Development of environmental-friendly biofoam cup made from sugarcane bagasse and coconut fiber

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Abstract. Styrofoam is in high demand by street vendors and is often used as food packaging. This can cause an emergence of environmental problems because it cannot decompose. On the other hand, there is much waste from agricultural products such as sugarcane bagasse and coconut fiber which frequently accumulate on the side of Banda Aceh’s road without further processing. In this research, the sugarcane bagasse and coconut fiber have been used in the production of biodegradable foam (biofoam) with addition of commercial mold (ragi tempe; Rhizopus sp.). The aim of this experiment was to design and create a biofoam cup to substitute plastic or styrofoam cups. The objectives of this research were to develop the formulation for biofoam production specifically in finding the best percentage of ragi tempe. Prior to the biofoam manufacturing process, a survey was conducted to assess the extent of styrofoam and plastic food packaging in Banda Aceh, Indonesia. Three experiments were then conducted to find the best biofoam formulation so that the mold could grow to cover the raw material. The survey showed that styrofoam is the most widely used type of food packaging (68.6%) followed by plastic (37.2%). The biofoam cup was made with 200 g sugarcane bagasse or coconut fiber, 35 ml water, 25 g flour, and 13 g ragi tempe. However, further research is needed to examine the strength of the resulting biofoam cup.

1. Introduction

Recently, the use of styrofoam as fast food containers has been increasing as a result of growing online food orders during the Covid19 pandemic. Small-scale traders or street vendors often rely on styrofoam because it is waterproof, lightweight, cheap, and easily manufactured and accessed. It can also resist heat for long periods of time. However, this reliance on styrofoam also causes environmental problems because the styrofoam ends up in landfills or polluting the oceans as litter. A study by the Indonesian Institute of Sciences (LIPI) showed that 250 thousand to 600 thousand tons of waste was found in Indonesia’s oceans in 2018, with styrofoam as the most common waste product [14]. Styrofoam is not an environmentally friendly packaging because it belongs to a type of plastic that cannot decompose making it one of the biggest factors in environmental pollution. Additionally, burning styrofoam waste which is often in Indonesia can produce carcinogenic dioxin [1][2].

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On the other hand, waste from agricultural products such as sugarcane bagasse and coconut fiber often accumulates on Banda Aceh roadides without further processing. Sugarcane bagasse is a by-product of the process of sugarcane crop crossing, while the coconut fiber is part of a thick and fibrous coconut shell. Sugarcane bagasse and coconut fiber are widely available in Banda Aceh, Indonesia because there are many sugarcane and coconut drink sellers on nearly every roadside in the city. Some vendors hoard sugarcane bagasse and coconut fiber which can cause various problems such as environmental pollution and aesthetic issues.

Therefore, it is necessary to produce a biodegradable foam or biofoam from agricultural waste like sugarcane bagasse and coconut fiber. This food packaging is not only environmentally friendly but also safe for peoples’ health. Previous studies have made biodegradable foam from mushroom mycelium with rice husks and wheat seeds [3], coconut fibers [4] and sawdust [5]. In this research, sugarcane bagasse and coconut fiber has been used in the production of biofoam along with commercial mold (ragi tempe). The selection of these two raw ingredients was based on their availability throughout the year in Banda Aceh. Both ingredients are also easily destroyed because they contain a lignocellulosic component. The cellulose content in sugarcane bagasse and coconut fiber can be used as bioplastic material. Cellulose is a biopolymer that can be obtained from agricultural fiber. According to [6], agricultural polymers have thermoplastic properties, so they have the potential to be shaped or printed into packaging. Ragi tempe is usually used in the processing of fermenting soybeans and contains Rhizopus sp. During processing, Rhizopus sp. will form a mycelium consisting of long threads called hyphae. The hyphae will bind the coconut and sugarcane fibers into a solid and compact three-dimensional shape.

In this experiment, the mycelium produced by the tempe mold were expected to bind the coconut and sugarcane fibers. The aim of this experiment was to design and create a biofoam cup to replace plastic or styrofoam cups. The objectives of this research were to develop the formulation of biofoam production specifically to find the best percentage of ragi tempe (Rhizopus sp.).

2. Materials and Methods

2.1 Materials

The main materials in this experiment were sugarcane bagasse and coconut fiber. These ingredients were collected from street vendors around Banda Aceh, Indonesia (Figure 1 and 2). Ragi tempe was obtained from Lambargo market, Aceh Besar, Indonesia. Ragi tempe which contains Rhizopus sp. was used to bind the coconut and sugarcane fibers.

![Figure 1. Coconut street vendors around Lampaseh (a), Keutapang (b) and Lamlagang (c).](image-url)
2.2. Experimental Design
The first step was carried out by using a survey to determine the amount of styrofoam currently used as food packaging in Banda Aceh, Indonesia and to determine how open the public is to replacing styrofoam with biofoam. The second step was an explorative project in the production of biofoam food packaging and was divided into three experiments. The first experiment was carried out to grow *Rhizopus* sp. on sugarcane bagasse and coconut fiber. The formulation contained 500 g sugarcane bagasse or coconut fiber, 200 ml water, 32 g flour, and 26 g *ragi tempe*. The second experiment was to optimise the growth of *Rhizopus* sp. by reducing the water to 35 ml, flour to 25 g, and *ragi tempe* to 13 g. The third experiment was to shape the produced biofoam into a cup. The materials were shaped by putting the materials mixture in the inside of two polypropylene plastic cups.

2.3. Preparation of Raw Materials
The coconut fiber was cleaned by soaking it in water to remove dirt and dust. The fiber was then dried [7]. The sugarcane bagasse was washed to remove the sugars from the fiber. The fiber was then combed with a wire brush to remove the cork that was stuck to the fiber. Then, it was sun dried for 7 days. The dried sugarcane bagasse and coconut fiber were then cut into small pieces [8].

2.4. Production of Biofoam
The cleaned and dried sugarcane bagasse and coconut fibers were autoclaved at 121°C for 15 minutes. They were kept at room temperature for about 24 hours. Each of the fibers was mixed with *ragi tempe* and flour. The mixture was moulded in between two stacked plastic cups and wrapped. The cups were perforated for air circulation and incubated for one week at room temperature. The incubated mixture was heated in a drying oven at 50°C for 46 hours to stop the mycelium growth [3].

3. Results and Discussions
3.1 Survey on the Use of Styrofoam
3.1.1 Description of Respondent Characteristics. Two hundred respondents were involved in this survey. Most respondents were undergraduate students (78%), followed by senior high school students (15%), diploma students (5.5%), post graduate students (1%) and junior high school students (0.5%). There were more female respondents (84%) than male respondents (16%). Most respondents were between 17-25 years old (92%), followed by age 26-35 years old (4.5%), 46-55 years old (2%), 36-45 years old (1%), and 12-16 years old (0.5%).

3.1.2 The Use of Styrofoam as Food Packaging. The survey showed that in Banda Aceh, 7.5% of respondents reported order food online very often (every day) and 24.5% of respondents often (three times per week) order food online (Figure 3). The survey also found that styrofoam was the most widely used type of food packaging (68.5%), followed by plastic (37.2%), wrapping paper (32.5%), brown paper (17.8%), cardboard (12.6%), mica plastic (12%), and aluminium foil (4.2%) (Figure 4). Styrofoam is frequently used as fast-food packaging because it can withstand heat from food, is waterproof, lightweight, easy to shape, and cheap [1] [2].
3.1.3 Public Knowledge of Styrofoam. Besides its advantages, styrofoam also has negative effects that are harmful to health. Styrofoam is carcinogenic because styrene is one of the raw materials used to manufacture styrofoam. When exposed to high temperatures for long periods, styrene in styrofoam can be transferred to food. If these chemicals accumulate in the body they can cause health problems and can cause cancer [6] [9]. Unfortunately, only 51.5% of respondents stated that the use of styrofoam as a food container is safe but for certain types of food and 45% of respondents stated that the use of styrofoam as a food container is unsafe (Figure 5). Figure 6 shows that 8% of respondents think styrofoam has no negative health effects at all.

![Figure 3. Frequency of ordering online food.](image1)

![Figure 4. Material packaging for foods ordered by online.](image2)

![Figure 5. Safety of styrofoam as food packaging.](image3)

![Figure 6. Effect of styrofoam as food packaging.](image4)

3.1.4 Public Enthusiasm for Styrofoam Replacement. Besides having an impact on health, styrofoam also causes environmental problems. Polystyrene compounds in styrofoam cannot naturally decompose so they will accumulate and pollute the environment which reduces environmental quality [10]. Based on Tetra Pak Index research in Indonesia, as many as 1.2% of consumers have used social media to shop for food in 2016 and this figure will increase to 5.4% in 2030 [15]. Based on this information, the survey shows that 93.5% of respondents wish to reduce styrofoam use (Figure 7).

According to Republic of Indonesia Regulation No. 7 Year 1996 every food producer is prohibited from using unsafe packaging that might contaminate food and be harmful to consumer health. Therefore, the use of styrofoam as a food container must be limited and should be avoided. The results of this survey showed that 93% of respondents strongly agree with the replacement of styrofoam as food packaging (Figure 8) and 92% of respondents support the use of environmentally friendly packaging instead of styrofoam (Figure 9).
3.2. Production of Biofoam

3.2.1 Growing of Rhyzopus sp. on Sugarcane Bagasse and Coconut Fiber

The results showed that the *ragi tempe* mycelium growth covered the bottom outer surface of the sugarcane bagasse completely (Figure 10). However, the top outer surface and inside of the sugarcane bagasse were not covered by mycelium. Figure 11 shows that *ragi tempe* mycelium did not cover the surface of coconut fiber perfectly, as the top of the coconut fiber was still visible. This was expected because the shape of biofoam was quite thick suggesting that additional fermentation time was needed for the mycelium to grow perfectly. In addition, the texture of this biofoam was moister than the sugarcane bagasse biofoam which resulted in the growth of undesired mold.

![Figure 9](image)

**Figure 9.** Desire to suggest the use of environmental-friendly packaging.

![Figure 7](image)

**Figure 7.** Desire to reduce styrofoam use.

![Figure 8](image)

**Figure 8.** Desire to replace the use of styrofoam.

![Figure 10](image)

**Figure 10.** The growth of *ragi tempe* mycelium in the first experiment of sugarcane bagasse biofoam at bottom surface (a), top surface (b), and inside (c).
3.2.2 Optimising the Growth of Rhizophus sp. Based on the first experiment, it was determined that the biofoam produced was too thick so the *ragi tempe* cannot grow inside the fiber well. Therefore, in the second experiment, the biofoam was made thinner and smaller than the previous experiment, and the amount of water was reduced to avoid undesired mold growth. After these modifications, better results (Figure 12) were achieved compared with the previous experiment. The thinner shape caused the mycelium in both biofoam samples to completely cover the surface of both biofoam. The mycelium growth could bind and penetrate every part of the fiber, but the growth of undesired mold was still detected on the surface of the biofoams, with the highest contamination found on the surface of coconut fiber biofoam.

![Figure 11](image1.png)  ![Figure 12](image2.png)  ![Figure 13](image3.png)

**Figure 11.** The growth of *ragi tempe* mycelium in the first experiment of coconut fiber biofoam at bottom surface (a), top surface (b), and inside (c).

**Figure 12.** The growth of *ragi tempe* mycelium in the second experiment of coconut fiber biofoam at bottom surface (a) and top surface (b).

**Figure 13.** The growth of *ragi tempe* mycelium in the second experiment of Sugarcane Bagasse biofoam at bottom surface (a) and top surface (b).
3.2.3 Shaping the Biofoam Cup. This experiment was conducted to determine how to form a cup with the biofoam mixture. The result showed that the shape of biofoam was almost perfect. The biofoam surface was well covered by the mycelium, all parts of the bagasse fiber were bound completely by the mycelium and the appearance of the cup produced in accordance with the expected shape (Figure 14). However, the resulting biofoam was not as strong as general styrofoam so additional fiber binding materials are needed.

Figure 14. Biofoam cup made from sugarcane bagasse (a) and from coconut fiber (b).

The survey results revealed respondent’s habits around buying food online with 7.5% of respondents doing so very often and 24.5% of respondents doing so often. This could cause the use of styrofoam packaging to increase as the purchased food must be delivered to the consumer with packaging that can resist the food’s heat for long periods until it arrives at its destination. Only 6.5% of respondents did not know about the risks of styrofoam packaging, meaning the majority of the public is already aware of the dangers and consequences of using styrofoam. The survey shows that the community is very supportive (93.5%) and willing (93%) to reduce styrofoam usage, because they realize the health and environmental impact caused by the accumulation of styrofoam.

Incubation conditions greatly affect the mold growth and mycelium formation of sugarcane bagasse and coconut fiber based biofoam. Making holes in the cup plays an important role in providing oxygen (aeration) for mold growth. Low aeration could inhibit and stunt the mold growth. However, when there was high aeration, the mold would grow rapidly and sporulation occurred. Sporulation would produce black spores to appear on the surface of the biofoam [11]. Rhizopus sp. requires a source of protein for its growth. Soybeans have up to 40% protein compared to other legumes which only contain protein ranging from 20-25% [12]. Therefore, soybean flour was used as a source of protein in this study. The protein was used as a nutrient for the fungus Rhizopus sp. to form structures and source of energy to form the mycelium. In addition to protein sources, carbon sources were needed to facilitate the mycelium cells’ structural and energy needs [3]. Generally, biofoam has low mechanical and thermal properties, to improve its properties it is necessary to add “reinforcement / filler”. Reinforcement or fillers are commonly used with natural fibers. Natural fibers come from natural resources like plants (cocoa pod husk, banana steam, oil palm, betel nut, pineapple leaf) or animals (chitin) [13].

4. Conclusion

The survey showed that styrofoam is the most widely used type of food packaging (68.6%), but 93.5% of respondents want to reduce styrofoam usage and 93% of respondents strongly agree with the replacement of styrofoam as food packaging. In addition, sugarcane bagasse and coconut fiber can be used as a raw material in biofoam production. The final formulation is composed of 200 g sugarcane bagasse or coconut fiber, 35 ml water, 25 g flour, and 13 g ragi tempe.
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