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The Utilization of Oil Palm Empty Fruit Bunches (OPEFB) for Biodegradable's Pot Raw Materials As An Alternative Container for Sustainable Nurseries

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ABSTRACT

Processing of waste oil palm empty fruit bunches (OPEFB) that is environmentally friendly is one of the things that should be considered in order to support the development of the palm oil industry in Indonesia. This study aims to determine the effect of the mass ratio between OPEFB and banana stems as raw materials and the effect of NaOH concentration to produce the best biodegradable pot composition formulation based on its physico-mechanical properties. The mass ratio of OPEFB to banana stems was 100%:0%, 80%:20%, 60%:40%, 40%:60%, and 0%:100%, while the concentrations of NaOH used were 3%, 5%, and 7%. Physico-mechanical tests were carried out on the parameters of mass, moisture content, water uptake, biodegradability, and tensile strength of biodegradable pots. The results showed that the biodegradable pots had a mass range of 9.58-18.48 grams, water content 50.42%-65.89%, water uptake 2.72%-4.82%, potential for biodegradation of 40.54%-76.39%, and tensile strength.8091 Pa-23418 Pa. The combination treatment R2C2 (80% EFB: 20% banana stem; 5% NaOH) is the best treatment formulation because it has a faster biodegradability and can support the durability of biodegradable pots through high tensile strength and resistance to water. However, the density of the biodegradable pot wall requires some improvement due to uneven fiber dispersion.

1. Introduction

Oil palm (*Elaeis guineensis*) is a plantation commodity with a large amount of production and consumption in the world. Indonesia is the largest palm oil producer by contributing 58% or as much as 43.5 million tons of total production in the world **(United States Department of Agriculture, 2020).** The recorded area of oil palm plantations reached 14.3 million hectares with a total production of CPO (Crude Palm Oil) of 42.9 tons in 2018 and is predicted to continue to increase in the following years **(Directorate General of the Ministry of Agriculture of the Republic of Indonesia, 2019).** However, the development of the palm oil industry in the global market is still constrained by black campaign issues related to environment, sustainability, and social issues.

Palm oil waste processing is a crucial aspect that must be considered, one of which is oil palm empty fruit bunches (OPEFB). There is 23% of OPEFB waste from Indonesia's total palm oil production, but the handling of OPEFB waste has only reached 10% of the total waste generated **(Dewanti, 2018).** On the other hand, non-strategic management and utilization of OPEFB waste can leave large emissions and have the potential to harm oil palm land and even have an impact on the environmental system **(Rame, 2018).** Even though OPEFB contains cellulose of 38.76% and fiber reaches 72.67% **(Dewanti, 2018)** so it has the potential to be utilized.

In addition, the organic waste that is in abundance is banana stems. Banana stems (*gedebog*) are an economical and potential source of natural fiber with a cellulose content of up to 65% **(Jaya, 2011).** Isolation of cellulose from natural fibers can be done through alkaline treatment (NaOH) by degrading lignin in the lignocellulosic structure of the fiber **(Fitriasari et al., 2019).** Cellulose fiber has the potential to be used as raw material for the manufacture of eco-products, one of which is the manufacture of biodegradable pots (biopots) to replace the use of polybags in the agricultural sector. Polybags made of polyethylene are widely used in the agricultural sector, especially in the plant nursery process, which is a source of plastic waste that is difficult to decompose **(Jaya et al., 2019).**

Based on the explanation above, this research was conducted with the aim of knowing the effect of the composition of the constituent materials and the addition of NaOH with different concentrations on the physico-mechanical properties of biodegradable pots.

2. Methods

The tools used in this study include a biodegradable pot mold made of iron plate consisting of an outer mold with dimensions of 5x8x9 cm^3 and an inner mold with dimensions of 4x7x8 cm^3, a machete, a pan, a bucket, a digital scale, a thermometer, a glass beaker, a glass stirrer, a stove, a plastic box, aluminum foil, soil, oven and PCE-FM 500 N. Meanwhile, the ingredients consist of OPEFB, banana stem, NaOH, tapioca adhesive, aquades and water.

Figure 1. Biodegradable Pot Mold

The study was conducted using a Completely Randomized Design (Factorial) consisting of 2 factors which were analyzed through the Analysis of Variance (ANOVA) test and the DMRT Advanced test at a probability of 5%. Factor 1 is the composition of biodegradable pot raw materials consisting of 5 treatment levels, they are:

1. R1 : 100% OPEFB
2. R2 : 80% OPEFB + 20% Banana Stem
3. R3 : 60% OPEFB + 40% Banana Stem

4. R4 : 40% OPEFB + 60% Banana Stem
5. R5 : 100% Banana Stem

The second factor is the concentration of NaOH which consists of 3 treatment levels, namely:

1. C1 : 3% NaOH
2. C2 : 5% NaOH
3. C3 : 7% NaOH

So the combination of these 2 factors will produce 15 variations of biodegradable pots.

2.1 Raw Material Preparation

One biodegradable pot requires 50 grams of raw materials. To make 45 samples, it requires OPEFB as much as 1,260 kg and banana stems as much as 0,990 kg. The NaOH used is in the form of PA (Pro Analysis) solid crystals which are then dissolved with distilled water according to the concentration used.

2.2 Raw Material Counting

Oil palm empty fruit bunches (OPEFB) and banana stems were chopped using a machete with a fiber length of 1-2 cm.

2.3 Raw Material Wash

OPEFB and banana stems that have been chopped are then washed by soaking the raw materials in a bucket and rubbing them on the surface to remove any adhering dirt and then rinsed thoroughly.

2.4 Drying

OPEFB and banana stems that have been washed are dried in the sun for 2x24 hours to reduce the moisture content of the material, so that the raw materials can last a long time during storage before the process of making biodegradable pots is carried out.

2.5 Boiling Stage 1

OPEFB and banana stems are boiled according to the composition of the raw materials. The first stage of boiling aims to soften the raw materials and remove impurities that may still be attached to the material. The ratio between the raw materials and the volume of water used during boiling is 50 grams : 1 liter, or until the ingredients are completely submerged. Boiling was carried out for 1 hour at a temperature of 95^{o}-$105\,^{o}$ C.

2.6 Boiling Stage 2

This boiling process is carried out as an alkaline treatment by adding NaOH according to the concentration in each treatment. Boiling stage 2 is carried out at a temperature of $95\,^{o}$ -$105\,^{o}$ C for 30 minutes. The addition of NaOH aims to break the bonds between cellulose fibers and lignin contained in the material. After the boiling process, drain the water and material to separate the cellulose from the degraded lignin.

2.7 Pulping

Pulping is done by smoothing OPEFB and boiled banana stems with a blender and adding 10% (m/v) tapioca adhesive until they become pulp and mixed well. The addition of tapioca flour solution aims as a natural adhesive to strengthen the bonds between fibers. Once smooth, the pulp is boiled again for 5 minutes until thickened.

2.8 Biodegradable Pot Printing

Before the printing process, the mold is first coated with aluminum foil to ease the printing process of biodegradable pots. The biodegradable pulp pot is slowly poured into the outer mold according to the shape of the mold, then push the inner mold and held down until the remaining pulp and water come out through the holes in the mold in order to obtain a biodegradable pot with a uniform thickness and dimensions of 5x8x9 cm.

2.9 Biodegradable Pot Drying

The process of drying biodegradable pots is done by drying the biodegradable pots in the sun for 2x7 hours until they are half dry to reduce the amount of surface water in the biodegradable pots, then dried using an oven at 105°C for 24 hours to obtain a constant mass.

Test Parameters

Biodegradable Pot Mass

The measurement of the mass of the biodegradable pot was carried out using a digital scale with an accuracy of 0,01 gram.

Water content

The moisture content test was carried out referring to ISO 287:2017 *Paper and board– Determination of moisture content of a lot– Oven drying method* by weighing a wet biodegradable pot as the initial mass (ma) then oven at 105°C for 24 hours, and weighed until a mass was obtained. constant as the final mass (mb). The water content of the biodegradable pot was calculated using the following equation (1).

$$\text{Moisture content (\%)} = \left[\frac{m_a - m_b}{m_a}\right] x\ 100\%$$

Water Uptake

The water uptake analysis showed the resistance of biodegradable pots to water through the percentage addition of sample mass from the swelling phenomenon during the soaking process, the analysis was carried out according to the ASTM D570-98 standard by weighing the dry mass of the sample (m_d) measuring 3x3 cm, then the sample was soaked for 24 hours at room temperature to become saturated. After that, it was drained until no surface water was left behind and weighed again to determine the wet mass (m_w). The value of water uptake can be determined by using the following equation:(2).

$$\text{Water Uptake(\%)} = \left[\frac{m_d - m_w}{m_w}\right] x\ 100\%$$

Biodegradation Test (Soil Burial Test)

The biodegradation test aims to determine the potential for biodegradable pots to be degraded in nature through the percentage loss of mass during the burial process in the soil. The test was carried out according to the ASTM D5988 standard – *Standard for determining aerobic biodegradation in soil,* by burying a sample measuring 3x3 cm in topsoil soil which is placed in a plastic box with a depth of 10 cm for 21 days with sample checking every 7 days of burial. Before the burial, the samples were weighed to determine the initial mass (m_i). After the test, the samples were cleaned with distilled water, baked in an oven at 105°C for 2 hours and weighed every 30 minutes until a constant sample mass was obtained as the final mass (m_f).The biodegradability of the biodegradable pot is obtained by the following equation (3).

$$\text{Biodegradability (\%)} = \left[\frac{m_i - mf}{m_f}\right] x\ 100\%$$

Tensile Strength

Tensile strength testing of biodegradable pots was carried out using a PCE-FM 500 N tool. Based on the ASTM D3039 standard- *Standard Test Method for Tensile Properties of Polymers Matrix Composite Materials*, the tensile strength test was carried out on a specimen with dimensions of 25x2.5 cm with a thickness of 2.5 mm which can be seen in Figure 2. The specimen is attached to the hook probe by being given a graded axial load with a certain speed of increasing the load until the specimen breaks. The tensile strength value is obtained by equation (4).

$$\sigma = \frac{F}{A}$$

Figure 2. Tensile Strength Test Specimen

This section briefly and clearly describes the research methods used in problem solving, including analytical methods. The research methods section includes an explanation of: (1) research location, (2) materials and tools used, (3) sampling methods, (4) measurement methods, (5) research design, (6) stages of research activities and (7) calculation of data analysis.

The formulas used in the calculation of the data are written using an equation editor or other standard applications. Formulas must not be images or screen captures from other sources. The formula is written by including the source of the library. The following formula is a formulas to calculate the soil moisture content **(BSN, 2002)**:

$$KA = \frac{BA\text{-}BKT}{BKT} \times 100\%$$

where KA is the soil moisture content (%), BA is the initial weight of the soil (g), and BKT is the dry weight of the soil after being oven-dried (g).

3. Results and discussion

3.1 Making Biodegradable Pots

The quality of the 15 variations of biodegradable pots is based on actual measurements including height, top diameter and bottom diameter. The measurement results obtained that the biodegradable pot height was 9 cm (±0.3), the top diameter was 8 cm (±0.4), and the bottom diameter was 5 cm (±0.3) as shown in Fig. Table 1.The discrepancy between the size of the biodegradable pot and the dimensions of the mold (5x8x9 cm^3) is caused by the finishing process which aims to improve the shape of the biodegradable pot that is less tidy from the printing process, and the addition of aluminum foil into the mold causes a reduction in the top diameter and bottom diameter of the biodegradable pot. Biodegradable pots with more OPEFB fiber composition tend to be coarser. This is due to the morphological difference in fiber size between OPEFB fiber and banana stem fiber, also according to **Valasek et al., (2021)** the surface roughness of the fiber is influenced by the effect of alkali. The coarseness of natural fibers increased after alkali treatment due to the disintegration of hemicellulose and lignin in the lignocellulosic structure. And if the color uniformity was analyzed, the biopots were brown and tended to be whiter when the NaOH concentration in alkaline treatment was increased because there was more lignin and impurities in the hydrolyzed fiber, as can be seen in Table 2.

Table 1. Quality of Biodegradable Pots

Sample	Height (cm)	Top diameter(cm)	Bottom diameter(cm)
R1C1	9.2	7.8	4.7
R2C1	9	7.6	4.7
R3C1	8.9	7.7	4.7

R4C1	9	8	4.8
R5C1	9.1	7.8	4.9
R1C2	9.1	7.6	4.7
R2C2	9	7.7	4.7
R3C2	8.9	7.7	4.7
R4C2	9	7.8	4.7
R5C2	9	7.7	4.8
R1C3	8.9	7.6	4.7
R2C3	8.8	7.7	4.7
R3C3	8.8	7.8	4.7
R4C3	9	7.9	4.8
R5C3	8.7	7.7	4.9

Table 2. Results of Making Biodegradable Pots

Treatment	Formulation	Results
R1C2	100% OPEFB	
R2C2	80% OPEFB: 20% Banana stem	
R3C2	60% OPEFB: 40% Banana stem	
R4C2	40% OPEFB : 60% Banana stem	
R5C2	100% Banana stem	

3.2 Biodegradable Pot Mass

The ANOVA results showed that the mass of the biodegradable pot was affected by the composition of the raw materials, while the NaOH concentration and the interaction between the two factors had no effect. The mass of biodegradable pots ranged from 9.58-18.48 grams as shown in Figure 3.

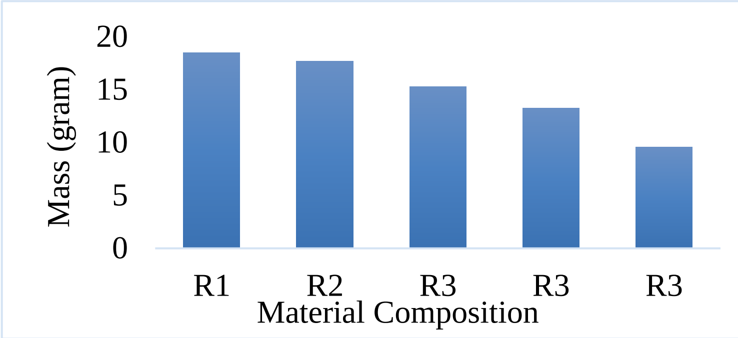

Figure 3. Mass of Biodegradable Pot in Each Treatment of Material Composition

In the treatment of raw material composition, the mass of the biodegradable pot tends to decrease. It can be seen that treatment R1 (100% OPEFB) has the highest value and continues to decrease until treatment R5 (100% Banana Stem). This tendency can occur due to the difference in fiber size morphology between OPEFB fiber and banana stem fiber, as well as due to the physical properties of the fiber, namely density. According to **Rahmasita et al., (2017)**, OPEFB fiber has a size of 343–365 µm and density reaches 1.55 g/cm^3, while banana stem fiber only measures 5.8 µm and a density of 1.35 g/cm^3 **(Nopriantina & Astuti, 2013)**. In this case, with large fiber size and density, the use of OPEFB fiber as a raw material can subsidize the mass of biodegradable pots produced, which causes the higher the percentage of OPEFB used, the mass of biodegradable pots will increase.

Table 3. The results of the average mass of biodegradable pots due to the Treatment of Raw Material Composition

Treatment	Average (grams)
R1	18.48c
R2	17.68c
R3	15.29b
R3	13.28b
R3	9.58a

Information : The mean value followed by the same letter was not significantly different based on the DMRT test through the SPPS application (P>0.05)

In Table 3. it can be seen that biodegradable pots with the addition of higher banana stem fiber caused a decrease in the mass of biodegradable pots from R2 R3 and R4 to R5. According to **Randa & Alimin (2019)**, the addition of banana stem fiber can reduce the mass and density of the composite material. As a seedling container, biodegradable pots are expected to have a heavy mass to avoid tearing or breaking during use **(Evans et al., 2010)**.

3.3 Biodegradable Pot Moisture Content

The ANOVA results showed that there was no effect given by the composition of the raw materials, the concentration of NaOH, or the interaction between these two factors on the water content of the biodegradable pot. The value of water content ranges from 50.42%-65.89% as can be seen in Figure 4.

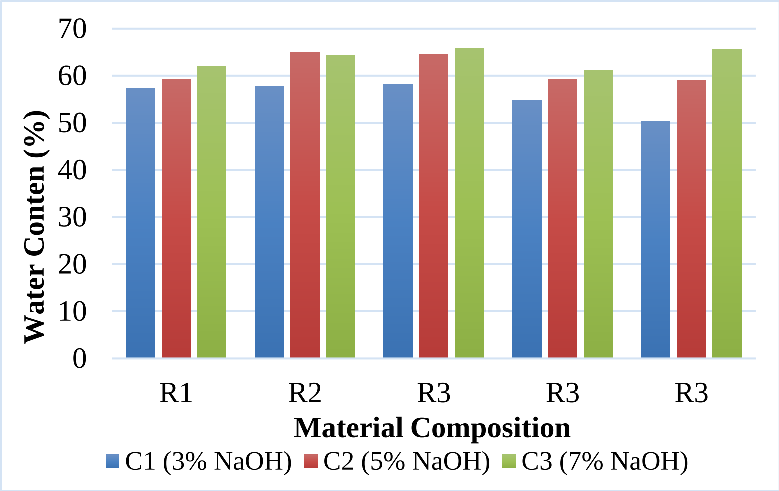

Figure 4. Biodegradable Pot Moisture Content in Each Treatment

In Figure 4 it is known that the lowest water content was obtained in the R5C1 treatment while the highest water content was in the R3C3 treatment. According to **Jaya et al., (2019)**, the composition of raw materials in the manufacture of biodegradable pots does not affect the water content. On the other hand, the increase in NaOH in the alkaline treatment can break the fiber bonds more completely so that it can increase the porosity of the biodegradable pot, and affect the increase in the water content stored in the biodegradable pot **(Pudjiono et al., 2012)**. However, in this study, the opposite results were found for the NaOH concentration factor. This was due to the uneven increase in the porosity of the biodegradable pots due to irregular fiber dispersion in the matrix of the biodegradable pots during the printing process so that no significant effect was found, as shown in Figure 5.

Dispersion Regular Irregular Dispersion

Figure 5. Appearance of Fiber Dispersion in Biodegradable Pots

In Figure 5, regular fiber dispersion is indicated by perfectly bonded fibers. Meanwhile, the irregular fiber dispersion showed the presence of breaking points, causing the fiber bonds to break in the biodegradable pot. In addition, this difference in results can also be caused by the optimum concentration of NaOH used in alkali treatment, especially for crosslinked biocomposites. Because according to **Valasek et al., (2021)** each type of natural fiber tends to have a different optimum NaOH concentration, which will result in a different amount of cellulose obtained. This encourages changes in different fiber dimensions after alkaline treatment, including fiber expansion, lumen diameter enlargement, and cell wall thinning due to the content of dissolved lignin in the fiber **(Fitriasari et al., 2019)**.

However, the water content value obtained in this study was better than that of **Jaya et al . (2019)**, in the manufacture of biodegradable pots from OPEFB and fiber with a moisture content of 70.93% (wet basis) and was in accordance with SNI 03-2105-2006 for composites with moisture content is less than 14% (dry basis) or 93% (wet basis). Biodegradable pots as nursery containers are expected to have a low water content to avoid damage due to the growth of unfavorable microorganisms **(Jaya et al., 2019)** and is related to the flexibility of use both indoors and outdoors.

3.4 Water Uptake

The ANOVA results indicate that there is an influence given by the composition of the raw materials, the concentration of NaOH, and the interaction between these two factors on the value of the biodegradable water uptake pot. The water uptake value ranges from 2.72%-4.82% as can be seen in Figure 6.

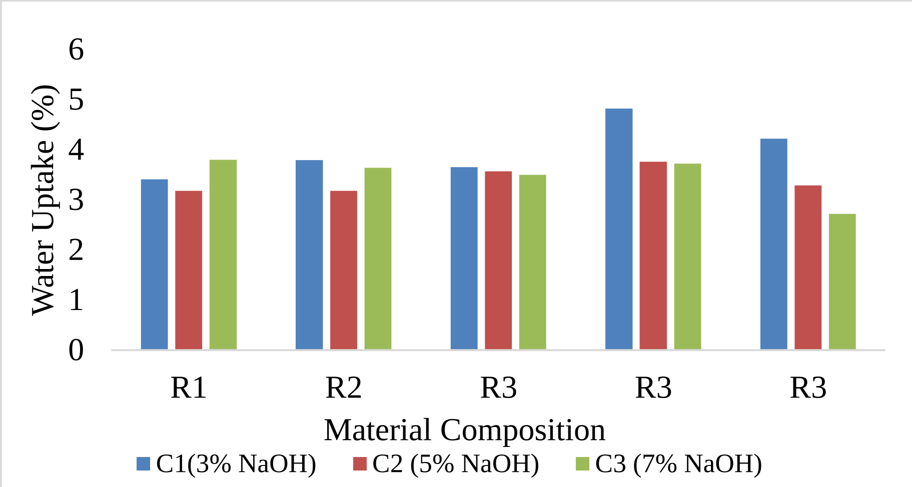

Figure 6. Biodegradable Water Uptake Pot in Each Treatment

In Figure 6. it is known that the R5C3 treatment had the lowest water uptake value and the highest value was obtained in the R4C1 treatment.According to **Akhir et al. (2018)**, water uptake or water absorption is influenced by fiber density in biopots. The higher the fiber density on the surface of the biopot, the tendency for water penetration to be inhibited. In this case, it can be proven by increasing the thickness of the biopots when the swelling phenomenon occurs. The average water uptake for the combination of raw materials and NaOH concentration is presented in Table 4 below.

Table 4. The average yield of biodegradable water uptake pot due to the interaction between composition and concentration of NaOH

R treatment	C treatment			
	C1	C2	C3	Average
R1	3.41a	3.18a	3.80b	**3.46a**
R2	3.79b	3.18a	3.64a	**3.54a**
R3	3.65a	3.57a	3.50a	**3.57a**
R4	4.82d	3.76b	3.72b	**4.10b**
R5	4.22c	3.29a	2.72b	**3.41a**
Average	**3.98b**	**3.40a**	**3.47a**	

Information: The mean value followed by the same letter was not significantly different based on the DMRT test through the SPPS application (P>0.05)

In Table 4. It shows an increase in porosity in the treatment of crosslinked samples when the concentration of banana stem fiber in the raw material increased, seen in the combination of treatments R3C1 to R4C1, R2C2 to R4C2, and R2C3 to R4C3. In this case, it is known that cross-linked biodegradable pots with higher fiber content of banana stems can absorb more water, compared to biodegradable pots without crosslinking both R1 (100% OPEFB) and R5 (100% banana stems). This is due to the hydrophilic nature of banana stem fibers, thus facilitating the process of water absorption in the composite **(Randa & Alimin, 2019)**. **Schettini et al. (2013)**, said that biocomposites consisting of several raw materials will form cross-linked polymers, causing differences in the volume of free space between biocomposites. This is supported by the difference in fiber size between OPEFB and banana stem which is responsible for the difference in fiber pore characteristics. Pore characteristics play a very important role in determining the movement of water **(Maria et al., 2018)**. However, it was found a phenomenon of decreasing water uptake value in crosslinked biopots when the banana stem concentration was increased from the combination of R2C1 to R3C1 and R2C3 to R4C3 treatments. This may be due to the irregular fiber dispersion as shown in Figure 5, which causes voids and discontinuity points in the biopots, so that the sample cannot be wetted higher.

On the other hand, alkaline treatment can reduce the hydrophilic properties of natural fibers. In alkaline treatment, the hydrophilic hydroxyl group is reduced by reacting with NaOH which then forms alkaline cellulose, causing inhibition of water absorption from the composite **(Reddy et al., 2018).** According to **Zebua (2015)**, cellulose fiber that reacts with alkali causes reduced fiber permeability, so water is difficult to penetrate the composite surface. Therefore, it was concluded that there was a tendency for the water uptake value to decrease as the NaOH concentration increased due to more isolated cellulose. However, an unusual phenomenon was found in the combination treatment of R1C2 to R1C3 and R2C2 to R2C3 where there was an increase in the value of water uptake. This indicates the optimum alkaline treatment at C2 (5% NaOH) consequence decrease in cellulose content from C3 treatment (7% NaOH)

In addition, based on the results of water uptake there is an indication that water uptake is inversely proportional to the value of water content as can be seen in Figure 7.

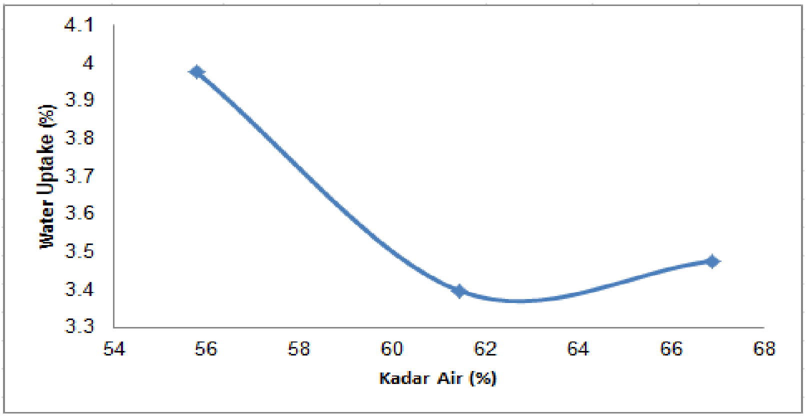

Figure 7. Relationship between Water Uptake and Biodegradable Pot Moisture Content

The phenomenon in Figure 7. is related to the process of osmosis where the osmosis process is driven by the difference in osmotic pressure between the solvent and the solute **(Jiao et al., 2015).** Therefore, the higher the osmotic pressure difference between the water and the biopots, the more water molecules migrated into the biopots, causing a higher percentage of water uptake. Water uptake showed the resistance of biodegradable pots to water through the ability to absorb water which was related to the level of durability of biodegradable pots as nursery media when applied in open land. The lower the water uptake of the biodegradable pot, the better the quality of the biodegradable pot will be.

3.5 Biodegradation Test

The ANOVA results showed that there was an influence given by the composition of the raw materials, the concentration of NaOH, and the interaction between these two factors on the biodegradability of biodegradable pots. The value of biodegradability ranges from 40.54%-76.39% as can be seen in Figure 8.

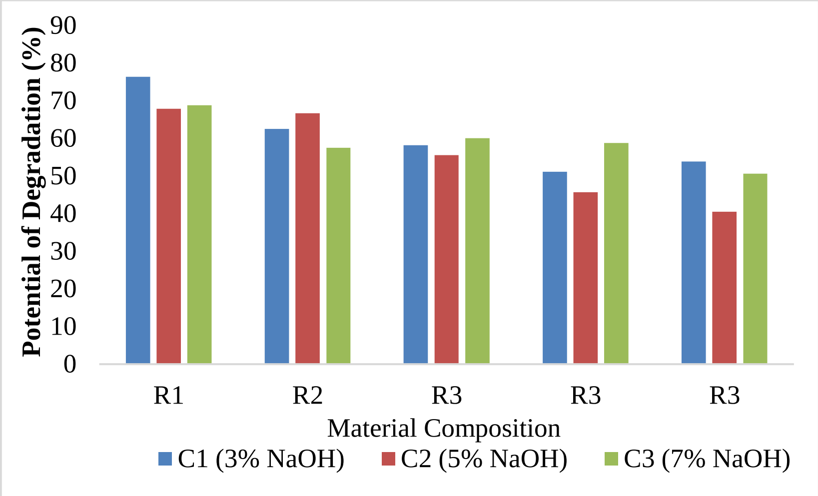

Figure 8. Potential for Degradation of Biodegradable Pots in Each Treatment

In Figure 8. it is known that the R5C2 treatment had the lowest biodegradability while the highest biodegradability was found in the R1C1 treatment. Biodegradable pots as a good alternative media for nurseries are at least able to be degraded up to 60% in good natural conditions, including soil conditions and temperature **(Nambuthiri et al., 2013)**. In this case, the treatment combination was between R1 (100% OPEFB) and R2 (80% OPEFB: 20% Banana stem). The average biodegradability of the combination of raw materials and NaOH concentration is presented in Table 5 below.

Table 5. The results of the average biodegradability of biodegradable pots due to the interaction between the composition and concentration of NaOH

R treatment	C treatment			Average
	C1	C2	C3	
R1	76.39g	67.86f	68.85f	**71.03c**
R2	65.52d	66.66e	57.55c	**63.24b**
R3	58.16c	55.54b	60.05c	**57.91b**
R4	51.14b	45,70a	58.77c	**51.87a**
R5	53.82b	40.54a	50.66a	**48.34a**
Average	**61.00b**	**55.26a**	**59.18b**	

Information: The mean value followed by the same letter was not significantly different based on the DMRT test through the SPPS application (P>0.05)

In Table 5. The results showed that non-crosslinked biodegradable pots R5 (100% Banana stems) were more difficult to degrade in nature when compared to R1 (100% OPEFB) and crosslinked biodegradable pots (R2, R3, R4). The type of fiber greatly affects the ability of biodegradable pots to be degraded in nature, the lower the percentage of OPEFB in the raw materials used, the potential for biodegradation of biodegradable pots will decrease. The high content of microcrystalline cellulose in the fiber results in a low level of biodegradability of biopolymers, because hydrophilic chain macromolecules are not easily attacked by microorganisms **(Schettini et al., 2013)**. Adding banana stems in the raw material subsidizes the amount of cellulose content in biopots. Therefore, the more the number of banana stems added to the raw material, the more difficult it is for biopots to be degraded. On the other hand, the morphology of the OPEFB fiber is porous and contains silica **(Rahmasita et al., 2017)**, making the fiber easier to react by microorganisms in the soil when buried. Silica is sensitive to enzymatic activity because it has a biodegradable organic group framework **(Chinnathambi & Fuyuhiko, 2020)**. However, it was found a phenomenon of increasing biodegradation potential when the concentration of banana stems increased from the combination of treatment R4C1 to R5C1 and from R2C3 to R3C3. This could be due to the irregular dispersion of the fibers in the biodegradable pots which caused the formation of cavities making it easier for microorganisms to reach the fiber bonds in the biopots and the polymer was more easily split.

In addition, the addition of NaOH concentration in alkaline treatment increased the cellulose content in the fiber due to the degradation of lignin. Cellulose is a simple polymer, but forms insoluble, crystalline microfibrils. Assemblages of individual microfibrils in crystalline cellulose are tightly bound enough to prevent penetration by enzymes **(Lakhundi et al., 2015)**. This can lead to high resistance to enzymatic hydrolysis. Therefore, the higher the cellulose content in the biopots, the more difficult the biopots to degrade in nature due to poor enzymatic attack. However, there is a tendency The decrease in cellulose content was due to the excess NaOH concentration at 7% NaOH, which was indicated by the increased biodegradation potential in the treatment combination R1C3, R3C3, R4C3, and R5C3 respectively from 5% NaOH concentration. The difference in the appearance of the sample before and after the biodegradation test can be seen in Figure 9.

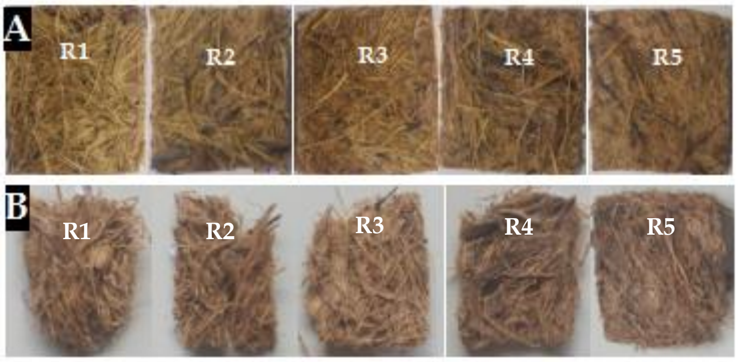

Figure 9. Biodegradation Test Sample (a) Sample before biodegradation test and (b) Sample after biodegradation test

The biodegradability test is also related to the age of the biodegradable pot as an alternative nursery medium that can be adapted to the plant production cycle. Extending the life of biodegradable pots as nursery containers can be done by adding natural or synthetic adhesives, resins, waxes, binders to strengthen the bonds between the fibers in the biopots.

3.6 Tensile Strength

The ANOVA results showed that there was an influence given by the composition of the raw materials, the concentration of NaOH, and the interaction between these two factors on the tensile strength of biodegradable pots. The tensile strength of the biodegradable pots ranged from 8091-23418 Pa as shown in Figure 10.

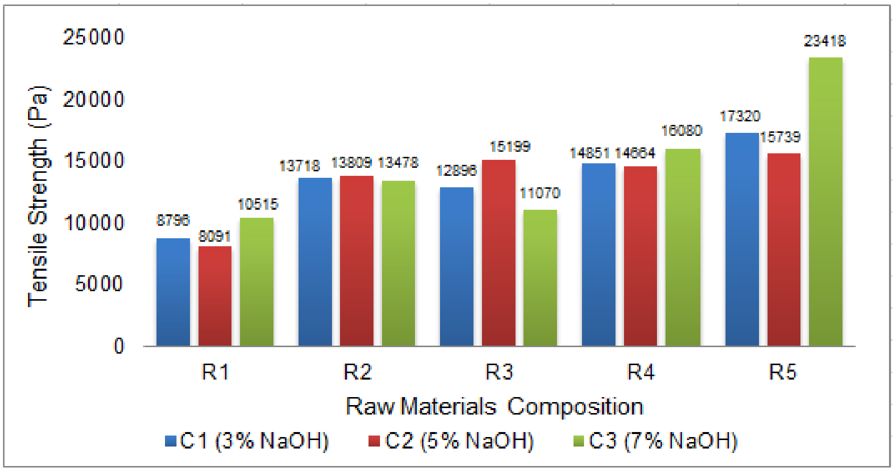

Figure 10. Tensile Strength of Biodegradable Pots in Each Treatment of NaOH Concentration

In Figure 10. it is known that the R1C2 treatment has the lowest tensile strength while the highest tensile strength is obtained in the R5C3 treatment.Until now, research and studies on the mechanical properties of biodegradable pots from natural fibers are still very limited. According to **Rachman (2010)**, an increase in the cellulose content causes an increase in the hardness of the material, which is directly related to an increase in the tensile and compressive strength of the composite.The average tensile strength of the combination of raw materials and NaOH concentration is presented in Table 6 below.

Table 6. The results of the average tensile strength of biodegradable pots due to the interaction between the composition and concentration of NaOH

R treatment	**C treatment**			
	C1	**C2**	**C3**	**Average**
R1	8796a	8091a	10515b	9134a
R2	13718c	13809c	13478c	13668c
R3	12896c	15199d	11010b	13034b
R4	14851d	14664d	16080e	15199d
R5	17320e	15739d	23418f	18826e
Average	**13515a**	**13500a**	**14900b**	

Information: The mean value followed by the same letter was not significantly different based on the DMRT test through the SPPS application ($P>0.05$)

In Table 6, the results showed that non-crosslinked biodegradable pots R5 (100% Banana stem) had the highest tensile strength compared to R1 (100% EFB) and crosslinked biodegradable pots (R2, R3, R4). Meanwhile, biopots R1 had the lowest tensile strength value. The composition of the raw material affects the tensile strength of the biodegradable pot, the increasing mass of banana stem fiber in the raw material indicates an increase in tensile strength. According to **Rao and Rao (2005)**, banana fiber is a natural fiber with a high tensile strength of up to 600 MPa, while oil palm fiber only reaches 377 MPa. Therefore, its use in large quantities can strengthen the tensile strength of biodegradable pots, it also explains the tendency of biodegradable pots R1 (100% OPEFB) to have the lowest tensile strength. Banana stem fiber has a stronger tensile strength based on the high cellulose content in the fiber. According to **Karimah et al. (2021)**, the cellulose content in natural fibers is positively correlated with tensile strength and Young's modulus. However, it was found a phenomenon of reduced tensile strength of biopots when the concentration of banana stems increased which was found in the combination of treatments from R2C1 to R3C1, R3C2 to R4C2 to R4C2, and R2C3 to R3C3. This was due to the uneven dispersion of the fibers which caused the formation of voids in the biopots, thereby weakening the load transfer. In a study by **Schettini et al., (2013)** on the process of making biodegradable pots from tomato and flax fiber, there is a tendency for tensile strength to be affected by fiber dispersion during the manufacturing process.

On the other hand, in the treatment of NaOH concentration, the tensile strength of the biodegradable pot increased along with the increase in NaOH concentration. This is related to the cellulose content obtained after the alkali treatment process. The tensile strength of the bopots increased from treatment C1 (3% NaOH) to treatment C3 (7% NaOH). These results indicate the highest cellulose content obtained, both in the treatment of non-crosslinked biodegradable pots and crosslinked biodegradable pots. However, these results were different from the water uptake and biodegradation tests which showed optimum delignification at a concentration of 5% NaOH. The phenomenon of the difference in the optimum NaOH concentration and the phenomenon of reduced tensile strength when the NaOH concentration increases in the treatment combination R1C1 becomes R1C2, and R3C2 to R3C3 can be affected by irregular fiber dispersion which causes the formation of voids in the biopots, thus affecting the fiber density in the biopots. According to **Herma et al. (2019)**, the density of composite fibers will weaken when more voids are formed in the composite. Fiber density is one of the physical properties of polymers that affect the mechanical properties **(Darni et al., 2018)**. The higher the fiber density, the better the mechanical properties of the composite. Based on this hypothesis, it can be assumed that the mechanical properties of biopots are not necessarily affected by the high content of cellulose in the fiber. Moreover, the phenomenon of irregular fiber dispersion showed poor uniformity of fiber density in the biopots, which significantly weakened the load transfer during the tensile test.

3.7 Best Treatment Formulation

The development of organic containers continues to focus on the proper use of biodegradable waste, increasing the strength of the material, and also increasing its biodegradability **(Juanga et al., 2021)**. Thus, the best treatment formulation in this study was obtained in the combination treatment R2C2 (80% OPEFB: 20% Banana stem; 5% NaOH) because the higher OPEFB content in the raw material was able to support the faster biodegradability of biopots, which was caused by the presence of silica content. Citing **Tomadoni et al., (2020)** the main thing to consider is that it is very important to offer faster biodegradation of planting biopots in the soil, this is to avoid accumulation and the occurrence of crop root circles, so it can increase the efficiency of water absorption when planting plants together with biopots.

On the other hand, the addition of banana stem fiber to the raw material can support the strength of the biopots, both in terms of tensile strength and resistance to water. However, it should be noted that the addition of excessive banana stem fiber should be avoided to prevent the formation of more cavities in the biopots which can cause low water resistance of the biopots. This plays an important role during the nursery process before the plant is ready to be transferred to the cultivated area. So that biodegradable containers or biopots become sustainable containers that can easily adapt to horticultural and folticultural production.

4. Conclusions

This study shows OPEFB fiber has the potential to be used, especially in the manufacture of biodegradable pots as an alternative to nursery containers, as well as the addition of banana stem fiber to raw materials, as well as increasing the concentration of NaOH can strengthen the physico-mechanical properties of biodegradable pots because the cellulose content in the fiber increases. It is known that the composition of raw materials affects the mass of the biodegradable pot, while the interaction between these two factors affects the value of water uptake, biodegradability and tensile strength. However, the water content of the biodegradable pot did not show a significant effect.

The quality analysis showed that the biodegradable pot had a height of 9 cm (± 0.3), an upper diameter of 8 cm (± 0.4), and an upper diameter of 5 cm (± 0.3), and an analysis of the physicomechanical properties showed that a biodegradable pot had a mass of about 9 cm. 58-18.48 grams, water content of 50.42%-65.89%, water uptake of 2.72%-4.82%, biodegradability of 40.54%-76.39%, and tensile strength of8091-23418 Pa. However, some improvement in fiber density in biodegradable pots is needed due to irregular fiber dispersion which is directly related to the quality of the biopots.

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6. Authors Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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