Production of biodegradable package material from tofu industry byproduct

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Abstract. Plastic has been widely used as single-use package and carrier material due to its low price, strength, practicality, and versatility. On the other hand, plastic requires a long period to naturally decompose. Nowadays, a huge number of plastic wastes have caused detrimental impacts to the global environment, hence a more environmentally benign substance of making plastic is a significant importance. This study proposed the production of biodegradable material from nata de soya, which is composed from whey waste using melt intercalation method. This environmentally-friendly substance was mainly obtained from tofu industry byproduct which is known as ‘whey’, through fermentation process using Acetobacter xylinum bacteria. Melt intercalation method was used to obtain desired texture and characteristic, the step was the fermented product mixed with chitosan, acetic acid, glycerol, and tapioca starch, with various range of concentration. The mixed component then underwent milling and drying process for finalization. As for characteristic of the materials, tested parameters include solubility, water resistance, and biodegradability in the environment. Our results showed the potential of this material to substitute the use of plastic and is applicable for versatile purposes. Water resistance was up to 95 minutes, and the material was able to be completely degraded in around 60 days.

1. Introduction
Since 1950, the amount of plastic waste has been increasing rapidly and littering the landfill and environment. More than 400 million tons plastic waste are dumped over the world each year, and Indonesia is the largest generator of plastic waste that totally contribute about 10% of global plastic waste [1]. Plastic packaging waste contributes nearly 50 % of global plastic consumption and only 9% of the plastic which can be recycled [2]. To overcome plastic waste, bioplastic is a promising alternative solution due to its benefits which are made from organic material and takes a shorter time to be degraded in the nature. Starch or cellulose is commonly used as the raw material of bioplastic because it is abundant in quantity and relatively low in price. There are a lot of starch/cellulose sources which has been extensively used to produce bioplastic. Cassava starch [3,4]; seaweed [5]; sweet potato [6] and sugarcane [7] are the major resources that has been studied as the bioplastic raw materials. Those materials were processed by mixing with other addition materials then turned into bioplastic. However, the relatively high cost of the raw material led the bioplastic to become unpopular at present. Thus, this study aims to answer that problem by using tofu industry byproduct or “whey”, which is abundantly available and cheap, as the raw material to produce bioplastic.
Tofu is one kind of food that is processed from soybeans and is highly demanded by Indonesian people. The consumption of tofu level in Indonesia reaches approximately 7.02 kg/person/year [8]. As to produce 80 kg tofu, about 2,610 L of whey are also produced and mostly wasted to waterbody and causing pollution due to its high content of organic compounds which may cause serious environmental problem [9]. The main constituents of whey are protein, carbohydrate, and fat [10]. In this study, those organic compounds are converted to nata de soya by using *Acetobacter xylinum* through fermentation process. With addition of chitosan and glycerol to improve the characteristic [11], this study investigates the potential of nata de soya to become the raw material of bioplastic.

2. Materials and Method

2.1. Materials

The materials used in the experiment were 60 g sugar, 20 g ammonium sulphate, *Acetobacter xylinum* culture, alcohol, aquades, 2 % (v/v) glycerol, 2% (w/w) chitosan, 2% (v/v) acetic acid, 2.5% (w/w) tapioca flour, and EM4.

2.2. Nata de soya making process

To produce nata de soya, whey from tofu production was filtered and then boiled. During the boiling process of whey, 60 g of sugar and 20 g of ammonium sulphate (ZA) which are sources of nutrition for fermentation bacteria, were added and stirred. The condition of pH was controlled to be around 3 by the addition of acetic acid to create an optimal condition during fermentation process with *Acetobacter xylinum*. Then, the mixture was cooled down at 20 – 30 °C and then poured into rectangular plastic container which had been sterilized. Container was isolated from air and stored in room temperature to prevent contamination for 10 days. The nata de soya then was washed by alcohol and aquadest for bioplastic making process [12].

2.3. Bioplastic making process

Bioplastic film is produced using melt intercalation method which involves the dispersion of nanoplates types of nanomaterials into the polymer matrix [13]. In the first step of bioplastic making process, nata de soya had to be blended to enable the nata to be easily mixed with other additives. Thus, nata de soya was treated in two ways. Two types of treatment were applied to observe which phase of nata de soya that is optimum for bioplastic production. In Treatment I, only put the liquid phase of the blended nata de soya that is used for bioplastic production. In Treatment II, the solid-to-slurry phase of nata de soya was also included.

The bioplastic was prepared by dissolving 2 % (v/v) glycerol, 2% (w/w) chitosan, 2% (v/v) acetic acid, 2.5% (w/w) tapioca flour, and 300 mL distilled water in a 500 mL glass beaker. Then, this mixture was heated on magnetic stirrer until the mixture was perfectly homogenized, which occurred at approximately 70 °C. Gelatinization process was conducted for 30 minutes. After the mixture was perfectly combined through gelatinization process, bioplastic was poured onto rectangular plastic container. The molding step was performed to obtain the material with the desired thickness, weight, and shape of bioplastic film. Lastly, bioplastic was dried up by using heat treatment. The heat treatment was conducted to remove the moist from the mixture. Heat treatment was completed by using both direct sunlight and oven drying.

2.4. Solubility

Solubility test in this experiment is following the method in by Gracia et al. [14]. Solubility test aims to study how soluble the material is, under varied water temperature. This test was performed by dissolving 1 g of bioplastic from each treatment into 800 mL water at 70-80 °C (hot) and 5 °C (cold) in beaker glass, within 0-100 minutes. After that, the mass of bioplastic was weighed.
2.5. Water resistance
To observe water resistance characteristic, adjusting from the methods conducted by Munthoub and Rahman [15] and Hemsri et al. [16], the bioplastic film was made into 6×6 cm size. Then, each of the bioplastics was put on the top of a beaker glass and was poured with 1-10 mL water at room temperature. Filter paper was prepared inside the beaker glass to absorb the water leakage, if any, from the bioplastic film.

2.6. Biodegradibility
Biodegradable characteristic of bioplastic was determined using soil burial degradation test [17] for Treatment I result, for reason that is explained hereafter. This test was performed by using two type of treatments, which were (1) natural decomposition on soil and (2) addition of 10 mL of Effective Microorganism (EM4) containing bacteria from the genus Lactobacillus, yeast, photosynthetic bacteria actinomycetes, bacteria and yeast phosphate, and solvent for the fermentation of organic matter to the soil. Two sheets of bioplastic film weighted 2.5 g from Treatment I was used. Using adjusted method provided by Isroi et al. [18], biodegradation rate was measured by using equation (1):

\[
% \text{ biodegradation} = \frac{W_i - W_f}{W_i} \times 100\%
\]  

Where:
Wi = Initial Sample Weight (g)
Wf = Final Sample Weight (g)

3. Results and Discussion
The produced bioplastics have different physical characteristics compared to the conventional plastic, as shown in Figure 1. Results from Treatment I show bright colored and flexible film, the texture is a slightly rough and thick, with no odor. Result from Treatment II shows yellowish brown and thinner film, the texture is smoother but stiff, also with no odor.

![Figure 1. Images of bioplastic resulted from Treatment I (left) and Treatment II (right).](image)

3.1. Solubility
Table 1 presents the result of solubility test for both bioplastic produced using Treatment I and Treatment II. Data presented in Table 1 was 1 g of bioplastic samples. Both treatments produced soluble material under relatively short time, particularly under hot water condition. Bioplastic sample produced from Treatment II shows higher rate in solubility test, possibly due to more heterogeneous nature of raw material, hence forming weaker bioplastic film structure.
Table 1. Results of solubility test

| Sample | Sample Weight | Temperature | Time (Minutes) | Degree of Solubility |
|--------|---------------|-------------|----------------|----------------------|
| I      | 1 g           | 5 °C        | 13             | Slightly Soluble     |
| I      | 1 g           | 70-80 °C    | 11             | Highly Soluble       |
| II     | 1 g           | 70-80 °C    | 0.5            | Highly Soluble       |

Bioplastic duration in hot water was shorter than cold water except for sample II2 caused by molecular of hot water will move faster and consequently heated water molecules will form a larger space, also providing energy to solubilized bioplastic film. Some residue remained after the test which shows that the bioplastic could not be completely be solubilized in water. This is possibly due to the addition of chitosan which is insoluble in water but dissolved in acid [19].

3.2. Water resistance

Table 2 shows the result of water resistance test. For Treatment I, no leakage was detected within 1 hour of bioplastic film and water interaction. On the other hand, for Treatment II water leakage was detected within 10 minutes, most likely due to its thin nature.

Table 2. Result of water resistance test

| Sample | Time (Minutes) | Degree of Water Resistance |
|--------|----------------|---------------------------|
| I      | 60             | Water Resistant           |
| II     | 10             | Leaked                    |

Additional materials such as glycerol and chitosan improve the hydrophobic characteristic of bioplastic film. Tapioca starch is very potential to be used as biodegradable plastic material, but it has hydrophilic characteristic [20]. Glycerol, on the other hand, is effective plasticizers due to its ability to reduce internal hydrogen bonds in the intermolecular structure and hence improve the elasticity [21]. In addition, chitosan also improves water resistant characteristic of the produced bioplastic [22].

3.3. Biodegradibility

Comparing results of the above tests, bioplastic produced from Treatment I shows more desirable characteristic. Hence, this test is conducted for result from Treatment I. The type of soil that is used for this test contained low moisture and was directly exposed to the sunlight. Thus, the soil was dry and had poor aggregate. After 15 days, weight of the remaining bioplastic was weighted as shown in Figure 2. The measurement results showed that the sample without EM4 bacteria was 1.678 g and another sample with EM4 was 1.281 g (initial weight was 2.5 g as mentioned in Subsection 2.6). Using equation 1, biodegradation rate can be calculated as 32.88% for biodegradation using only soil, and 48.68% with addition of EM4. From the conducted experiments, it can be estimated that it will took approximately 45 – 60 days to complete decomposition of bioplastic.
4. Conclusions

Bioplastic production using nata de soya as raw material shows promising potential to substitute the utilization of conventional plastic material. This environmentally-friendly substance was mainly obtained from tofu industry byproduct which is known as ‘whey’, through fermentation process using Acetobacter xylinum bacteria. Addition of glycerol, chitosan, tapioca improves physical characteristic of the produced bioplastic film. Tests of physical appearance, solubility and water resistance shows that utilization of liquid phase nata de soya revealed more desirable characteristic to be used as raw material of bioplastic. Finally, the produced bioplastic shows possibility of complete degradation under natural condition within an acceptable period of 45-60 days.

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