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Palm oil and cinnamon (anti-microbial agent) on the physicochemical, mechanical, and biodegradation properties of micrometer-sized cornstarch-based bioplastic

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Abstract

The purpose of this study was to determine the effect of the addition of palm oil and cinnamon on the physicochemical, mechanical, and biodegradation properties of cornstarch-based bioplastic. Experiments were done by adding cornstarch into water, glycerol, acetic acid, and cinnamon. Then, the mixed suspension was heated at 100ºC, added with palm oil (0.19; 0.30; 0.60; 0.90; 1.30; 1.90 %(v/v)), molded, and dried at room temperature without exposure to sunlight. To support the analysis, several characterizations (i.e. FTIR, digital microscope, puncture test, compressive test, and biodegradability test) were conducted. Based on puncture and compressive test, the bioplastic with an addition of 1.90 %(v/v) palm oil showed good mechanical properties. In general, the addition of palm oil increased the biodegradation rate. The palm oil contains double bonds in unsaturated fatty acids that can be distributed to the bioplastic matrix. Higher lipid content caused less moisture in the bioplastic so that the bioplastic was more brittle, inelastic, and degradable. However, the antimicrobial amount in the cinnamon reduced the biodegradability of bioplastic. This research provided new information on bioplastics as environmentally friendly plastic and alternative to conventional plastic.

***Keywords:** Bioplastic, Cornstarch, Palm oil, Cinnamon, Mechanical properties, Biodegradation, Education.*

1. Introduction

Bioplastic is an innovation of plastic that can significantly reduce environmental impacts in terms of greenhouse effects and energy consumption [1]. Bioplastic has a great role in sustainability, especially in consumption and production aspects [2]. Starch was a promising material for bioplastic due to its natural polymerization, abundant raw materials, and relatively cheap production cost [3]. In general, bioplastic relatively has a high moisture content, low resistance to drastic environmental temperature change, and some active bacteria/decaying microorganism compared to conventional plastic [4-5]. Thus, processes such as coating, mixing, adding nanoparticles/cellulose, and modifying chemical/physical structures were needed to overcome those limitations [6-7]. Recent studies found that adding other substrates such as zinc oxide [8], taro starch binder [9], cellulose acetate with triethyl citrate binder [10], calcium carbonate [11], cellulose binder (CNC) [12], and glycerol binder [13] could improve the quality of bioplastic. Another proposed alternative substrate that is low-cost and renewable is cinnamon. Cinnamon has antifungal and antibacterial properties, thus could improve bioplastic resistance to fungi and bacteria [14]. Furthermore, cinnamon has the effect of extending shelf life [15]. Palm oil also could be added to improve fiber content in bioplastic [13-16]. However, research on starch-based bioplastics and cinnamon with palm oil binders does not yet exist. Therefore, the purpose of this study was to investigate the effect of the amount of palm oil and cinnamon on physicochemical, mechanical, and biodegradation properties of micrometer-sized cornstarch-based bioplastic. The novelties of this research are the investigation of the effect of amounts of palm oil on on bioplastic characteristics and the use of cinnamon as an antifungal and antibacterial agent in bioplastic. This study was done by varying the palm oil amount (0.19; 0.30; 0.60; 0.90; 1.30; 1.90 %(v/v)) in bioplastic. Several analyses were conducted to analyze the prepared bioplastic characteristics. The physicochemical properties of bioplastic were evaluated by FTIR and digital microscope. The puncture and compressive test were used to evaluate the bioplastic's mechanical properties. Moreover, a biodegradability test was conducted by immersing the prepared bioplastic in water. The amount of palm oil could affect the biodegradability, physicochemical, and mechanical properties of bioplastic. The addition of cinnamon in bioplastic affected on the biodegradation rate. Palm oil contained double bonds in liquid unsaturated fatty acids and the lipid could be distributed to the bioplastic matrix. Higher lipid content caused less moisture content in the bioplastic, making it more brittle, inelastic, and degradable. This research provided new information on starch-based bioplastics as a solution to environmental problems caused by conventional plastic.

2. Materials and methods

2.1 Preparation bioplastic materials based on cornstarch, palm oil, and cinnamon

The raw materials for making bioplastic in this research were micron-sized cornstarch (purchased from PT Aneka Boga Nusantara, Karawang, Indonesia), acetic acid (25%), glycerol (95%), and aquades (purchased from Bratachem Subbranch, Tasikmalaya, Indonesia), palm oil (purchased from PT Salim Ivomas Pratama, Jakarta, Indonesia), and cinnamon (collected, Cianjur, Indonesia). Figure 1 shows the fabrication process of starch and cinnamon bioplastics with various palm oil amounts. The process of bioplastic fabrication was carried out through the following stages. In the early stage, cornstarch is mixed with glycerol (with a composition cornstarch/glycerol ratio of 1:1), acetic acid, aquadest, cinnamon, and palm oil (0.19; 0.30; 0.60; 0.90; 1.25; 1.90 %(v/v)). The mixture was heated (60°C) for 20-30 minutes until the product was homogenous and thick. Then, the mixture was molded into a petri dish and dried at room temperature for about a week until it dried.

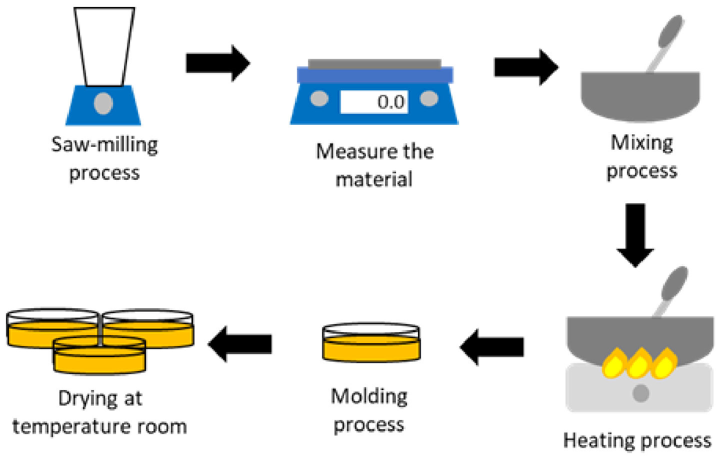

Figure 1. The fabrication process of starch and cinnamon bioplastics with various palm oil amount.ifferent phosphate particles size samples.

2.2 Physicochemical properties

To support the analysis, samples were characterized using a Fourier Transform Infrared (FTIR-4600, Jasco Corp., Japan). A Digital Microscope (BXAW-AX-BC), China also was used to analyze the morphology of the prepared samples.

2.3 Mechanical properties

To investigate the mechanical properties, the bioplastic was cut into 5 x 5 mm size. Compressive and puncture tests were performed to the sample. The compressive test used a screw stand test equipment (Mode I ALX-J China) equipped with a measuring instrument (Digital Force Gauge [Model HP-500, Serial No. H5001909262]). The puncture test was conducted using a Shore Durometer instrument (Shore A Hardness, In Size, China). A compressive test was performed by applying force on bioplastics. The test measured the hardness level of bioplastic, indicated by the curve's peak in Newton unit (N). The puncture test was done by puncturing a probe or needle into the bioplastic. The depth of the needle puncture was converted into numbers.

2.4 Biodegradability

Biodegradability test was done by cutting the prepared bioplastic into 1x1 cm size and immersing it in mineral water. Mass loss of samples was measured at intervals of 1, 2, 4, 6, 8, 10, and 14 days. During this test, changes on the bioplastic surface were observed daily, detecting the presence of fungi or other microorganisms.

3. Results and discussion

3.1 Physicochemical properties

The prepared bioplastics with an additional amount of palm oil and cinnamon are shown in Figure 2. Visually, the prepared bioplastic was brown due to the addition of cinnamon. Figure 2(a-f) indicates the impact of palm oil on bioplastics' appearance (corresponding to various amounts of palm oil (0.19; 0.30; 0.60; 0.90; 1.25; 1.90 %(v/v)), respectively). Bioplastic with palm oil has a yellow and transparent color compared to bioplastic without palm oil [13]. Bioplastic with a 1.90%(v/v) palm oil amount has a more homogeneous surface. Palm oil helped the gelatinization process and acted as a plasticizer.

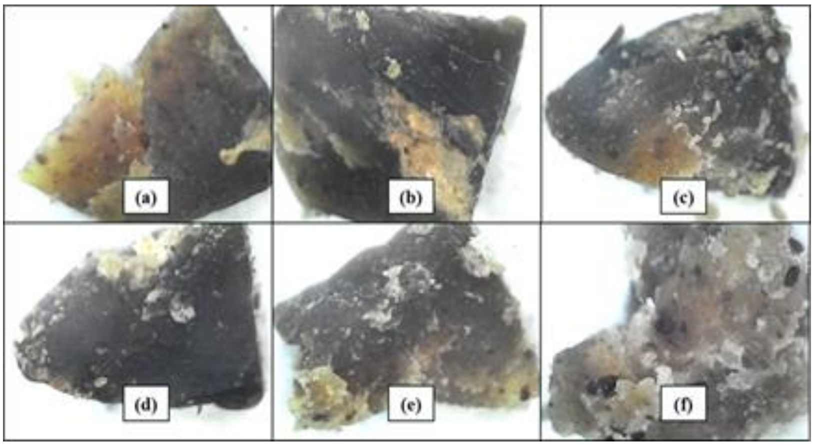

Figure 2. The photograph of bioplastics (a) 0.19; 0.30; 0.60; 0.90; 1.25; 1.90 %(v/v).

Figure 3 shows the FTIR analysis result of the as-prepared bioplastic, bioplastic immersed for 10 days and dried for 10 days, and bioplastic immersed for 20 days. All samples showed the characteristic of O-H stretching (3300-3500 cm^{-1}), C-H stretching (2800-3000 cm^{-1}), and lipid (1200-1800 cm^{-1}) [17-19]. The FTIR peaks for all bioplastic samples were similar but the intensities were different due to biodegradation during immersion. There was no complicated reaction during the biodegradation process, indicating only a simple dilution process of the bioplastic's surface components [20]. On the other hand, we observed that fungi started to grow on the bioplastic surface after immersion for 20 days. The fungi degraded the bioplastic (decreasing peak intensity) and transformed the chemical structure into fungal structure (2019-2034 cm^{-1}; see the dashed circle in Figure 3) [21].

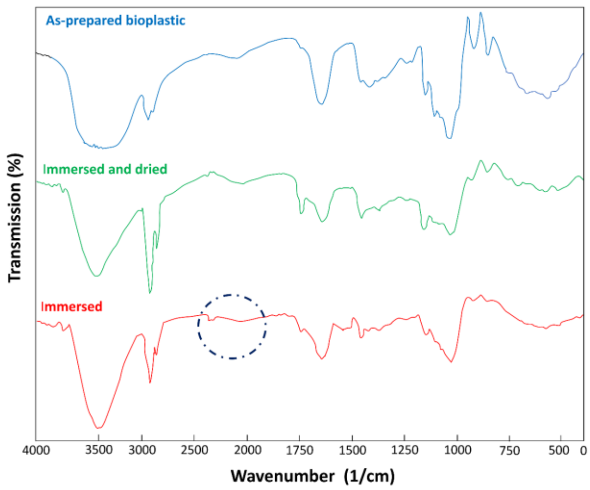

Figure 3. FTIR results of the as-prepared bioplastic, bioplastic immersed for 10 days and dried for 10 days, and bioplastic immersed for 20 days.

3.2 Mechanical properties

Table 1 showed the puncture test result of prepared bioplastic. Bioplastic with a 0.19 %(v/v) palm oil amount has the highest level of hardness (low average score) compared to other samples, making it harder to puncture. Bioplastic with an addition of 1.90 %(v/v) palm oil has the largest average score, indicating it was more brittle and easily punctured. These results were related to the elasticity of bioplastics. The addition of palm oil increased the lipid content in bioplastics. High lipid content in bioplastic caused less moisture and made it more brittle and inelastic [13].

Table 1. ***The puncture test of bioplastic based on cornstarch and cinnamon with the amount of palm oil 0.19; 0.30; 0.60; 0.90; 1.30; and 1.90 %(v/v)***

No.	**Amount of Palm Oil % (v/v)**					
	0.19	**0.30**	**0.60**	**0.90**	**1.30**	**1.90**
1	12.10	26.10	33.20	38.00	48.00	59.00
2	12.80	26.00	33.00	36.00	45.00	62.00
3	11.90	26.50	32.40	38.20	48.50	63.00
4	12.90	26.90	32.00	38.50	50.00	59.00
5	13.10	26.50	34.00	36.00	48.00	63.00
Average	12.56	26.40	32.92	37.34	47.90	61.20

The results of the compressive test are shown in Figure 4. Bioplastics with less oil content (0.19% (v/v)) showed the highest compressive test results while bioplastics with an oil content of 1.90% (v/v) showed the lowest compressive test results. The compressive test outcome indicated that the bioplastic was inelastic and brittle due to the higher palm oil content (confirmed by puncture test). Palm oil contained liquid unsaturated fatty acids. The double bond in liquid unsaturated fatty acids can be distributed to the bioplastic matrix [22]. The weak bond between fatty acids and bioplastic polymers formed inhomogeneous structure [23]. Inhomogeneous structure caused the bioplastic to be susceptible to compress and puncture force during the test.

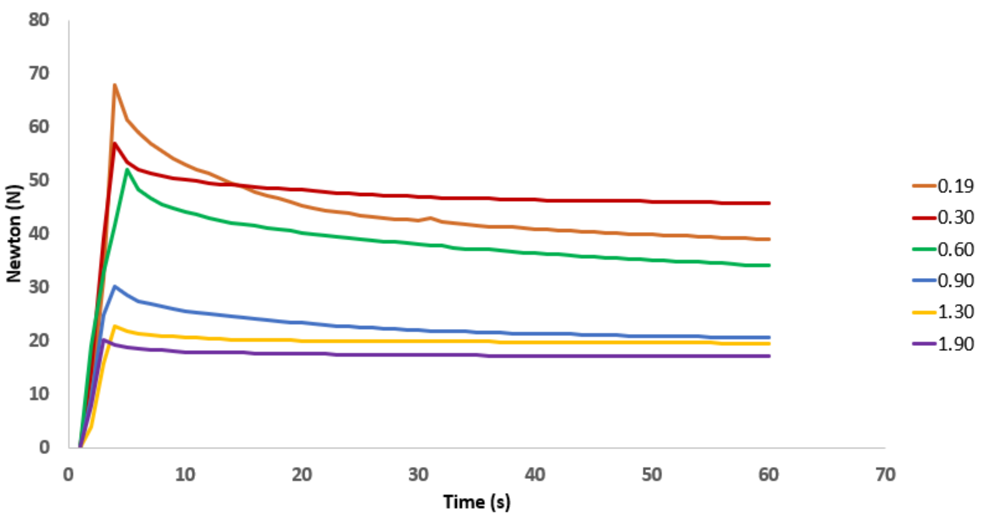

Figure 4. The compressive test of bioplastic based on cornstarch and cinnamon with the amount of palm oil 0.19; 0.30; 0.60; 0.90; 1.30; and 1.90 %(v/v).

3.3 Biodegradation

The biodegradation test was performed to find out the degradation rate by microorganisms in an environment. Water was used as the medium for the test. The data from the biodegradation test results is presented in Table 2. The results showed that all bioplastic samples suffered mass loss from the first day until the 14th day. This was most likely due to water erosion that occurred on the outer surface of the bioplastic (confirmed by the FTIR result). The prepared

briquette was biodegradable, suffering 51.71-75.00% mass loss during the test. Bioplastic with an addition of 0.90% (v/v) palm oil has the lowest weight loss value. The highest percentage of weight loss was shown by bioplastic with an addition of 1.30% (v/ v) palm oil. Starch and oil palm bioplastics were mainly interacting physically, producing defective and inhomogeneous mixtures. Consequently, higher palm oil in bioplastic causes the obtainment of fragile and inelastic structures. This affected the bioplastic weight loss in the biodegradation test. In contrast to cinnamon that can inhibit microorganism activity due to its antifungal and antibacterial properties [14], cornstarch-based bioplastics capable of making microorganisms that can easily break polymer chains in bioplastics [24]. As observed, the fungi began to appear on the bioplastic surface on the 8th day of immersion in water. The presence of palm oil caused the bioplastics to degrade more quickly [24] and inhibited the antimicrobial properties of cinnamon [14].

Table 2. ***Mass loss of bioplastic based on starch and cinnamon with amount of palm oil during biodegradation test***

Palm oil amount (%v/v)	Days	Initial Dimention (cm^2)	Initial Mass (g)	Mass After Immersion (g)	Mass Loss, (%wt)	Decay Dimension (g/cm^2)
0.19	1	5.410	1.405	0.550	61	0.158
	2	6.610	1.570	0.650	59	0.139
	4	5.390	1.180	0.430	63	0.139
	6	6.560	1.550	0.690	56	0.131
	8	5.810	1.195	0.400	67	0.139
	10	6.380	1.140	0.410	64	0.115
	14	5.600	1.345	0.250	82	0.198
0.30	1	5.740	1.080	0.455	56	0.106
	2	5.990	1.110	0.605	43	0.077
	4	4.480	0.810	0.330	56	0.102
	6	5.030	1.045	0.515	49	0.101
	8	5.570	1.045	0.385	59	0.110
	10	5.400	0.990	0.420	57	0.105
	14	6.590	1.430	0.260	82	0.180
0.60	1	6.960	1.505	0.525	67	0.146
	2	5.380	1.010	0.410	57	0.106
	4	6.190	1.235	0.400	61	0.124
	6	5.560	1.200	0.505	57	0.122
	8	5.810	1.195	0.400	80	0.164
	10	5.380	1.370	0.580	58	0.147
	14	4.580	0.970	0.020	99	0.204
0.90	1	5.980	1.190	0.580	50	0.099
	2	5.970	1.170	0.560	34	0.067
	4	4.530	0.925	0.465	60	0.122
	6	7.470	1.620	1.195	26	0.057

	8	5.450	0.910	0.455	50	0.087
	10	5.590	1.115	0.450	59	0.118
	14	6.710	1.645	0.275	83	0.203
1.30	1	3.980	0.695	0.195	74	0.130
	2	5.240	0.795	0.440	68	0.098
	4	4.470	0.605	0.145	74	0.101
	6	4.120	0.625	0.190	69	0.106
	8	4.060	0.710	0.265	63	0.111
	10	5.200	0.915	0.175	80	0.149
	14	3.690	0.505	0.015	97	0.132
1.90	1	5.800	1.310	0.480	56	0.126
	2	4.980	0.920	0.365	40	0.074
	4	6.410	1.230	0.605	52	0.099
	6	5.280	1.160	0.560	53	0.117
	8	5.270	1.010	0.340	66	0.128
	10	5.010	1.085	0.370	66	0.143
	14	6.160	1.090	0.025	98	0.171

4. Conclusion

The physicochemical, mechanical, biodegradation properties of starch and cinnamon-based bioplastics with an additional amount of palm oil have been evaluated. The addition of palm oil increased the biodegradation rate and decreased the antimicrobial effect of cinnamon. The growth of fungi on the bioplastic surface was observed on the 8th day of immersion in water. Levels of cracks in bioplastics are not affected by the amount of palm oil added. Bioplastic with a 1.30%(v/v) amount of palm oil has the best biodegradable properties (suffered 75% mass loss and has more fungi). Based on the puncture and compressive test, bioplastic with an additional 1.30%(v/v) of palm oil has the most elastic and sturdy structure. Generally, the addition of palm oil in prepared bioplastic was making the briquette more inelastic and brittle.

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