Journal of Engineering Science and Technology
Special Issue on IEC2022, November (2022) 228 - 238

BIOMASS COMPOSITION (CASSAVA STARCH AND BANANA (*MUSA SP.*) PEELS) ON MECHANICAL AND BIODEGRADABILITY PROPERTIES OF BIOPLASTICS FOR SUPPORTING SUSTAINABLE DEVELOPMENT GOALS (SDGs)

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Abstract

In the quest for a sustainable environment to assist sustainable development goals (SDGs) in developing countries, this study demonstrates the effect of the biomass composition (banana (Musa sp.) peels combined with cassava starch) on the mechanical properties and biodegradability of bioplastics. The fabrication of bioplastics was started by dissolving cassava starch and banana peels with a composition ratio of 15:1; 15:3; 15:5; and 15:7. To ensure the effect of banana peel biomass, the cassava starch content was kept constant. Then, we added glycerol and acetic acid to the mixture and heated it at 60˚C for 20 min to obtain a brown bioplastic solid. The results showed that bioplastics with a composition ratio of cassava starch and banana peels of 15:1 had the best mechanical and biodegradable properties, compared to other samples. The high cellulose content in banana peels made bioplastics brittle and rigid. This study shows the effectiveness of the composition of the biomass ratio as an alternative raw material in fabrication of bioplastics.

Keywords: Banana peels, Biodegradability, Composition ratio, Cassava starch, Mechanical properties, SDGs.

1. Introduction

The need for a sustainable environment to support sustainable development goals (SDGs) in developing countries is essential. One of the issues is plastic. Plastic is a material often used by humans because of its versatility and practicality. Plastics are made from oil-based polymers mixed with additives such as fillers, plasticizers, and lubricants that are difficult to decompose [1, 2]. Due to the wide variety of processes, recycling plastics is complex, and some of the recycled products available are generally of poor quality [3]. Plastic waste is usually disposed of by piling up in landfills which causes a high volume of plastic waste coupled with a slow rate of degradation (at least 100 years) [4]. Therefore, it is necessary to develop new materials that are innovative and environmentally friendly to reduce the negative impact of using plastics, namely bioplastics [4, 5].

Bioplastics are plastics made from natural materials that are environmentally friendly. Thus, they are easily decomposed by soil microorganisms [6, 7]. Natural materials that can be used in the production of bioplastics are derived from materials containing starch, vegetable oil, cellulose, lignin, protein, fruit waste, and lipids [7]. Starch is a material that is easily degraded into environmentally friendly compounds. In addition, starch-based bioplastics are easy to obtain and inexpensive. Therefore, many researchers are developing starch-based bioplastics (Table 1).

Table 1. Development of starch-based bioplastic fabrication.

Source of Starch	Raw Materials	Results	Ref.
Sweet potato	Sweet potato, distilled water, and glycerol	The evaluation of mechanical properties revealed that the bioplastic with the 3.5:1 (starch: glycerol) ratio had the highest tensile strength of 2.57 MPa and the lowest elongation of 6.27%. In addition, bioplastic with a ratio of 3.5:1 (starch: glycerol) was also presented, which showed the fastest enzymatic degradation and the highest microbial growth.	[13]
Sago	Sago, distilled water, ethanol, Sodium hydroxide, iodine, potassium iodide, glycerol	The feasibility of a sago-based bioplastic film has a tensile strength of 0.9 MPa, Young's modulus of 22 MPa, and an elongation at break of 13.6%, respectively.	[14]
Jackfruit seeds	Jackfruit seeds, acid citric, glycerol, baking soda, and distilled water	The manufactured bioplastic-based jackfruit seeds starch has less mechanical strength than plastics made from petroleum.	[15]
Wheat chaff	Wheat chaff, glycerol, distilled water, ammonium oxide, and sorbitol	High tensile strength and elongation values are possessed by bioplastics, with variations in starch and glycerol being 0.7 g and 1.45, respectively.	[16]
Mango kernel	Mango kernel, glycerol, and distilled water	Bioplastics with a mixture of 60-75% mango kernel starch and 10-15% glycerol increased the degradation rate.	[17]
Avocado peel	Avocado peel, glycerol, H_2SO_4, sodium	The mass variation of 2 g glycerol and 6 g starch gave the best bioplastic performance with a stress value of 1.53 MPa, 21.25% deformation, and a modulus of elasticity of 10.04 MPa, respectively.	[18]

Source of Starch	Raw Materials	Results	Ref.
Corn-starch	Corn-starch, polylactide,	The thermal stability of bioplastics decreases with higher corn starch content. In contrast, the bioplastic biodegradation properties are very good with high corn starch content	[19]
Durian seed	Durian seeds, ultrapure water, chitosan, acetic	The test results for the mechanical properties of bioplastics made from durian seeds were still far from the standard, namely Young's modulus of 4.1515 M and elongation of 2.1875%, and tensile strength of 0.1158 MPa.	[20]
Cassava starch	Cassava starch, glycerol, and	A starch content of 5% increased Young's modulus and tensile strength by 7.0 MPa and 132.1%, respectively.	[21]
Tamarind seed	Tamarind seed, ethanol, NaOH, and glycerol	Bioplastic with 3% starch variation has good tensile strength and biodegradability.	[22]

Although many researchers have succeeded in fabricating starch-based bioplastics, there are weaknesses when starch is used as a base material for making bioplastics, such as having high hydrophilicity, poor mechanical properties, high density, and not being robust against temperature changes [8]. Thus, a strategy is needed to overcome the disadvantages of starch-based bioplastics, including coating, combining, adding nanoparticles/cellulose, and chemical/physical structure modification [7, 9].

In this study, we used biomass from banana (*Musa sp.*) peels for the fabrication of bioplastics. Banana peel is an agricultural waste that is not widely used, straightforward to find, broadly available, and also cheap, making it discarded after the pulp is taken [10]. Using banana peels as a primary material in the fabrication of bioplastics can solve the issue as well as increased use-valuable waste. Banana peel contains 0.98% of starch, 40.74% of carbohydrates, 17.04% of cellulose, 0.9% of pectin, and 15.36% of lignin, which can be used as raw materials for the fabrication of bioplastics [11, 12]. Cassava starch is one of the best binders for being used in bioplastic production. Here, the purpose of this study was to evaluate the effect of biomass composition (i.e., banana peel) with cassava starch in the production of bioplastics on its mechanical and the biodegradation properties. This research is essential to provide a further understanding of the development of bioplastics, including knowing the composition ratio of the combined materials that can give good results of the mechanical properties of bioplastics.

2. Materials and Method

2.1. Production of bioplastic based on cassava starch and banana peel

In this study, several raw materials were used micron-size of cassava starch (purchased by PT Budi Starch and Sweetener, Jakarta, Indonesia), banana peels (obtained from the Geger Kalong Girang market, Bandung, Indonesia), 95% of glycerol (purchased from Sakura Medical). Stores, Bandung, Indonesia), 25% of acetic acid (purchased from Sakura Medical Stores, Bandung, Indonesia), and distilled water (purchased from Sakura Medical Stores, Bandung, Indonesia). Before we made bioplastics, banana peel powder were prepared by separating flesh banana from the peels, cleaning and washed it with pure water, cut into small pieces, and dried to remove water at 60°C using an electric oven under atmospheric pressure for 2 h. Finally, the dried banana peels were ground using a saw-milling process at a speed of 18,000 rpm for 5 min to obtain a brown banana peel powder. The saw-milling process was done using similar apparatus in our previous studies [23, 24].

Bioplastic was prepared by mixing cassava starch and banana peel powder with a composition ratio of 15:1, 15:3, 15:5, and 15:7. The amount of cassava starch was kept constant. Then, the mixture was added glycerol, acetic acid, and distilled water. The solution was stirred and heated for 20 min at 60 ˚C until thickened. Furthermore, the thickened bioplastic solution was moulded using a mold and dried at room temperature to obtain a brown bioplastic solid.

2.2. Physicochemical properties

The prepared bioplastics were analysed using a Digital Microscope (BXAW-AX-BC, China; to determine the surface structure and morphology of bioplastics) and Fourier Transform Infra-Red (FTIR) characterization on prepared bioplastics (FTIR-4600, Jasco Corp., Japan; to analyse the chemical composition).

2.3. Mechanical properties

In the mechanical analysis, the prepared bioplastic samples were cut into 1 × 1 × 1 cm size. The compression test instrument used a screw mount (Model I ALX-J, China) and a digital force meter (Model HP-500, Serial Number H5001909262). Compression tests were carried out by applying a force to the bioplastic. A compressive and stress–strain curve was produced to describe the texture profile of the simultaneous recording of the compressive force. The compressive strength was then determined based on the peak of the curve. In addition, the maximum amount of force (measured in MPa) applied was used to determine the hardness of the sample. The puncture test was carried out using a shore durometer (Shore A Hardness, In Size, China). The puncture test was carried out by inserting a 1 mm diameter needle into the bioplastic, and the results were converted into scale numbers from 0 to 100.

2.4. Biodegradability test

The biodegradability test was conducted by cutting the prepared bioplastics to a size of 0.7 × 0.7 × 0.7 cm and then immersed in pure water. Bioplastic samples were taken and dried, and then the weight loss of bioplastic was calculated every time (with interval of 1 day to 2 weeks). The level of bioplastic degradation is expressed in terms of the percentage of weight loss bioplastic.

3. Results and Discussion

3.1. Physicochemical properties of bioplastic based on cassava starch and banana peel

The bioplastics prepared from banana peels and cassava starch exhibited brown colour (Fig. 1). Figure 1 depicts photograph images of bioplastic from cassava starch and banana peel. Figs. 1(a)-(d) clearly shows a difference in colour intensity due to the composition of cassava starch and banana peel. The greater composition of banana peel resulted in the browner colour of the bioplastic. In addition, as shown in Fig. 1(a)-(d), there is cracking due to the addition of banana peels.

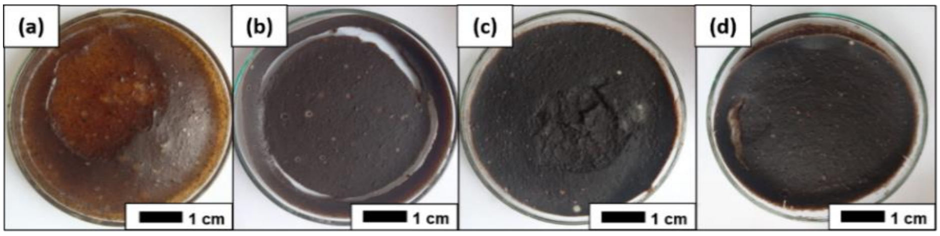

Fig. 1. Photograph images of bioplastic samples prepared made from cassava starch and banana peels with composition ratio (a) 15:1, (b) 15:3, (c) 15:5, and (d) 15:7.

Figure 2 shows the microscopy of surface analysis of bioplastics made from cassava starch and banana peels. Figures 2 (a-d) depict a heterogeneous and agglomerated bioplastic surface. The large composition of banana peel causes the bioplastic to become brittle. It was found that there was swelling of the bioplastic immersed in water without a colour change (see Fig. 2(e)). Figure 2 (f) is the appearance of fungi growing on the surface of the bioplastic after being left for 2 weeks at room conditions. The surface of the bioplastic, which was initially brown, mainly was covered by a yellow fungus. The main idea for the appearance of yellow fungus is possibly due to the interference and penetration of yellow fungus in the air into the water.

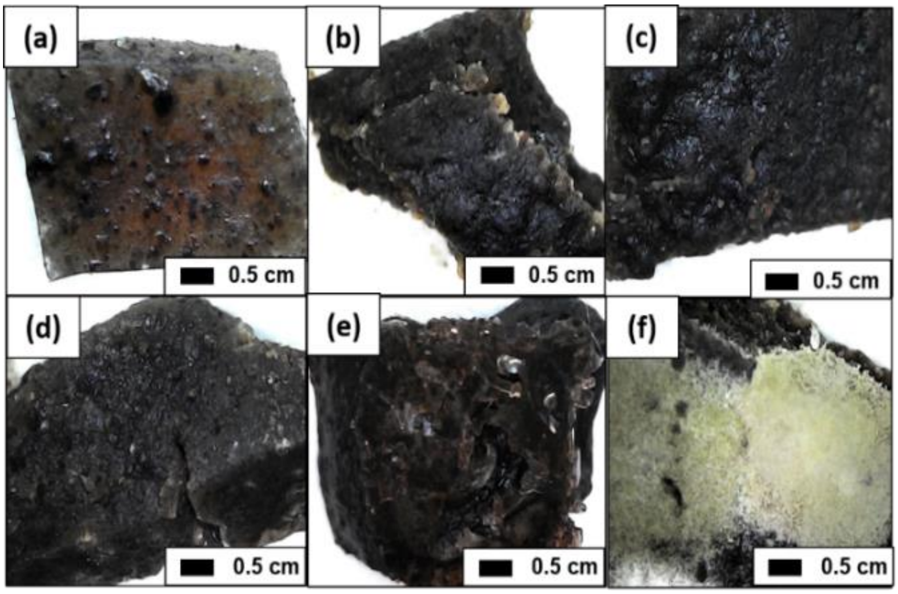

Fig. 2. (a)-(d) Microscopic results of bioplastic samples made from cassava starch and banana peels with composition ratio (a) 15:1, (b) 15:3, (c) 15:5, and (d) 15:7); (e) bioplastic surface with fungus for 2 weeks.

The FTIR bioplastics (shown in Fig. 3) showed 3 different spectra. The first blue spectrum is the spectrum of bioplastics made from cassava starch and banana peels. The second spectrum, which is orange, is the spectrum of bioplastics immersed in water for 7 days, and the third spectrum, which is green, is the spectrum of bioplastics with fungal surfaces. Based on Fig. 3, the first and second spectra have identical functional group characteristics, namely O-H stretching (3300-3500cm^{-1}), C-H stretching vibration (2850-3000 cm^{-1}), C=C (2300-2500 cm^{-1}), C=O (1630-1740 cm^{-1}), stretching C-O (1000–1200 cm^{-1}) [25-28]. There was no drastic change in the spectrum between the first and second spectra, indicating that there was no change in the structure during immersion in water. Soaking using water as a solvent only dissolves the bioplastic components. Findings are similar to research conducted other report [29] who reported the similarity observed in the FTIR spectra of bioplastics made by immersion in water because starch and water have the same functional group, namely polyols. On the other hand, the third spectrum shows a decrease in peak intensity which indicates a change in chemical structure due to bioplastic degradation (at a wavelength of 2110-2138 cm^{-1}; see red dot circle in Fig. 3) [30, 31]. In addition the appearance of C=C after 2-week immersion is due to the existence of fungi.

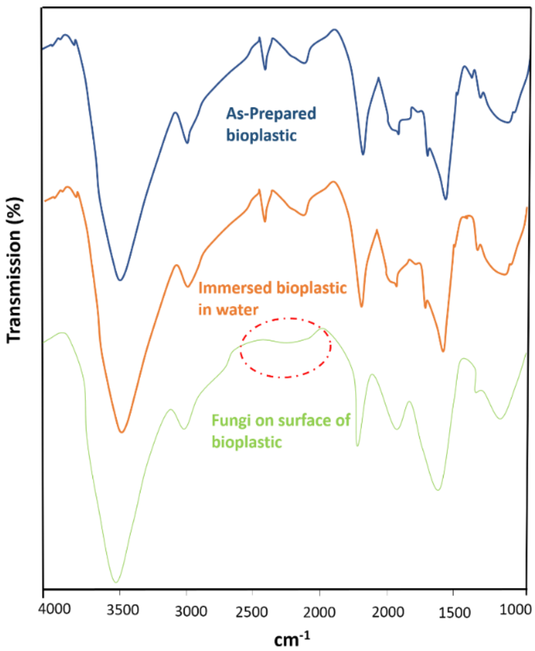

Fig. 3. FTIR results of bioplastics made from cassava starch and banana peel, bioplastic immersed in water for 7 days, and bioplastic surface with fungus for 2 weeks

3.2. Mechanical properties of bioplastic based on cassava starch and banana peel

Figure 4 shows the compressive test results of bioplastics made from cassava starch and banana peels. The highest compressive test results were obtained from bioplastics with a composition ratio of cassava starch and banana peels of 15:1. In contrast, the lowest compressive test results were obtained with a composition ratio of cassava starch and banana peels of 15:1. Based on the compression test results, bioplastics with a higher banana peel composition are stiff, inhomogeneous and brittle. In addition, the lack of bioplastics homogeneity will weaken the interfacial bond between the fiber surface and the matrix and potentially reduce the mechanical properties of bioplastics [32].

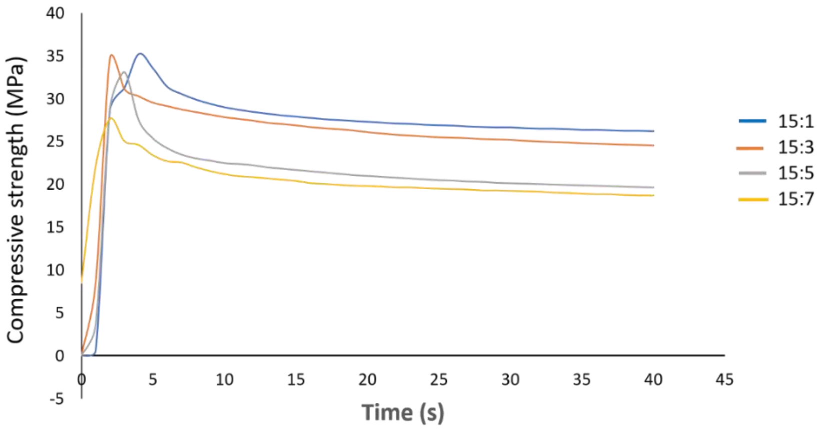

Fig. 4. The compression test of bioplastic made from cassava starch and banana peel with a composition ratio of 15:1; 15:3; 15:5; 15:7.

Table 2 is the result of the puncture test of bioplastics made from cassava starch and banana peels. A puncture test was performed to confirm the compressive test. The test puncture was carried out seven times to produce more accurate results. The results of the puncture test show that when the material has a high level of hardness, a lower value is obtained. Based on the results of the puncture test presented in Table 2, the bioplastic sample with a composition ratio of 15:1 cassava starch and banana peel had the highest hardness (low average score) compared to other samples, indicating that the sample was difficult to pierce. The results of the puncture test obtained were following the results of the compression test (see Fig. 4), which revealed that the order of the brake linings with the highest hardness was obtained sequentially with the composition ratio of cassava starch to banana peels, namely 15 :1, 15:3, 15:5, and 15:7 (see Table 2). This is related to the elasticity of bioplastics which is affected by the addition of banana peels. The composition of banana peels in large quantities causes bioplastics to become brittle and stiff. Moreover, banana peels contain cellulose, which is dry, hard, and easily brittle [33]. In addition, as discussed in the introduction, bioplastics can be used as an alternative for common plastics. However, additional techniques must be added since the present mechanical results are still lower.

Table 2. The puncture test of bioplastic based on cassava starch and banana peels with a composition ratio of 15:1; 15:3; 15:5; and 15:7.

Testing number	**Ratio composition cassava starch and banana peels**			
	15:1	**15:3**	**15:5**	**15:7**
1	20.00	29.00	42.00	56.00
2	20.00	30.00	43.00	58.00
3	22.00	34.00	45.00	59.00
4	25.00	35.00	44.00	64.00
5	28.00	38.00	46.00	65.00
6	26.00	39.00	47.00	67.00
7	27.00	37.00	48.00	68.00
Average	**24.00**	**34.57**	**45.00**	**62.42**

3.3. Biodegradation of bioplastic based on cassava starch and banana peels

Table 3 is the result of testing the level of bioplastic biodegradation. The test was carried out by immersion method with water as the test medium. The test results showed that the highest percentage of weight loss for bioplastics within 2 weeks was bioplastics with a composition ratio of cassava starch and banana peels of 15:1, namely 89%. The reduction in bioplastic weight is likely to occur within 2 weeks because the dilution on the bioplastic surface in water is confirmed by an identical FTIR pattern (see Fig. 3). Apart from that, bioplastics also decrease in mass, followed by the appearance of fungi (see Fig, 2((e)), which indicates bioplastics' decomposition by microbes [34]. This study also shows that the smaller the amount of banana peel composition, the better the rate of degradation of bioplastics. This is influenced by the strength of molecular hydrogen bonds between starch and cellulose (which is contained in banana peels). The high content of banana peels (which contain cellulose) in bioplastics tends to cause the starch-banana peel polymer bonds to become stronger, making bioplastics more challenging to decompose [35].

Table 3. Weight loss bioplastic with cassava starch and banana peels with a composition ratio of 15:1; 15:3; 15:5; and 15:7 during the biodegradation test.

Ratio composition cassava starch and banana peels	Days	Initial Dimensions (cm^2)	Initial Mass (g)	Mass after immersion (g)	Mass loss (%wt)	Decay dimension (g/cm^2)
15:1	1	1.68	0.13	0.10	26	0.02
	2	1.58	0.16	0.10	38	0.03
	7	1.26	0.13	0.07	42	0.04
	10	1.28	0.13	0.05	62	0.06
	12	1.31	0.15	0.03	80	0.09
	14	1.20	0.14	0.015	89	0.10
15:3	1	1.85	0.14	0.11	24	0.01
	2	1.36	0.14	0.09	33	0.03
	7	1.00	0.15	0.09	35	0.06
	10	1.20	0.13	0.07	42	0.04
	12	0.98	0.15	0.03	76	0.11
	14	1.08	0.14	0.03	80	0.11
15:5	1	1.18	0.15	0.08	22	0.02
	2	1.62	0.13	0.09	30	0.02
	7	1.34	0.14	0.08	41	0.04
	10	1.19	0.17	0.08	49	0.07
	12	1.31	0.13	0.07	62	0.06
	14	1.19	0.15	0.04	70	0.09
15:7	1	1.46	0.15	0.13	16	0.01
	2	1.29	0.12	0.11	24	0.02
	7	1.58	0.16	0.11	31	0.03
	10	1.42	0.17	0.09	44	0.05
	12	1.32	0.15	0.07	50	0.06
	14	1.38	0.16	0.05	66	0.07

4. Conclusion

The analysis results showed that adding banana peels affected the rate of degradation and mechanical properties of bioplastics. Bioplastic with a composition ratio of 15:1 cassava starch and banana peel had the best biodegradation rate with a mass loss of 89% for 2 weeks, which was indicated by fungal growth. Based on the puncture and compression test, the bioplastic with a ratio of 15:1 cassava starch and banana peel composition had more elastic and sturdy structure properties than the other samples. This is because banana peels contain cellulose, which is dry, hard, and easily brittle. The large quantity of banana peel ratio composition causes brittle and stiff bioplastics.

References

1. Briassoulis, D.; Tserotas, P.; and Athanasoulia, I.G. (2021). Alternative optimization routes for improving the performance of poly (3-hydroxybutyrate) (PHP) based plastics. *Journal of Cleaner Production*, 318, 128555.
2. Mariana, M.; Alfatah, T.; HPS, A.K.; Yahya, E.B.; Olaiya, N.G.; Nuryawan, A.; and Ismail, H. (2021). A current advancement on the role of lignin as sustainable reinforcement material in biopolymeric blends. *Journal of Materials Research and Technology*, 15, 2287-2316.
3. Faraca, G.; and Astrup, T. (2019). Plastic waste from recycling centres: characterisation and evaluation of plastic recyclability. *Waste Management*, 95, 388-398.
4. Nandiyanto, A.B.D.; Fiandini, M.; Ragadhita, R.; Sukmafitri, A.; Salam, H.; and Triawan, F. (2020). Mechanical and biodegradation properties of cornstarch-based bioplastic material. *Materials Physics and Mechanics*, 44(3), 380-390.
5. Atiwesh, G.; Mikhael, A.; Parrish, C.C.; Banoub, J.; and Le, T.A.T. (2021). Environmental impact of bioplastic use: A review. *Heliyon*, 7(9), e07918..
6. Triawan, F.; Nandiyanto, A.B.D.; Suryani, I.O.; Fiandini, M.; and Budiman, B.A. (2020). The influence of turmeric microparticles amount on the mechanical and biodegradation properties of cornstarch-based bioplastic material: From bioplastic literature review to experiments. *Materials Physics and Mechanics*, 46(1), 99-114.
7. Anggraeni, S.; Nandiyanto, A.B.D.; Nurjami, A.M.; Hofifah, S.N.; Putri, S.R.; Girsang, G.C.; and Fiandini, M. (2021). Palm oil and cinnamon (anti-microbial agent) on the physicochemical, mechanical, and biodegradation properties of micrometer-sized cornstarch-based bioplastic. *Moroccan Journal of Chemistry*, 9(3), 9-3.
8. Nandiyanto, A.B.D.; Triawan, F.; Fiandini, M.; Suryani, I.O.; and Sunnardianto, G.K. (2021). Influence of the size of turmeric microparticles reinforcing agent on mechanical and biodegradation properties of cornstarch-based bioplastic material: Current studies, experimental results, and proposal material crack phenomena during mechanical testing. *Materials Physics and Mechanics*, 47(2), 266-284.
9. Liyanage, S.; Acharya, S.; Parajuli, P.; Shamshina, J.L.; and Abidi, N. (2021). Production and surface modification of cellulose bioproducts. *Polymers*, 13(19), 3433.
10. Silva, V.D.; Arquelau, P.B.; Silva, M.R.; Augusti, R., Melo, J.O.; and Fante, C. A. (2020). Use of paper spray-mass spectrometry to determine the chemical profile of ripe banana peel flour and evaluation of its physicochemical and antioxidant properties. *Química Nova*, 43(5), 579-585.

11. Alam, M. N.; and Illing, I. (2019). Pembuatan bioplastik berbahan dasar pati kulit pisang kepok/selulosa serbuk kayu gergajI. *Cokroaminoto Journal of Chemical Science*, 1(1), 14-19.
12. Hassan, H.F.; Hassan, U.F.; Usher, O.A.; Ibrahim, A.B.; and Tabe, N.N. (2018). Exploring the potentials of banana (musa sapietum) peels in feed formulation. *International Journal of Advanced Research in Chemical Science*, 5(5), 10-14.
13. Abdullah, A.H.D.; Sri, P.; Myrtha, K.; Oceu, D.P.; and Rani, H.F. (2018). Fabrication and characterization of sweet potato starch-based bioplastics plasticized with glycerol. *Journal of Biological Sciences*, 19(1), 57-64.
14. Tan, S.X.; Andriyana, A.; Lim, S.; Ong, H.C.; Pang, Y.L.; and Ngoh, G.C. (2021). Rapid ultrasound-assisted starch extraction from sago pith waste (SPW) for the fabrication of sustainable bioplastic film. *Polymers*, 13(24), 4398.
15. Nguyen, T.K.; That, N.T.T.; Nguyen, N.T.; and Nguyen, H.T. (2022). Development of Starch-Based Bioplastic from Jackfruit Seed. *Advances in Polymer Technology*, 2022 (special issue), 1-9.
16. Nain, N.; Kumar, K.G.; Sharma, R., Lakshmi, M.A.; Singh, A.; and Sharma, S.G. (2019). Synthesis of bioplastic from wheat chaff. *Think India Journal*, 22(17), 4227-4238.
17. Hamidon, N.; Zamre, N.A.F.; Sunar, N.M.; and Hamid, H.A. (2019). A Study of biodegradable plastic utensils from mango kernel. *Journal of Applied Chemistry and Natural Resources*, 1(1), 1-4.
18. Sánchez, H.; Ponce, W.; Brito, B.; Viera, W.; Baquerizo, R.; and Riera, M.A. (2021). Biofilms production from avocado waste. *Ingenieria y Universidad*, 25, 1-16.
19. Zoungranan, Y.; Lynda, E.; Dobi-Brice, K.K.; Tchirioua, E.; Bakary, C.; and Yannick, D.D. (2020). Influence of natural factors on the biodegradation of simple and composite bioplastics based on cassava starch and corn starch. *Journal of Environmental Chemical Engineering*, 8(5), 104396.
20. Arini, D.; Ulum, M.S.; and Kasman, K. (2017). Pembuatan dan pengujian sifat mekanik plastik biodegradable berbasis tepung biji durian. *Natural Science: Journal of Science and Technology*, 6(3), 276 – 283.
21. Alves, V. D.; Mali, S.; Beléia, A.; and Grossmann, M.V.E. (2007). Effect of glycerol and amylose enrichment on cassava starch film properties. *Journal of Food Engineering*, 78(3), 941-946.
22. Sudharsan, K.; Mohan, C.C.; Babu, P.A.S.; Archana, G.; Sabina, K.; Sivarajan, M.; and Sukumar, M. (2016). Production and characterization of cellulose reinforced starch (CRT) films. *International Journal of Biological Macromolecule*s, 83, 385-395.
23. Nandiyanto, A.B.D.; Andika, R.; Aziz, M.; and Riza, L.S. (2018). Working volume and milling time on the product size/morphology, product yield, and electricity consumption in the ball-milling process of organic material. *Indonesian Journal of Science and Technology*, 3(2), 82-94.
24. Nandiyanto, A.B.D.; Zaen, R.; and Oktiani, R. (2018). Working volume in high-energy ball-milling process on breakage characteristics and adsorption performance of rice straw ash. *Arabian Journal for Science and Engineering*, 43, 6057-6066.

25. Nandiyanto, A.B.D.; Oktiani, R.; and Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. I*ndonesian Journal of Science and Technology*, 4(1), 97-118.
26. Nandiyanto, A.B.D.; Ragadhita, R.; and Fiandini, M. Interpretation of Fourier Transform Infrared Spectra (FTIR): A Practical Approach in the Polymer/Plastic Thermal Decomposition. *Indonesian Journal of Science and Technology*, 8(1), 113-126.
27. Sultan, N.F.K.; and Johari, W.L.W. (2017). The development of banana peel/corn starch bioplastic film: A preliminary study. *Bioremediation Science and Technology Research*, 5(1), 12-17.
28. Ab Razak, S.N.; Yahaya, N.A.; Rohmadi, R.N.A.; and Nordin, N.S. (2020). Biodegradable banana peels-based plastic–a review. *Multidisciplinary Applied Research and Innovation*, 1(1), 38-44.
29. Ambrosio, G.; Faglia, G.; Tagliabue, S.; and Baratto, C. (2021). Study of the degradation of biobased plastic after stress tests in water. *Coatings*, 11(11), 1330.
30. Abotbina, W.; Sapuan, S. M.; Sultan, M.T.H.; Alkbir, M.F.M.; and Ilyas, R.A. (2021). Development and characterization of cornstarch-based bioplastics packaging film using a combination of different plasticizers. P*olymers*, 13(20), 3487.
31. Merino, D.; Simonutti, R.; Perotto, G.; and Athanassiou, A. (2021). Direct transformation of industrial vegetable waste into bioplastic composites intended for agricultural mulch films. *Green Chemistry*, 23(16), 5956-5971.
32. Anugrahwidya, R.; Armynah, B.; and Tahir, D. (2021). Bioplastics starch-based with additional fiber and nanoparticle: Characteristics and biodegradation performance: A review. *Journal of Polymers and the Environment*, 29(11), 3459-3476.
33. Singh, S.; and Mohanty, A.K. (2007). Wood fiber reinforced bacterial bioplastic composites: Fabrication and performance evaluation. *Composites Science and Technology*, 67(9), 1753-1763.
34. Acquavia, M.A.; Pascale, R.; Martelli, G.; Bondoni, M.; and Bianco, G. (2021). Natural polymeric materials: A solution to plastic pollution from the agro-food sector. *Polymers*, 13(1), 158.
35. Li, S.; Ma, Y.; Ji, T.; Sameen, D.E.; Ahmed, S.; Qin, W.; and Liu, Y. (2020). Cassava starch/carboxymethylcellulose edible films embedded with lactic acid bacteria to extend the shelf life of banana. *Carbohydrate Polymers*, 248, 116805.