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Biodegradable pot from oil palm fronds waste: production process, physical properties, and biodegradability study

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ABSTRACT

This research investigated the potential use of oil palm frond waste as a new raw material for developing biodegradable pots (biopot), which could substitute planting containers made from petroleum-based materials such as pots or plastic polybags. This study was aimed, in particular, at examining the physical characteristics and biodegradability of biopot products. This objective was essential for ensuring that the functionality, characteristics, and biodegradability of biopots were technically acceptable for their agricultural application. Production of biopot was done by cold pressing method, which started by mixing the frond fibers as reinforcement with tapioca as a matrix and molding it using the cold pressing method. Furthermore, testing of physical characteristics includes density, moisture content, water absorption, and biodegradability in soil media. The research shows that the biopot from oil palm fronds has a density of 0.27-0.44 g / cm^3, moisture content of 1.28-4.71%, and water absorption of 179.88-285.74%. The degradability of biodegradable pots ranged from 11.07-34.22%. Based on the above characteristics, the biodegradable pot from oil palm fronds has the potential to be used for planting containers. Biopot from oil palm fronds was interesting to develop since it performed suitable characteristics, compared to the Indonesian National Standard (SNI) of the similar composites product and the characteristics of biodegradable pot from other previous reliable research .

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INTRODUCTION

Oil palm is the primary commodity of Indonesia, which contributes significantly to the nation's economy. Currently, Indonesia is the world's largest palm oil producer, with a production of 13.9 million tons in 2009, increasing to 51.8 million tons as of October 2019. South Kalimantan Province has a large area of palm oil plantations of 424,932 hectares, with CPO production of 1.1 million tons in 2019 (Sari 2019). The increase in production has led to an increase in the volume of palm oil industry waste which contains high organic matter (Krishnan et al. 2017; Tao et al. 2018; Triyono et al. 2019). One hectare of oil palm plantations annually can produce up to 55 tons of solid waste in the form of fibrous biomass in addition to the main oil product, which is 5.5 tons/ha (Hasamudin and Soom 2002). The total fiber biomass from lignocellulose is obtained from stems, leaves, fruit mesocarp, oil palm empty bunches, and oil palm fronds. One of the major solid wastes of oil palm plantations is the fronds because the fronds must be cut every 2 weeks to maintain plant growth and productivity. This frond waste is then piled up or burned to contribute significant carbon dioxide emissions to the air, whichs very detrimental to society and the environment (Zainuri et al. 2019). The accumulation of fronds on the land as natural mulch also leaves a problem since it potentially invites pests to nest.

On the other hand, the world is currently facing another environmental problem that is no less important, namely the accumulation of plastic waste, which is contributed by the use of plastic seedling pots or containers commonly used in the nursery and planting process. The use of plastics raises environmental problems because it is not easily decomposed or decomposed by natural processes in the environment, either by rain, sun heat, or microorganisms that live in the soil, so the use of plastic materials can cause accumulation of waste in the environment (Akhir et al. 2017; Jambeck et al. 2015).

The breakthrough proposed to address the two problems above (the accumulation of palm oil frond waste and the accumulation of agricultural plastic/agro-plastic), which is interesting to study is the use of frond waste to be used as raw material for making biodegradable pots (from now on referred to as "biopot") which in turn are expected to replace the use of plastic pots in agricultural activities. Research on biopot has been carried out by previous researchers using several media such as peat moss, cow dung, wood fiber, mushroom substrate logs, empty fruit bunches, coconut coir, peat soil, husks and straw (Beeks and Evans 2013; Postemsky et al. 2016; Zhang et al. 2019; Sahari and Sapuan 2012; Schettini et al. 2013; Jaya et al. 2022, 2023).

However, efforts to find new raw materials need to be carried out, considering the potential of each region. In this research, another new potential waste will be used, namely oil palm fronds. The objectives of this research are to examine the manufacture of biopot from oil palm frond waste using tapioca as a matrix, as well as to examine the physical characteristics and biodegradability of biopot.

METHODS

Materials

The main material used in this research was fresh palm fronds. The fronds were separated from the leaves and chopped into small pieces. The chopped fronds were dried in the sun for 2 days or until the water content was below 10%. The material was then crushed using a machine and prepared for biopot production.

The matrix used in biopot production was tapioca, which also functions as an adhesive. Tapioca was dissolved in boiling water at 100^{o}C and manually stirred until a gel formed.

Tabel 1 Formulation of oil palm fronds and tapioca starch for biopot production

Formula	Adhesive/Matrix (%)	Fronds (g)	Tapioca (g)	Water (ml)
BP-1	5	40	2	100
BP-2	10	40	4	100
BP-3	30	40	12.5	100
BP-4	50	40	20	100

Production of Biopot

The palm fronds were chopped and mashed using a dry blender. The smooth material is then mixed with tapioca as an adhesive dissolved in boiling water (100°C) and stirred homogeneously. Various compositions of fronds and tapioca can be seen in Table 1.

The mixture of fronds and tapioca formed a paste, which was then molded in a definite mold using the cold pressing method. After that, the biopot is dried under the sun for 20 hours (4-5 days) to achieve the appropriate dryness. The biopot products obtained were obtained through physical characterization and biodegradability tests.

Characterization of Biopot

Density

Biopot density measurement refers to a modified method from similar research (Jaya et al. 2019; Postemsky et al. 2016; Sun et al. 2019) using a product specimen size 10 x 10 mm^2. The thickness of the specimens was measured using a spade micrometer. Volume was calculated by multiplying the area and thickness of the specimen. Furthermore, the specimen is weighed (W), and its density is measured (d) using the Equation (1).

$$d = \frac{W}{V} \quad \text{Eq.(1)}$$

Water Content

Measuring the moisture content of biopot refers to a modified method from (Jaya et al. 2019) using a product specimen of 10 x 10 mm2 size. The empty plates were dried in an oven at 105°C for 15 minutes, cooled in a desiccator, and weighed as W_2. Product specimens with a size of 10 x 10 mm^2 were inserted into a Petri dish and weighed in initial weight (W). Then, put it in the oven at 105°C for 3 hours or until the weight is constant. The plate containing the sample was cooled in a desiccator for 30 minutes and then weighed (W_1). The water content is calculated using the Equation (2).

$$Water\ cont\ (\%) = \frac{W - (W_1 - W_2)}{W} x\ 100\% \quad \text{Eq.(2)}$$

Water Absorption

Measurement of biopot moisture refers to a modified method from previous studies (Schettini et al. 2013; Zhang et al. 2019) using biodegradable pot specimens. A 10 x 10 mm2 biopot specimen was prepared to be placed on a petri dish and weighed as W_0. The specimens were then immersed in distilled water for 60 minutes, after which they were drained and weighed using an analytical balance to the nearest 0.1 mg. Before weighing, the excess water adhering to the surface of the specimen was gently wiped with a tissue. The weight after immersion was denoted by W_t. Each of these treatments was repeated in triplicate, and the results were averaged to obtain the water adsorption value (Q) through the Equation (3) and (4).

$$Q = \frac{W_{H_2O}}{W_0} \quad \text{Eq.(3)}$$

$$W_{H_2O} = W_t - W_0 \quad \text{Eq.(4)}$$

$$W_{H_2O} = water\ adsorbed$$

Biodegradability Test

The Biopot degradability test was carried out through the weight loss test method referring to the modified test method from (Rafee et al. 2019 Schettini et al. 2013; Sun et al. 2019; Zhang et al. 2019) for the organic seed container test. Tests were carried out 3 times by placing the specimen in the ground (burial test). A biopot specimen measuring 10x10 mm^2 was prepared and weighed using an analytical balance as W_0.

The degradability of the biopot was determined based on the decrease in the weight of the biopot specimen over time. The sample specimens previously put into the media for 7 days were then taken, cleaned from the media, dried using an oven at 55°C for 48 hours, then weighed (W_t). Weight loss was calculated using the Equation (5).

$$Weight\ Loss\ (\%) = \frac{W_0 - W_t}{W_0} \quad \text{Eq.(5)}$$

RESULTS AND DISCUSSION

Production of Biopot from Oil Palm Fronds

According to (Beeks and Evans 2013), a biopot or biocontainer is a planting container made from organic materials (non-petroleum based) which decomposes quickly when placed in the soil or composting container. In this study, oil palm fronds were selected as the raw material for making biopot because of their large abundance in plantations and are one of the largest sources of solid waste from oil palm plants. The selection of raw materials for making biopot, both the fiber and the type of adhesive used, must consider aspects of sustainability and the resulting environmental impacts. The concept of recycling and being environmentally friendly is a special consideration in choosing palm oil frond waste to reduce environmental pollution and become an alternative to plastic pots that have been used so far (Sutrisno and Wahyudi, 2012)

In this study, several material formulations were made to determine their effect on the quality of biopot, which included physical characteristics and product biodegradability. The biopot developed in this research is a biocomposite composed of a natural fiber of palm fronds as a reinforcing component (filler or reinforcement) and tapioca flour, which functions as an adhesive and a matrix. The palm frond fibers act as reinforcement. Meanwhile, tapioca flour functions as a matrix, which, among other things, transfers stress to the fiber as a filler, forms a coherent bond on the surface of the matrix fiber, and protects the fiber. Tapioca flour is used as one of the constituent components (matrix) because of its natural "green footprint," its large abundance in various plant sources, and its thermoplastic characteristics. Also, the price of starch derived from plants can compete with synthetic polymers such as polyethylene (PE), polystyrene (PS) and polystyrene terephthalate (PET) (Ali 2017; Nandi and Guha 2018; Sapuan and Ilyas 2018).

Adding tapioca can increase the flexural strength and decrease the organic pot products' stiffness (more elastic). Research challenges in determining fiber as the primary constituent material of biopot are its availability, price, and the final characteristics of the biopot produced (Budi et al. 2012).

Based on the research, it is known that the fiber and adhesive composition affects the quality of the biopot. Biopot with an adhesive concentration of 50% (of the total mixture) showed more robust results than products with a lower adhesive composition. The next subtopic will explain the physical characteristics of biopots in more detail. The figure for biopot products is displayed in Table 2.

Tabel 2 Biopot from oil palm fronds

Treatment	*Biopot*	
	Side view	Top view
BP-1		
BP-2		
BP-3		
BP-4		

Table 3 Physical characteristics of biopot

Treatment	Density(g/cm^3)	Water Content (%)	Water Absorption (%)
BP-1	0.44	4.71	179.88
BP-2	0.39	3.03	183.77
BP-3	0.32	1.39	255.72
BP-4	0.27	1.28	285.74

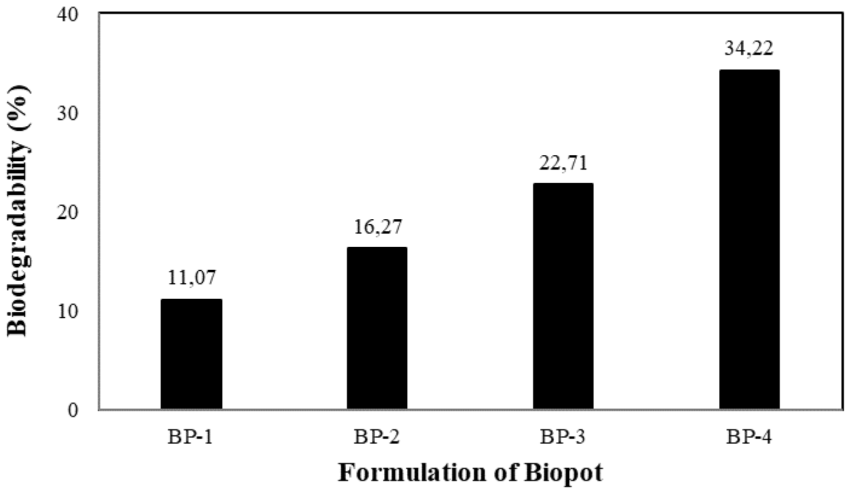

Figure 1 Biodegradability of biopots in soil medium

Physical Characteristics of Biopot

The characteristics of the biopot are its properties, which follow its function as a planting container that is quickly degraded in the environment. The final characteristics of a biopot, which are generally in the form of a biomaterial biocomposite, are determined by many things, such as the type of matrix material, fiber, fiber direction, production method, and others (Yıldızhan et al. 2018). Biopot characteristics include physical, mechanical, and morphological characteristics. This biopot's characteristics depend on the material that makes up the biopot. The physical characteristics of the biopot can be seen in Table 3.

Density

Based on the research, the biopot density of oil palm fronds ranges from 0.27-0.44 g/cm^3. The highest density was obtained from biopot with an adhesive or matrix composition of 50% with a density value of 0.44 g/cm^3. The higher the concentration of tapioca flour produces a biopot with a higher density. This is because tapioca flour, besides functioning as a matrix, also functions as an adhesive because it forms a hydrogen bond between tapioca and fiber, which functions as a filler (Gadhave et al. 2017; Hemmil 2017).

Based on the results, biopot BP-1 with an adhesive concentration of 50% has a density that meets the Indonesian National Standard (SNI) for fiber composites density (0.40-0.90 g/cm^3). While biopot BP-2, BP-3, and BP-4 are slightly lower than the SNI density for fiber composites (Badan Standardisasi Nasional 2006). Of course, this cannot be thoroughly compared because biopot and fiber composites (fiber boards) have different functions. However, at least this gives the idea that the higher the adhesive concentration of the composites, the higher the product density. Compared to similar previous research, biopot density in this study was higher than biopot made from palm fiber (Jaya et al. 2019) and former mushroom cultivation substrate (Postemsky et al. 2016). However, it was lower than a biopot made from straw fiber (Sun et al., 2019). This fact shows us that the density of the biopot depends on the constituent material and the method of manufacture

Water content

Water content testing was carried out to determine the characteristics of the resulting biopot. The high water content in biopot allows the growth of microorganisms in the form of bacteria and fungi, which can cause damage or decomposition of materials during storage or application of biopot (Jaya et al. 2019; John 2017; Sun et al. 2019).

Based on the research results, it was shown that biopot BP-1 with the addition of adhesive by 50% has the highest water content of 4.71%. In comparison, the lowest water content was obtained from biopot BP-4 (5% adhesive), which has a water content of 1.28%. The higher the adhesive content, the more adhesive was added as a material for making biopot, the more water was contained in the organic pot. The water from the adhesive fills the cells in the oil palm frond fiber in the composite system.

Water Absorption

The water absorption capacity of the biopot was determined by the constituent materials. It was closely related to the porosity and density of biopot (Zhang et al. 2019). Water absorption is the amount of water mass absorbed in the biocomposite after immersion at a predetermined time. The water absorption in biopots is also related to the chemical properties of the materials as constituents.

Based on the research, biopot water absorption capacity from oil palm fronds ranged from 179.88-285.74%. The highest water absorption was obtained from biopot BP-4 with an adhesive or matrix composition of 5%. The higher concentration of tapioca flour tends to produce biopot with lower water absorption. This is because the high concentration of tapioca starch increases the strength of the bonds between the fibers and causes the density of the biopot to increase, thus making it difficult for water to enter the biopot cavity. The biopot water absorption resulting from this study is lower than the biopot water absorption capacity from peat, cow dung, and wood fiber (Zhang et al. 2019), with a water permeability ranging from 316-476%. However, the value was higher when compared to the water absorption capacity of biopot, which was made from hemp fiber and tomato waste (Schettini et al. 2013), which ranges from 130-190%. The value of water absorption depends on the type of fiber material, matrix material, and the method of making biopot.

Biodegradability of Biopot

One of the advantages of biopot is that it can degrade quickly in the environment because it comes from natural materials. Degradation in the environment can occur through photodegradation, biodegradation, and other mechanisms. The ease of biodegradation of the biopot avoids the build-up of abundant post-agricultural waste, as happens with plastic pots or polybags. This is because the biopot is made of natural hydrocarbon fibers, which makes it easier for endogenous microorganisms to carry out renovation processes.

Biopot degradability in this study was carried out through a weight loss test, which refers to the modified test method (Schettini et al. 2013); (Sun et al. 2019; Zhang et al. 2019) for the organic seed container test. Based on the results of observations that have been made, the most considerable weight loss was found in biopot BP-4, namely 34.22%, while the smallest weight loss was obtained in biopot BP-1, namely 11.07%. Increasing the concentration of tapioca adhesive causes an increase in the density of the biopot, thus making it difficult for water particles to enter the pores of the material and making it difficult for digestion bacteria to break down the material.

Apart from the above, biodegradability depends on the internal conditions of the biopot (materials, manufacturing processes, and others) and the external conditions of the environment (microorganisms, light, chemicals, and minerals that interact with the biopot). It was reported that biopot made from banana peel waste decomposed in the soil by 39.38% within 60 days after being placed in the soil (Rafee et al., 2019). Another report on biopot made from straw and soybean dregs shows a biodegradation process of nearly 50% during 24 months of incubation with indigenous soil bacterial cultures (Sun et al. 2019). Another report also tested the degradation of biopots planted with seaweed in containers filled with salinity seawater, showing 19.24% (1.18) after 26 months of experimentation (Balestri et al. 2019).

CONCLUSIONS

This research shows that oil palm frond waste has the potential to be developed as a biopot material because it has appropriate characteristics and degradability, both compared to the SNI for fiber composites and when compared to previous reliable research on biopots. The best biopot was obtained from the BP-1 formulation, which contained 5% tapioca as the matrix or adhesive and 40 g of palm oil frond. BP-1 showed the highest density (0.44 g/cm^3) and the lowest water absorption (179.88%). Apart from that, BP-1 also showed a degradability of 11.07%, which indicates stronger resistance when applied to soil compared to other biopots. This innovation is expected to reduce the accumulation of oil palm frond waste in the field while increasing the economic value of the waste, which, in the end, is expected to increase the welfare of farmers.

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