Biodegradable foam tray based on sago starch with beeswax as coating agent

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Abstract. Biodegradable foam is an original packaging as a styrofoam alternative. Sago starch is used to produce biodegradable foam because of its huge amount, low-cost, and high biodegradability. Starch as a prospectus foam material is sensitive to water due to its hydrophilic properties. Thus, improvement is necessary to boost its water resistance capability. Coating the foam with a hydrophobic material prevents water contact with the starch. In this work, Beeswax was used as a coating agent due to its hydrophobicity. The purpose of this work to determine the concentration and time of beeswax coating on the mechanical properties of biodegradable foam. Beeswax was varied at 0, 2, 4, 6, 8, and 10% wt concentration with coating duration process for 30, 60, 90, 120, and 150 seconds. Biodegradable foam was produced by baking process at 80°C for 1 hour 20 minutes. The results showed that the beeswax coating process increases the water resistance, although it does not significantly affect the tensile strength. Beeswax addition as much as 4% wt, for 150 seconds had improved the biodegradable foam properties as much as 1.92%, 73% in 28 days, and 0.09 MPa for water absorption capability, biodegradability, and tensile strength, respectively.

1. Introduction

Styrofoam or polystyrene is a type of container with superior properties for packaging such as high and low-temperature resistance, water resistance, lightweight, and durable. The Republic of Indonesia Food and Drug Supervisory Agency (BPOM) stated that styrofoam contains hazardous styrene substance. Moreover, styrofoam has a difficult nature decomposed by microorganisms; thus, the Environmental Protection Agency (EPA) established styrofoam as the fifth largest generated waste in the world during the manufacturing process. It is necessary to replace styrofoam with environmentally friendly foam polymer, such as starch-based biodegradable foam. Starch has a high biodegradability property, inexpensive, and abundant availability, thus it is suitable as raw materials for biodegradable foam instead of Styrofoam [1].

In general, biodegradable foam from natural starch can bind the water, so it is sensitive to a humid environment while being stored and used [2]. Hendrawati et al, study explained the water absorption on biodegradable foam from natural and modified starch as much as ± 38.26% and ± 10%. Biodegradable foam with modified starch is less economical than the natural one because it still requires chemicals and special treatment in the form of alcoholic acid hydrolysis [3]. Coating natural starch with other materials is another way to reduce the water absorption issue on biodegradable foam.

Several researchers had conducted the study regarding the coating method on biodegradable foam. Bergel et al applied chitosan as a coating substance on Thermoplastic Starch Foam (TPS) derived from...
potato, cassava, and maize starch using the thermo-pressing method [4]. The water absorptions of coated and uncoated TPS were 140% and 280%. The tensile strength of coated TPS derived from maize starch was 1.61 MPa. Moreover, Bergel et al studied TPS production from potato starch with 25%, 4%, 6% w/v polylactic acid as the coating agent [5]. The addition of 6% w/v polylactic acid mostly decreased the water absorption capability as much as four times from 2.24 to 0.56 g of water/g of solid. The uncoated TPS had 1.332 MPa of tensile strength value. Reis et al implemented beeswax as a coating agent of biodegradable tray derived from cassava starch. The concentration was varied as much as 0; 1; 2; 3 g wax/g solution [6]. The lowest water vapor permeability was $0.2 \times 10^{-11}$ g/m.s.Pa with 3 g wax / g solution of beeswax. The value was increased without beeswax addition as much as $7.9 \times 10^{-11}$ with 8.875 MPa of tensile strength value. Based on the description above, research on making biodegradable foam from natural starches becomes interesting by using beeswax as a coating material to increase the water-resistant capability because of its high hydrophobicity.

2. Materials and methods

2.1. Materials

Materials used were include sago starch with brand Sapapua, soy protein isolate (local), carrageenan (local), beeswax and chitosan were bought from the local grocery store in a food-grade label. Magnesium stearate (Macron), glycerol (Merck), acetate acid (Merck), citrate acid (MultiChem), polyvinyl alcohol(Merck), sodium bicarbonate (Pudak Scientific, 99%), ethyl alcohol and tween 80 were purchased in technical grade.

2.2. Biodegradable foam production

Sago starch was initially dried at 80 ºC for 24 hours. The drying process removes the water content of the sago starch. Chitosan, 30% weight of starch, was dissolved in of 2% acetate solution until homogenous. Pure protein isolate 11.12% w/w starch, magnesium stearate 5.56% w/w starch, carrageenan 2.08% w/w starch, glycerol 16.67% w/w starch, chitosan solution, NaHCO₃:citric acid (1.3:1) of 12% w/w starch dissolved in 100 ml distilled water with rapid agitation speed (500 rpm) until homogeneous then the mixture is left for 15 minutes to maximize the process. Moreover, 36 g of dried sago starch was added to the mixture with slow agitation speed until homogenous and gelatinized at 72 ºC until the gel was formed. The mixture was poured into the mold until half the baking pan's volume and baked in an oven at 80 ºC for 80 minutes. The biodegradable foam was leftover in ambient temperature overnight. The foam was cut accordingly, coated, and analyzed.

2.3. Coating

The beeswax was weighted as much as 0, 2, 4, 6, 8, and 10 g. Beeswax was melted at 65 ºC and mixed in 100 g of hot ethyl alcohol and tween 80 as much as 25% of beeswax weight. The solution was stirred at 200 rpm for 2 minutes. The biodegradable foam was coated by immersion in the beeswax solution for 30, 60, 90, 120, and 150 seconds.

2.4. Water absorption analysis

The biodegradable foam was cut 2.5 x 5 cm and weighted accordingly. The sample was immersed in the water for 1 minute. The sample, then, was wiped from water and weighted. Water absorption analysis was analyzed based on ABNT NBR NM ISO 535, 1999 standard. The equation to calculate the water absorption capability is presented below:

$$\text{Water absorption} (\%) = \frac{W_f - W_0}{W_0} \times 100\% \tag{1}$$

$W_0 = \text{Initial sample weight, g}$

$W_f = \text{Final sample weight, g}$
2.5. Biodegradability analysis
The foam biodegradability was analyzed by calculating the weight difference of biodegradable foam buried in the soil for 28 days. The observation was conducted every seven days. The sample was firstly cleaned and weighted. The biodegradability was measured with this following equation:

$$\text{Weight loss} (\%) = \frac{W_0 - W_1}{W_0} \times 100\%$$ (2)

Where:
- $W_0$ = Initial sample weight, g
- $W_1$ = Final sample weight, g

2.6. Tensile strength analysis
The biodegradable foam was cut accordingly as standardized. The sample was analyzed using the Technical Association of the Pulp and Paper Industry (TAPPI) standard Number T404 to generate the samples' maximum stress. The tensile strength of the sample is calculated with the following equation:

$$\sigma = \frac{F_{\text{max}}}{A}$$ (3)

Where:
- $\sigma$ = Tensile strength, MPa
- $F_{\text{max}}$ = Maximum stress, N
- $A$ = Surface area, mm$^2$

3. Results and Discussions

3.1. Water absorption analysis
Water absorption analysis is used to determine biodegradable foam resistance to water by calculating sample mass changes before and after the biodegradable foam is immersed in water [7]. As a styrofoam substitute, the biodegradable foam should have a similar characteristic; thus, water absorption capability in the study referred to ASTM C578 "Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation." The water absorption analysis result is presented in Figure 1.

![Figure 1. Water absorption capability of biodegradable foam.](image)

Figure 1 shows that the higher the concentration and the longer the coating duration, the lower the water absorption capability. Water absorption value on biodegradable foam with beeswax coating was 0.63% – 3.02%, which is under ASTM C578; less than 4%. The uncoated biodegradable foam had a 7.14%
This research is in line with Reis et al, who used beeswax as a coating material and applied it to biodegradable trays. It stated that the more beeswax content in the coating the transmission of water vapor permeability of biodegradable trays are getting smaller [6]. It is also following Li et al, who used beeswax solution for wood impregnation and explained that the longer the immersion time, the value of water absorption decreases [8]. It is caused by more beeswax solution trapped in the pores, which increases its hydrophobicity. Beeswax's hydrophobic nature is due to the content of esters, alcohols, alkanes, and a long chain of fatty acids so that it could limit the solubility and diffusion of water through it [9]. Beeswax is classified as animal fat [10]. If animal fat is being cooled, the lost heat will slow the molecular movement. Thus, the distance between molecules becomes smaller and attractive forces between molecules called Van der Walls force to occur. The force caused the fatty acids in the fat molecules to be arranged in a row, overlapping, and bond together to form crystals [11]. This procedure is occurred by beeswax as a coating agent.

3.2. Biodegradability

Biodegradability test is used to determine the duration of biodegradable foam degraded in the environment. The standard biodegradability value in the study applies the European standards listed in EN 13432. The standard explains the degradation time of biodegradable polymers such as bioplastic will be degraded by 90% in 12 weeks or 30% in 28 days. The result of biodegradability analysis in this study is presented in Figure 2.

Figure 2 displays that the lower the concentration and the shorter the biodegradable foam coating time, the more easily degraded the foam were. In 28 days, the degradation of the foam was 95%, 76-91%, 73-81%, 69-84%, 65-81%, 60-77% for 0, 2%, 4%, 6%, 8%, and 10% addition of coating agent, respectively. It is following Lewkittayakom et al who implemented beeswax as a coating agent for biodegradable plates; the higher the beeswax concentration, the lower the degradable property was [12]. As explained further, the longer the coating time, the hydrophobicity value of biodegradable foam is higher. It means that the water absorbed is less than others. In contrast, microorganisms need enough water for metabolism to degrade biodegradable foam [13]. Svagan et al stated that the moisture content in the biodegradable foam could reduce the strength and soften the cell walls, making it easier for microorganisms to degrade the biodegradable foam [14]. Soil conditions will also affect this analysis, according to Widyati Soils with clay textures are suitable for the growth of worms and soil organisms, and vice versa, sand-textured soils with low water holding capacity are not suitable for the organisms'
growth[15]. Based on Stres et al study, the moisture content of soil regulates the oxygen diffusion in which maximum value occurred at 50%–70% [16]. High water content reduces the rate of decomposition of organic matter due to the low oxygen supply. It is caused by diffusion in water is smaller (10^4 times) than in air [17]. Otherwise, low moisture reduces microbial activity by reducing microbial mobility.

3.3. Tensile strength

The tensile strength test on biodegradable foam is used to determine biodegradable foam's maximum capability when under load. The tensile strength value of biodegradable foam refers to the ASTM C578 standard "Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation," 10-100 psi or 0.06-0.6 MPa. The tensile strength analysis of biodegradable foam with beeswax coating can be seen in Figure 3.

![Figure 3. The relationship of coating time and tensile strength of the biodegradable foam.](image)

Figure 3 shows the tensile strength of biodegradable foam with beeswax coatings were ranging from 0.04 MPa to 0.09 MPa. Meanwhile, the tensile strength of biodegradable foam without coating was 0.08 Mpa. The beeswax coating has no significant effect on the tensile strength value because it occurs on the surface, and beeswax is not an ingredient in the formulation [6]. Khwaldia indicated that the coating concentration using paraffin wax could not affect the tensile strength [18]. The tensile strength in Figure 3 shows fluctuate values because the unsteady of the stirring process on biodegradable foam affect the bubble production within the solution. Hou and Wang that the higher the agitation speed, the higher the bubble produced; thus, the porosity of biodegradable foam increases [19]. The increasing value of porosity and gas shows that biodegradable foam can expand excessively. It causes the polymer to be easily damaged or deformed, so the tensile strength of biodegradable foam is lower [20]. The polymer chain breakage is caused by the amount of gas production, which increases the polymer chain's pressure. Thus, the cell walls get thinner, and the lower the tensile strength of biodegradable foam is. Moreover, the study also used NaHCO3 in biodegradable foam production as a chemical blowing agent. Sodium bicarbonate generates carbon dioxide if it reacts with water or reacts with citric acid. The addition of a chemical blowing agent can increase the amount of porosity and pressure formed in the polymer to affect the tensile strength of the biodegradable foam.
4. Conclusions
The higher the concentration and the longer the coating duration, the lower the value of water absorption and biodegradability was. The concentration and time of coating had no significant effect on the tensile strength value. The best biodegradable foam was a coating concentration of 4% beeswax with a coating time of 150 seconds which has a water absorption value of 1.92%, with a value of biodegradability were 73-87% in 28 days., and tensile strength were 0.09 MPa.

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