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Sorbitol-Based Biodegradable Plastics from Rubberized Cassava Starch and Tofu Dregs Starch

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ABSTRACT

In daily life, the use of plastic is widespread, causing serious problems with plastic waste. Moreover, as the population continues to grow, the amount of waste will also increase. Therefore, immediate action is to switch from plastic made from petroleum, which is difficult to decompose, to plastic made from biodegradable materials. In this study, biodegradable plastic was made from rubberized cassava starch and tofu dregs with the addition of sorbitol as a plasticizer. This research aimed to determine the effect of the plasticizer composition of sorbitol, rubber cassava starch, and tofu dregs starch for making biodegradable plastics and to determine the characteristics of the plasticproducts.The production of biodegradable plastic using rubber cassava starch and tofu dregs starch added with sorbitol as a plasticizer was divided intothree stages, namely producing flour from rubberizedcassava starch and tofu dregs starch, making biodegradable plastic and analyzing biodegradable plastic samples. The best results from various sample analyses were a tensile strength value of 4291.9 kPa, an elongation percentage of 35%, a water absorption capacity of 41.94%, and a biodegradation test of ± 2 weeks had decomposed around 80% in the soil.

Keywords: tofu dregs, cassava starch, biodegradable plastic, plasticizer.

INTRODUCTION

Plastics play an essential role today in both industry and household appliances. Plastics are widely used for various purposes, such as carry bags, cold drink bottles, toys, food packaging, electronic equipment components and containers, vehicle modules, office block segments, furniture, clothing materials, and so on (Marichelvam et al., 2019). Annually, 368 million tons of plastic are produced globally, and biodegradable plastic accounts for nearly 1% of total plastic production (Abraham et al., 2021). Although plastic materials with various materials and manufacturing costs have high quality, it is of great concernthat these plastic materials cannot be adequately managed in society (Weinstein et al., 2020). Large amounts of plastic are released into terrestrial and marine ecosystems as industrial waste products (Shimao, 2001). Indeed, due to a lack of recycling and poor end-of-life management, discarded plastics have become a significant problem, posing clear risks to the marine environment and the safety of animals and humans (Karan et al., 2019). It is estimated that by 2023, the amount of plastic entering the world's aquatic ecosystems could reach 90 Mt/year in a scenario where the current plastic production trend continues without any improvements to the waste management system (Borrelle et al., 2020). Bio-based and biodegradable plastics can be seen as one of the alternative materials to achieve sustainable growth of the plastics industry and offer a solid alternative to petrochemical plastics in the near future (Steven, 2020). Biodegradable plastic can decompose into carbon dioxide (CO_2) and water (H_2O) in 20–45 days if there is sufficient moisture, oxygen, and the appropriate number of microorganisms. can be found in landfills or natural manure compared to conventional plastic, which has a life expectancy around hundreds to thousands of years (Ghimire et al., 2020). In addition, the application of biodegradable plastic can also reduce greenhouse gas emissions in its use because, after disposal, biodegradable plastics are naturally reduced to non-toxic elements at the composting site (Moshood et al., 2022). One of the innovations in producing biodegradable plastic is utilizing starch from rubber cassava, a potential source of starch to be used as a raw material for making biodegradable plastic. Apart from that, one of the reasons for using it as a raw material is because cassava contains a toxic compound, namely HCN, which cannot be traded and is underutilized by the community. Therefore it is very appropriate for cassava to be used as a raw material for plastic production (Winarno, 2021). Tofu dregs contain large amounts of protein, among other food waste. Dried tofu dreg-shaveaprotein content of 23.39% wt (East Java Provincial Livestock Service, 2019). Soy protein is a good choice as a material for biodegradable plastic because it contains 20 amino acids in each chain (Selpiana, 2016). In biodegradable plastic production, sorbitol acts as a plasticizer (Pranamuda, 2020).

MATERIALS AND METHODS

The research materials used were rubber cassava, tofu dregs, sorbitol, 98% acetic acid, and distilled water. The research tools used were sieves, basins, watch glasses, spatulas, stirring rods, analytical balances, beaker glasses, Erlenmeyer flasks, magnetic stirrers, rubber balls, measuring cups, measuring pipettes, chemical funnels, thermometers, hotplates, glass plates, sample containers, and tensile testing equipment.

Research procedures

Prepare 5 kg of rubber cassava, and wash using clean water. Peel the skin and cut it into small sizes so that it can be blended. Blended rubber cassava is filtered, followed by precipitating the rubber cassava starch that has been obtained for 30 minutes until the precipitate is separated from the water then dry the smooth and still moist starch in the oven at 70 °C for 30 minutes. Sievethe starch until smooth, this step is done repeatedly until there is no coarse starch left, because it cannot be sieved. Prepare 5 kg of dried tofu dregs. Then squeeze the tofu dregs little by little or ½ kg at a time using a clean cloth to produce starch. Next, leave the tofu dregs in the container for 24 hours till the starch settles. After that, take the starch precipitate by removing the liquid, filter the starch precipitate using finer cloth and then dry it in the oven. Coarsely grind the dried tofu dregs starch then put it in a blender and sift it to produce flour. Add 5 grams of rubber cassava starch with 5 grams of tofu dregs. Stir the mixture with a magnetic stirrer at 100 rpm on a hotplate until homogeneous for ± 10 minutes, filter the mixture using filter paper. Next, add various concentrations of sorbitol (3 mL, 5 mL, 7 mL, 9 mL, 11 mL), followed by adding 3 mL acetic acid. Heat the mixed ingredients to varying temperatures of 70 °C, 80 °C and 90 °C using a hotplate and stir using a magnetic stirrer at 100 rpm for 30 minutes until the gelatinization process occurs. After producing a thick solution like glue, turn off the heater and stirrer, then mold using a glass plate measuring 10×15 cm. Dry the plastic that has been molded in a drying equipment.Tensile strength indicates a measure of biodegradable plastic durability, namely the acceptable maximum stretch of the sample. Percent elongation is the maximum length change experienced by plastic during the tensile strength test, which is when the sample is torn (Sinaga et al., 2014). A water absorption test is needed to determine whether the properties of the biodegradable plastic being made are close to the properties of synthetic plastic or not. A biodegradation test is performed to determine the time needs for biodegradable plastic sample to degrade.

RESULTS AND DISCUSSION

Tensile strength analysis

The tensile strength test of biodegradable plastics was conducted to determine the ability of biodegradable plastics to withstand the load that occurs when the plastic is stretched. The addition of sorbitol will affect the strength value of biodegradable plastics made from cassava starch and tofu waste, as observed in Figure 1.

Figure 1 illustrates that the tensile strength of biodegradable plastic decreases with the addition of sorbitol, particularly when the sorbitol concentration added is 3–5 ml and temperatures of 70–90 °C. The optimum condition for the tensile strength of biodegradable plastic was achieved

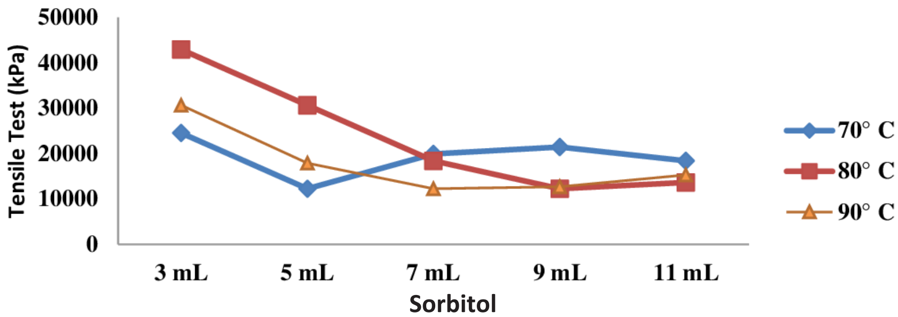

Figure 1. Tensile test

with the addition of 3 ml sorbitol, resulting in a tensile strength value of 4291.9 kPa at 80 °C. This increase occurs due to attractive forces between starch molecules containing hydroxyl (OH) groups and sorbitol molecules containing carboxyl (COOH) groups, resulting in increased molecular weight and a denser structure of the biodegradable plastic produced (Krisnadi et al., 2019). Research conducted on avocado seed starch showedincreased tensile strength by adding sorbitol concentration of 40% (w/w starch), resulting in a tensile strength of 7.79 MPa (Lydia et al., 2020). Conversely, the highest decrease in tensile strength occurred with the addition of 5 ml sorbitol at 70 °C, resulting in a tensile strength of 1226.3 kPa. The decrease is attributed to the shortened carbon chains of the bioplastic formed with sorbitol, which can enhance the flexibility of the bioplastic and reduce intermolecular strength between polymer chain bioplastic molecules (Lydia et al., 2020). Research conducted on Cilembu sweet potato starch with the addition of 2 ml sorbitol plasticizer showed a decrease of 91.1%, while the addition of 0.5 ml sorbitol resulted in a tensile strength decrease of 1.9% (Lailatin Nuriyah et al., 2018). When compared to the mechanical properties of plastics according to SNI, the tensile strength of plastics ranges from 2420 to 302000 kPa. In this study, only a few samples met the SNI requirements. This is influenced by several factors, including the fact that the produced products are not fully plastic but only have plastic properties, the composition of the amount of starch used with inappropriate sorbitol additions, manual sample preparation without using molding tools resulting in varying sample thicknesses, which will affect the obtained tensile strength values, and the influence of the drying temperature set during drying in the drying apparatus.

Elongation analysis

The elongation test was conducted to determine the increase in length of the biodegradable plastic before and after being stretched. The addition of sorbitol concentration affects the biodegradability value of cassava rubber starch and tofu dregs starch as indicated in Figure 2.

Figure 2 illustrates that the results of the elongation test decrease with the addition of sorbitol, when sorbitol is added in amounts ranging from 3 to 11 mL and temperatures of 70–90 °C, resulting in elongation test results of 35–4%. The highest test result is obtained from the addition of 3 mL sorbitol and a temperature of 90 °C, yielding an elongation test result of 35%. This is also evident in the physical texture of the sample, which

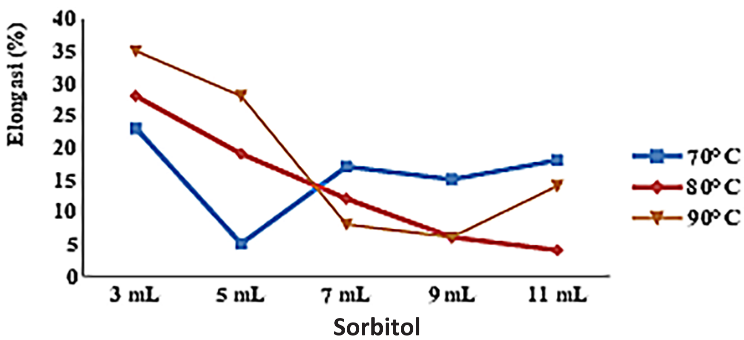

Figure 2. Elongation test

appears elastic. Meanwhile, the lowest test result is observed with the addition of 11 mL sorbitol, resulting in an elongation test of 4%. The reduction in the elongation test results of biodegradable plastic occurs due to excessive sorbitol addition, resulting in reduced distance and strength between biodegradable plastic molecules, making the plastic more prone to tearing. The decrease in the elongation of biodegradable plastic is caused by imperfect material mixing, leading to particle dispersion accumulation at a certain point (Putra et al., 2019). A study on bioplastics with a starch concentration of 2 g yielded an elongation value of 15.40±0.96%, while a starch concentration of 3 g resulted in an elongation value of 8.39±1.17% (Kirana Fatika Brilianti et al., 2023). Thicker bioplastics will increase tensile strength but decrease elongation (Rusli et al., 2017). The elongation values are lower compared to the carrageenan-cassava starch bioplastics in the study by Wahyuningtyas et al. (2019), ranging from 28.55–32.22%.

Water absorption capacity analysis

The water absorption test was conducted to analyze the presence and regularity of bonds in plastic made from cassava rubber starch and tofu waste starch with the addition of sorbitol. The water absorption test of biodegradable plastic is shown in Figure 3.

Figure 3 illustrates a decrease with the addition of sorbitol, where samples with a sorbitol composition of 3 mL at a temperature of 90 °C became biodegradable plastic with the highest water resistance, with water absorption reaching 41.94%. Meanwhile, biodegradable plastic with the lowest water resistance is the sample with a sorbitol composition of 11 mL, reaching 11.92% at 70 °C. This decrease is presumed to be due to the molecular size of sorbitol, where sorbitol has a larger size, which enlarges the free volume between chains, facilitating water molecule transfer (Donhowe et al., 1993). On the other hand, smaller molecular sizes assist in more penetration into the network, reducing the space and opportunity for water adsorption (McHugh et al., 1994). Sugar alcohols like sorbitol, glycerol, and propylene glycol can induce moisture balance due to their hygroscopic properties (Grenby et al., 1994). The water absorption value is lower in the use of sorbitol plasticizer for kolangkaling (*Arenga pinnata*) edible films, ranging from 25–28% with the use of 3 mL of sorbitol (SagitaSitompul et al., 2017).

Biodegradation analysis

The addition of 3 ml of sorbitol at 80 °C influences the extent of weight loss of biodegradable plastic tested for degradation over a period of ±2 weeks, with a biodegradation rate of 80% concerning the percentage of biodegradable plastic. When buried in soil, decomposing microorganisms penetrate all sides or walls of the plastic film, as indicated in Figure 4 of the biodegradable plastic and Biodegradation Test results.

Polymers that can biodegrade possess uniqueness due to the presence of ester bonds in their structure, which are susceptible to hydrolytic or oxidative cleavage. Ultimately, the biodegradation ability of a material depends on crystallinity, molecular weight, co-polymer composition, polymer size, and environmental conditions (temperature, pH, moisture content) (Anjaly et al., 2023). Structural differences in polymers also result in variations in complex compounds undergoing comprehensive transformation into simpler

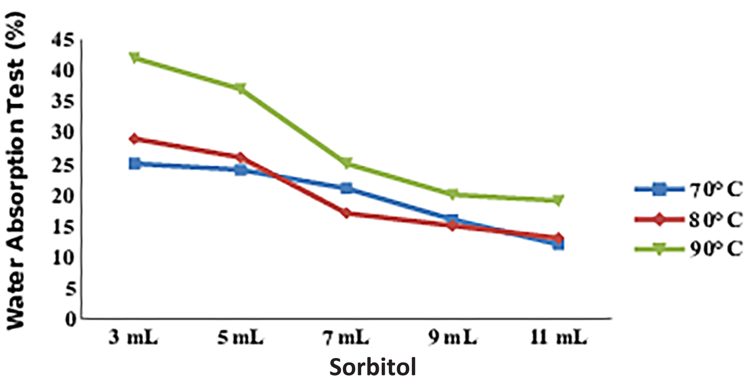

Figure 3. Water absorption test

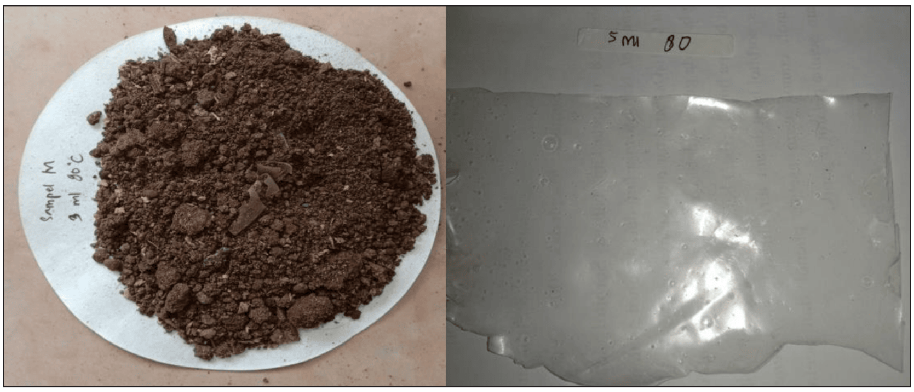

Figure 4. Biodegradation test and bioplastic results

substances, such as water (H_2O) and carbon dioxide (CO_2), which are subsequently released. According to the American Society for Testing and Materials (ASTM), biodegradable plastics degrade due to the action of natural microorganisms, producing fragments with lower molecular weights within a reasonable timeframe. However, plastics that can be used as compost can biologically decompose (Eden Shlush et al., 2023).

CONCLUSIONS

The composition to produce biodegradable plastic is 3 mL sorbitol at a temperature of 80 °C seen from the results of the analysis tests carried out, with a tensile strength of 4291.9 kPa, elongation of 35%, water absorption capacity of 35% and degraded by 80% in ± 2 weeks in the soil. Based on SNI 7818:2014 by the National Standardization Agency regarding biodegradable plastic bags, the minimum quality requirements for tensile strength are 13.7 MPa or equivalent to 13700 kPa, minimum elongation of 400% and complete degradation in 60 days. The most optimal value in the tensile strength test was 4291.9 kPa, the highest percent elongation was 35% and the highest water absorption value was 41.94%. The tensile strength and elongation values do not meet the minimum requirements of SNI 7818:2016, while the plastic degradation met requirement for being completely degraded in the soil within ± 2 weeks.

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