complete Block Design (RBL) method consisting of 2 factors and 2 repetitions carried out to obtain accurate results, namely:

Factor I (A) is the ratio of TKKS powder to tapioca starch.

1. A1 = 75:25 (gram)
2. A2 = 50:50 (gram)
3. A3 = 25:75 (gram)

Factor II (B) is the use of PVA based on the weight of the filler material (TKKS powder and tapioca starch) 100 gram

1. B1 = 10% (10 gram)
2. B2 = 20% (20 gram)
3. B3 = 30% (30 gram)

The experiment was conducted with a complete block design (RBL) combining the 2 factors repeated 2 times, resulting in 3 x 3 x 2 = 18. Both factors and levels are interconnected for total AxB data, then computational analysis and diversity are carried out to obtain the effect of differences in factors. In the digital scale data processing was carried out using the IBM SPSS

Statistic sv 25 application. The data obtained was carried out an analysis of variance to determine the influential factors and then the Duncan test was carried out to determine the differences between the influential treatments.

Results and Discussion

Density Analysis

Table 1. Duncan tests density of biodegradable foam (g/cm3)

The ratio of TKKS fiber and tapioca starch	Usage of PVA B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	0.33±0.01	0.41±0.02	0.47±0.01	0.40^{c}±0.07
A2 (50:50)	0.27±0.01	0.32±0.03	0.37±0.02	0.32^{b}±0.05
A3 (25:75)	0.21±0.01	0.26±0.02	0.30±0.04	0.26^{a}±0.05
Averages B	0.27^{x} ±0.06	0.33^{y} ±0.08	0.38^{z} ±0.08	

Based on Table 1, the ratio of TKKS powder and tapioca starch A3 (25:75) has a low average density of 0.26 g/cm3. The more the amount of starch and the less the amount of TKKS fiber, the lower the density value. This happens because the molecular weight of starch is lower than that of TKKS fiber, according to Sipahutar (2020) starch has a molecular weight of 162,000 g/mol while TKKS fiber is 300,000-500,000 g/mol. Because the molecular weight of starch is smaller than that of TKKS fiber, it will reduce the viscosity of the dough. Since tapioca starch will dissolve in water, it will not form a composite in the biodegradable foam, but rather form air cavities and vacuum in the biodegradable foam which causes the foam to expand to its maximum. According to Iriani (2013), the greater the proportion of tapioca used, the greater the expansion ability of bio foam is expected so that the density will also decrease.

The ratio of TKKS fiber and tapioca starch A1 (75:25) has a high average density of 0.40 g/cm3. The more TKKS fiber used, the greater the density value produced. This happens because the molecular weight of TKKS fiber is higher than tapioca starch, according to Sipahutar (2020) starch has a molecular weight of 162,000 g/mol while TKKS fiber is 300,000-500,000 g/mol. Because the molecular weight of the fiber is greater than that of starch, the viscosity of the dough will be higher, if the viscosity of biodegradable foam dough is higher, the dough will be difficult to expand. This is following the statement of Iriani (2013) that high fiber content in the manufacture of bio foam will affect the viscosity of the dough so that the more TKKS is added, the expansion ability will decrease which has an impact on increasing density.

When viewed from the mean of factor B, the higher the concentration of PVA used, the greater the density value. This indicates that increasing the concentration of PVA in all variations of the ratio of TKKS fiber and tapioca starch tends to increase the density value of the bio-foam produced. This is following the research of Iriani (2013) that fiber and PVA added to the manufacture of biodegradable foam produce a high density because the materials fill the empty spaces and the materials will be bound to each other by PVA which acts as an adhesive. The density value in this study ranged from 0.21-0.47 g/cm3.

Water Absorption Analysis

Table 2. Duncan tests biodegradable foam water absorption (%)

The ratio of TKKS fiber and tapioca starch	Usage of PVA			
	B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	$0.23^{p}\pm0.11$	$0.27^{q}\pm0.11$	$0.34^{r}\pm0.11$	$0.28^{a}\pm0.06$
A2 (50:50)	$0.26^{p}\pm0.11$	$0.32^{q}\pm0.11$	$0.37^{r}\pm0.11$	$0.31^{b}\pm0.06$

A3 (25:75)	$0.36^{p}\pm0.11$	$0.50^{q}\pm0.11$	$0.57^{r}\pm0.11$	$0.47^{c}\pm0.11$
Averages B	$0.28^{x}\pm0.07$	$0.36^{y}\pm0.12$	$0.43^{z}\pm0.13$	

Based on Table 2, the ratio of TKKS fiber and tapioca starch A1 (75:25) produces the smallest average water absorption of 0.28%. This is because the addition of TKKS fiber has not gone through the cellulose preparation process. If it has not undergone a cellulose preparation process, the natural fiber (TKKS) still contains hydrophobic cellulose. This is following Iriani (2013) statement that the addition of fiber can increase the crystallinity of the resulting biodegradable foam product. Presumably, this is because fiber whose main content is cellulose is hydrophobic and has a larger crystalline area than starch, as well as a tighter microfibril structure so that the water absorption of the resulting bio foam product will decrease.

Based on Table 2, the higher the ratio of starch in the mixture will increase the water absorption. The ratio of TKKS powder and tapioca starch A3 (25:75) produced the highest average water absorption of 0.47%. This is because starch is hydrophilic which tends to bind with water. This property makes the bio-foam not resistant to water so that a greater water absorption process occurs. Based on the statement of Kaisangsri et al. (2014), the hygroscopic nature of starch molecules causes water molecules to attack the hydrogen bonds of starch, thus reducing the water resistance of a product, causing high water absorption in biodegradable foam.

As seen in Table 2, the higher the concentration of PVA will increase the water absorption of biodegradable foam. That is because according to Sarlinda et al. (2022), the hydrophile nature of PVA will make water exposed to biodegradable foam not only bound to starch but also to PVA. In addition, the addition of more PVA also indicates the amount of water used in the biodegradable foam dough formula. This is because the addition of PVA requires the addition of water to dissolve it so that it can be mixed homogeneously in the biodegradable foam dough formula. The percentage of water absorption in this study ranged from 0.23-0.57%.

Color Brightness Level Analysis (L* Value)

Table 3. Duncan tests biodegradable foam color analysis (L*)

The ratio of TKKS fiber and tapioca starch	Usage of PVA B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	52.68±2.64	54.60±0.04	55.09±0.04	54.13^{a} ±1.27
A2 (50:50)	56.91±1.11	56.10±0.02	59.00±1.76	57.88^{b} ±1.50
A3 (25:75)	59.76±0.74	60.73±0.08	64.02±1.24	61.55^{c} ±2.23
Averages B	56.45^{x} ±3.56	57.74^{x} ±3.20	59.37^{y} ± 4.48	

Based on Table 3, the ratio of TKKS and tapioca starch A3 (25:75) has the highest average lightness (L*) value of 61.55. This value indicates that the biodegradable foam produced is quite bright. This happens because the ratio of tapioca starch is more than the fiber used. The tapioca starch used in this study has a bright white color that affects the bright color produced in the biodegradable foam. According to Berutu et al. (2022), the addition of starch in biodegradable foam causes the appearance of white or bright color. Starch is a complex polymer with two main molecules, amylose, and amylopectin. Amylose and amylopectin have refractive properties that cause light that hits the material to be evenly dispersed. This results in a white or bright color on the biodegradable foam.

The ratio of TKKS and tapioca starch A3 (75:25) has the smallest average lightness value of 54.13. When seen in the mean of factor A, the higher the fiber concentration used, the smaller the value. This indicates that the higher the fiber concentration used, the darker the L* value in each sample. This is due to the presence of lignin in the fiber because the cellulose preparation process has not been carried out on the fiber used. This is supported by a statement from

Etikaningrum (2017) who made bio-foam from empty palm bunches, where the higher the concentration of empty palm bunches used, the smaller the (L*) value produced which indicates that the bio-foam is getting darker, this happens because there is still lignin contained in the fiber.

Based on Table 3, it can be seen in the average of factor B that the higher the concentration of PVA used, the greater the brightness level. This is because the transparent nature of PVA makes the resulting biodegradable foam bright. According to Widyastuti and Hidayati (2020) the addition of PVA to biodegradable foam can increase the lightness value because PVA has transparent properties compared to some biodegradable polymers. PVA will be mixed with fiber and starch to form a homogeneous material matrix, because of its transparent nature, it results in a significant increase in the brightness of biodegradable foam. The L* value of biodegradable foam produced in this research ranges from 52.68-64.02.

Total Color Difference Analysis

Table 4. Duncan tests analysis of total color difference of biodegradable foam

The ratio of TKKS fiber and tapioca starch	Usage of PVA			
	B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	33.95±2.61	32.01±0.04	31.56±0.06	32.51^{c}±1.27
A2 (50:50)	29.78±1.11	28.88±0.02	27.66±1.67	28.77^{b}±1.06
A3 (25:75)	26.99±0.68	25.73±0.13	22.66±1.18	25.13^{a}±2.23
Averages B	30.24^{y}±3.50	28.88^{y}±3.14	27.29^{x}±4.46	

Based on Table 4, the higher the amount of TKKS used, the greater the total color difference value, meaning that the resulting color tends to stay away from the control color (commercial styrofoam). In the comparison of TKKS and tapioca starch A1 (75:25) has the largest average total color difference value of 32.51. This shows that the higher the use of TKKS fiber, the greater the color difference with the control (commercial styrofoam). This is following the research of Dyas (2022) the brightness level of biodegradable foam tends to decrease or get darker with the amount of fiber added. This is due to the presence of lignin content in the fiber because the cellulose preparation process has not been carried out on the fibers used.

In the comparison of TKKS and tapioca starch A3 (25:75) has the smallest total color change value of 54.13. When seen in the mean of factor A, the higher the concentration of tapioca starch used, the smaller the value. It indicates that the higher the concentration of tapioca starch used, the smaller the total color difference with the control (commercial styrofoam). This happens because the tapioca starch used in this study has a bright white color that affects the bright color produced on biodegradable foam. This is in line with the research conducted by Dyas (2022) who used CMC material as a filler for biodegradable foam, where the CMC used in his research was brightly colored and affected the brightness of the biodegradable foam produced.

In factor B (PVA usage), it can be seen that the higher the concentration of PVA used, the smaller the total color difference value. This indicates that the higher the concentration of PVA used, the value of the total color change produced is relatively small with the control (commercial styrofoam). According to Standau et al. (2019), PVA has transparent properties, when molding biodegradable foam PVA will melt and spread evenly in the bio-foam dough. During the cooling process, PVA will form strong bonds with fibers and starch and form a solid matrix which will increase the brightness of the resulting biodegradable foam.

Biodegradability Analysis

Table 5. Duncan test biodegrability analysis biodegradable foam day 7 (%)

The ratio of	Usage of PVA	Averages A

TKKS fiber and tapioca starch	B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	
A1 (75:25)	27.89±1.29	23.84±0.72	19.71±1.10	23.81^{a} ±4.09
A2 (50:50)	36.25±1.63	31.24±1.46	26.29±1.49	31.26^{b} ±4.98
A3 (25:75)	48.51±1.15	40.73±0.42	32.94±0.66	40.72^{c} ±7.79
Averages B	37.55^{z} ±10.37	31.93^{y} ±8.47	26.31^{x} ±6.62	

Table 6. Duncan test biodegrability analysis biodegradable foam day 14 (%)

The ratio of TKKS fiber and tapioca starch	Usage of PVA			
	B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	62.19±2.01	58.05±2.01	54.78±2.98	58.34^{a} ±3.71
A2 (50:50)	78.42±0.62	72.90±1.87	67.27±2.49	72.86^{b} ±5.58
A3 (25:75)	85.77±2.21	78.19±1.71	74.59±0.76	79.51^{c} ±5.71
Averages B	75.46^{z} ±12.07	69.71^{y} ±10.44	65.54^{x} ±10.02	

Based on Table 6, the ratio of TKKS and tapioca starch A3 (25:75) has the highest percentage of mass reduction due to the use of more starch than fiber. Starch is hydrophilic which tends to bind with water. This property makes bio foam have a greater level of water absorption. According to Sinaga (2020), the percentage of biodegradability of biodegradable foam increases with the addition of glycerol and tapioca starch, because biodegradable foam will have high water absorption. The more water content in biodegradable foam, the faster the material decomposes. This is also supported by the statement of Hevira et al. (2021) that starch-based biodegradable foam can generally absorb moisture from the environment and easily interact with water and microorganisms so that it will decompose faster.

In the comparison of TKKS and tapioca starch A1 (75:25) has the smallest percentage of mass reduction, this is due to the use of more fiber compared to tapioca starch. Fiber has lignin content that protects cellulose fibers in the cell wall, cellulose itself is a carbohydrate polymer that is more easily decomposed than lignin. The presence of lignin forms a matrix that protects cellulose fibers from the access of degrading enzymes, making cellulose degradation more difficult. According to Berutu et al. (2022) who made biodegradable foam from banana stems, the more banana stem fiber, the smaller the water absorption and the longer the degradation of biodegradable foam, and the biodegradability decreases. This is because the fiber has a high cellulose content, the large amount of cellulose content in biodegradable foam causes the degradation process to be longer because cellulose has hydrophobic properties.

When viewed from the average B factor, the higher the concentration of PVA used, the value of biodegradability in each sample decreases. According to Rusdianto et al. (2022), the addition of PVA in the manufacture of biodegradable foam causes the biodegradation rate to decrease. This is because although PVA is biodegradable, it is still more difficult to decompose than other organic materials. After all, PVA can keep the mixed components in a material from active components such as microorganisms.

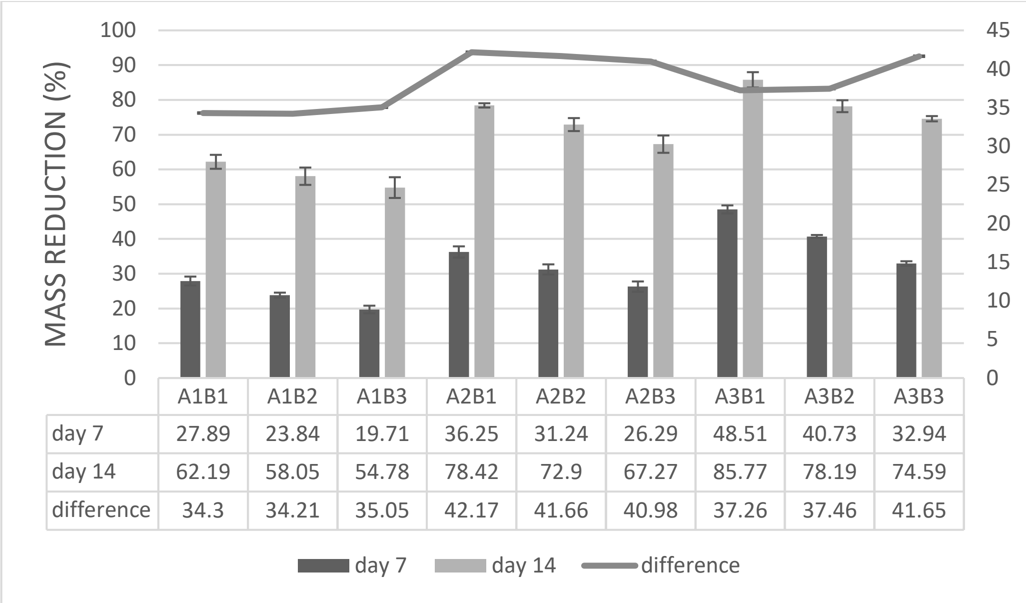


Figure 1. Graph of average percentage and difference of mass reduction of biodegradable foam

Thickness Analysis

Table 7. Duncan test biodegrability analysis biodegradable foam day 14 (%)

The ratio of TKKS fiber and tapioca starch	Usage of PVA			
	B1 (10 gram)	B2 (20 gram)	B3 (30 gram)	Averages A
A1 (75:25)	$0.42^{p}\pm0.01$	$0.42^{q}\pm0.01$	$0.41^{r}\pm0.01$	$0.41^{b}\pm0.01$
A2 (50:50)	$0.31^{p}\pm0.01$	$0.42^{q}\pm0.01$	$0.43^{r}\pm0.01$	$0.38^{a}\pm0.07$
A3 (25:75)	$0.44^{p}\pm0.01$	$0.51^{q}\pm0.04$	$0.45^{r}\pm0.01$	$0.46^{c}\pm0.04$
Averages B	$0.39^{x}\pm0.07$	$0.44^{z}\pm0.05$	$0.42^{y}\pm0.02$	

Based on Table 6, it can be seen that the greater the amount of starch used, the higher the thickness value of biodegradable foam. In the comparison of TKKS and tapioca starch A3 (25:75) has the highest average thickness value of 0.46 cm. This shows that the higher the use of tapioca starch, the greater the thickness value. Tapioca starch has a smooth texture and hydrophilic properties or like water, because the ratio of tapioca starch is more than TKKS fiber as a result tapioca starch will dissolve into water. If tapioca starch dissolves in water, the dough only forms a small composite in the biodegradable foam while air cavities or vacuum will form in the resulting biodegradable foam and cause the biodegradable foam to expand maximally and have a large porosity and thickness (Iriani, 2013). This is following the statement of Cinelli et al. (2006) that high expansion ability in biodegradable foam will result in high porosity.

In the comparison of TKKS powder and tapioca starch A2 (50:50) has a small average thickness value compared to the other two comparisons, namely 0.38 cm. This happens because the more fiber concentration used, the smaller the thickness value produced. According to Iriani (2013), the addition of fiber will cause the tearing of the cell walls of the air bubbles formed in the expansion process, as a result, the expansion process does not run perfectly, the disruption of this expansion process will have an impact on the porosity or thickness of biodegradable foam which is getting smaller.

In factor B (use of PVA) it can be seen that the use of PVA B2 (20 grams) has the greatest value of 0.44 cm. The addition of PVA affects the thickness due to the adhesive properties possessed by PVA. This is following the research of Rusdianto et al. (2022) who made biodegradable foam with bagasse and PVA, the addition of PVA affects the thickness due to the adhesive properties possessed by PVA. 20% PVA concentration is thicker than biodegradable foam with 40% PVA concentration. This is because the ability to glue components between one another is stronger than PVA 40% so empty cavities are filled and biodegradable foam becomes somewhat thinner than biodegradable foam with the addition of PVA 20%.

Physical and Mechanical Characteristics of Biodegradable Foam

The characteristics of biodegradable foam are done by looking at the results of the analysis that has been done for the analysis of density and water absorption already meet the standards of biodegradable foam synbra technology. The addition of TKKS fiber can improve the mechanical structure and strength of the biodegradable foam. The amount of TKKS fiber added makes the water absorption of biodegradable foam decrease due to the content of lignin and cellulose contained in TKKS which is hydrophobic or does not like water. The density of biodegradable foam in this study decreased along with the amount of tapioca starch added due to the lower molecular weight of tapioca starch compared to fiber. Because the molecular weight of starch is lower, it causes a decrease in the viscosity of the biodegradable foam dough which makes the biodegradable foam expand maximally and makes the density of biodegradable foam drop. Can be seen in Table 8 comparison of synbra technology standards and the results of research that has been done.

Table 8. Comparison of biodegradable foam standards and research results

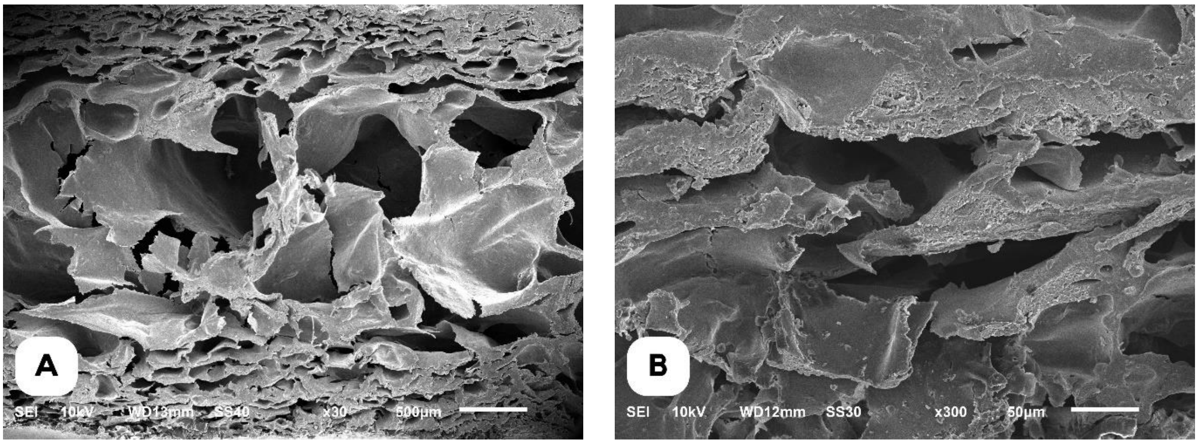
Sample	Density (g/cm^3)	Water absorption (%)	*Biodegradablility* (%)
A1	0.40	0.28	58.34
A2	0.32	0.31	72.86
A3	0.26	0.47	79.51
B1	0.27	0.28	75.46
B2	0.33	0.36	69.71
B3	0.38	0.43	65.54
Synbra technology standard biodegradable foam	0.66 (max)	2 (max)	6 weeks (max)

At the level of color brightness and total color difference, the characteristics of biodegradable foam produced with the addition of more and more TKKS fibers make the biodegradable foam produced have a darker color. This happens because the TKKS fiber used is blackish brown and there is still lignin content because the fiber used has not gone through the process of cellulose preparation and bleaching or removing color from the fiber. When compared to the color of the control (commercial styrofoam) the biodegradable foam produced has a dark color compared to commercial styrofoam which is white.

The characteristics of biodegradable foam produced in biodegradability and thickness analysis are that the more TKKS fiber is added, the more the biodegradability value and thickness of biodegradable foam produced decreases. The decrease in biodegradability value occurs because the TKKS fiber has lignin content that coats the cellulose fiber which makes it difficult to be decomposed by microorganisms. And in the thickness analysis, the more fiber added, the expansion process in biodegradable foam is not perfect which will have an impact on the porosity or thickness of biodegradable foam getting smaller.

Scanning Electron Microscope Analysis

Characterization of biodegradable foam using Scanning Electron Microscopy (SEM) was carried out to see the morphological structure and determine the interactions that occur between the filler material and the matrix at the broken part of the biodegradable foam. SEM characterization of biodegradable foam can be seen in Figure 2.



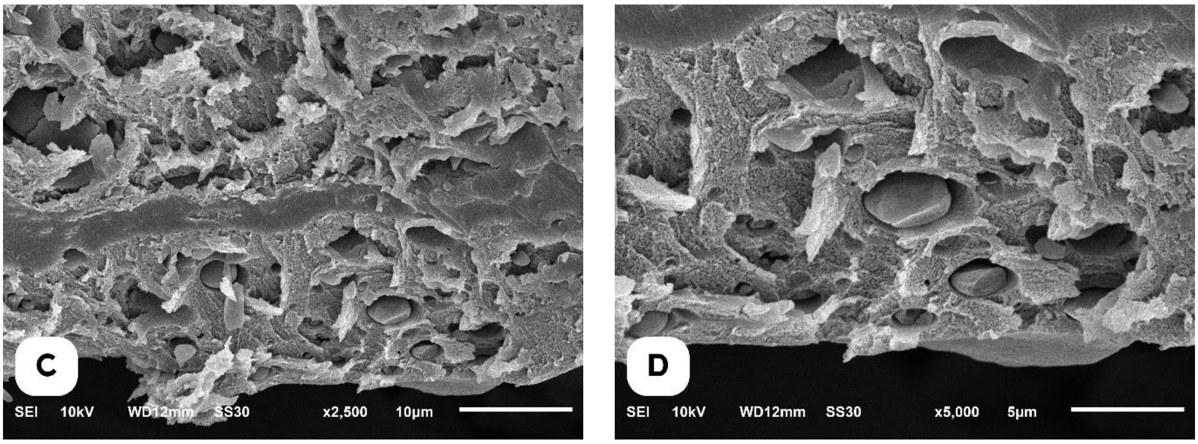


Figure 2. SEM microscopy of biodegradable foam sample A1B1. (A) magnification -500 μm, × 30 at 10kV, (B) magnification -50 μm, × 300 at 10kV, (C) magnification -10 μm, × 2,500 at 10Kv and (D) magnification -5 μm, × 5,000 at 10Kv

Based on Figure 2, it can be seen that the biodegradable foam structure produced has large voids. This is indicated because the A1B1 sample, which has the smallest water absorption with a high fiber ratio, does not blend perfectly with starch and PVA. According to Ritonga (2019), voids in biodegradable foam occur because the cohesiveness bond between cellulose and PVA interfaces does not interact to form a perfect composite. The addition of fiber generally causes the cavity formed to be larger with an irregular shape as shown in Figure 5 with x30 and x300 magnification. In the figure, it can be seen that the cross-section of the biodegradable foam surface shows a sandwich shape where the outside or surface consists of small and tight cells while the center consists of large cells. This is in line with the research of Cinelli et al. (2006) which also illustrates the existence of a sandwich shape in the transverse observation of biodegradable foam. In addition, there are also holes formed as a place for water vapor to escape during the expansion process. The more holes that are formed, the compressive strength of the bio-foam will decrease because there is nothing that can withstand the amount of pressure exerted on the surface of the biodegradable foam.

At x2,500 and x3,000 magnification, it can be seen that the increase of PVA addition tends to decrease the expansion ability of biodegradable foam. This can be seen from the cell size in the interior of the biodegradable foam which tends to decrease. The polymer melt appears to fill the voids formed due to the expansion process. This causes the compressive strength of biodegradable foam to increase. According to Iriani (2013) who made biodegradable foam with tapioca starch and ampok fiber, when PVA and starch are mixed, the hydroxyl groups present will form strong hydrogen bonds resulting in a compact stable structure and will affect the increase in compressive strength. it can be seen in the picture that the filled cavity is TKKS fiber, fibers that are still less fine will be able to fill empty cavities in the biodegradable foam.

Conclusion

The ratio of TKKS fiber to tapioca starch affects the density, water absorption, color brightness value (L*), total color difference, biodegradability test, and thickness test of biodegradable foam. The amount of PVA used affects the density, water absorption, color brightness value (L*), total color difference, biodegradability, and thickness of the biodegradable foam. There is an interaction between the ratio of TKKS and tapioca starch and the variation of the amount of PVA on water absorption and thickness. The results of this study indicate that the best biodegradable foam that is close to Synbra Technology standards is made with a combination of 75:25 TKKS fiber and tapioca starch ratio and 10% PVA.

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