International Journal of Applied Science and Engineering Review

IJASER

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 51-62

To cite this article: Nur Rokhati, Aji Prasetyaningrum, Asep Muhamad Samsudin, Fakhri Santo Khoirudin, Umi Widi Astuti and Widyah Anggraini (2024). SYNTHESIS AND CHARACTERIZATION OF BIOPLASTICS FROM CORN-STALK FIBER AND CHITOSAN, International Journal of Applied Science and Engineering Review (IJASER) 5 (2): 51-62 Article No. 184 Sub Id 279

SYNTHESIS AND CHARACTERIZATION OF BIOPLASTICS FROM CORN-STALK FIBER AND CHITOSAN

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DOI: https://doi.org/10.52267/IJASER.2024.5204

ABSTRACT

The plastics used by the public are generally made of petrochemicals which take a long time to degrade completely. One of the solutions to overcome the problem of plastic waste is to make produce bioplastics. Bioplastics are made from renewable natural materials and are environmentally friendly. One of the materials that can be made into bioplastic is chitosan. Chitosan has been widely used in the packaging industry, especially in food packaging, because of its biocompatibility, biodegradability, and non-toxicity. However, the relatively high price of chitosan will limit the use of chitosan film in various applications. In this study, bioplastics were made from chitosan and cellulose. Cellulose was obtained from the corn-stalks waste extract. The results showed that the glycerol addition increases the swelling degree, decreases the tensile strength, increases the elongation break, and accelerates the degradation of bioplastics. The optimum conditions for producing bioplastics were obtained by 1% glycerol addition, cellulose: chitosan ratio of 25:75, and 1% glutaraldehyde addition.

KEYWORDS: Bioplastics, Chitosan, Cellulose, Corn-stalk

1. INTRODUCTION

The production of plastic materials in Indonesia reached 7.23 million tons in 2018, with a growth rate of about 5% per year. In 2019, plastic waste reached 9.52 million tons [18]. Plastics circulating in the community are generally made from petrochemicals that have a prolonged biodegradation rate and take a

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long time to degrade completely. If this is allowed to continue, this will cause environmental pollution problems. Usually, handling plastic waste is only disposal, landfill, burning, or recycling. Carbon emissions from combustion can be a new source of environmental pollution [1].

One of the solutions to overcome the problem of plastic waste is to make bioplastics. Bioplastics are made from renewable natural materials and have environmentally friendly properties. Chitosan is a natural polysaccharide that can be obtained from the deacetylation of chitin in the shells of invertebrate animals. Chitosan is widely used in the packaging industry, especially in food packaging, due to its biocompatibility, biodegradability, and non-toxicity. Chitosan has a cationic (amine) group and an anionic (hydroxyl) group resulting in a good film with high strength [19]. In addition, chitosan also has a hydrophobic acetyl group that makes bioplastics more resistant to water. However, the price of chitosan is relatively high. This challenge will limit the use of chitosan film in various applications [15]. Therefore, additional materials are needed to produce chitosan bioplastics.

Cellulose is a natural polymer with biodegradable properties and can decompose up to 67% within 2-3 weeks [5]. Cellulose is found in many agricultural wastes, including corn stalk waste [25]. Corn stalks have renewable properties, biodegradability, and abundant availability [26]. Corn stems contain 42.6% cellulose, 21.3% hemicellulose, and 8.2% lignin. With the high content of cellulose, which is more than 40%, corn stalks can potentially become bioplastic raw materials.

The research aims to make bioplastics based on chitosan and cellulose from corn stalks. Corn stalks were chosen because they contain large amounts of cellulose. The effect of glycerol addition and crosslinking agent of glutaraldehyde on the characteristics of bioplastic products was investigated.

2. MATERIALS DAN METHODS

2.1 Materials

Corn-stalk was obtained from Kebumen, Indonesia. Chitosan (deacetylation degree of 85.78%) was purchased from Biotech Surindo, Cirebon, Indonesia. Sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), sulfuric acid (H_2SO_4), acetic acid (CH_3COOH), glycerol, and glutaraldehyde were purchased from Merck, Germany. Aquadest was produced by a homemade integrated membrane unit (conductivity 1.7 μΩ/cm).

2.2 Pretreatment of Corn-stalk fiber

Corn stalks were cut into ±5 cm and dried in direct sunlight. The dried corn stalks were crushed with a blender, sieved using a 60-mesh sieve, and then dried again. The crushed corn stalks were suspended in NaOH 25% (w/v) solution at 100^{o}C for 1 hour. The residues were collected and washed extensively with

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water until pH neutral and dried at 65°C. The results showed that the cellulose content of corn stalks was 47.706%.

2.3 Bioplastics synthesis

Bioplastic synthesis was done by mixing corn stalk fiber with chitosan with various mass ratios (w/w). The mixture was dissolved in 1% acetic acid solution at a concentration of 3% (w/v). The mixture solution was heated at a constant temperature of 70°C and stirred at 700 rpm for 30 minutes. Glutaraldehyde was then added to the mixture and stirred for 60 minutes. The mixed solution was left for 24 hours to remove air bubbles. Subsequently, the solution was poured into the mold and soaked in 2% NaOH solution at room temperature for 24 hours. The bioplastic was removed from the mold and dried in ambient conditions.

2.4 Characterization of Bioplastic

- Swelling degree

The dried bioplastic was weighed and then immersed in water for 8 hours. The wet bioplastic was carefully wiped with a tissue to remove excess water and then weighed again. The swelling degree was determined by Eq. (1)

$$SD = \frac{w_2 - w_1}{w_1} X100\% \qquad (1)$$

where w_1 and w_2 are the bioplastic weight before and after water immersion

- Mechanical properties

In order to evaluate the mechanical properties of the bioplastic, tensile strength and elongation at break of the bioplastics were determined. The tests were carried out with the Ta Plus Texture Analyzer.

- Biodegradation test

The dried bioplastic was weighed and then buried in the ground for seven days. After the periods of stockpiling, the weight of decomposed bioplastic was measured. The biodegradability of bioplastic was determined by calculating the difference between weight before and after being buried and then divided by initial weight [11].

- Functional groups

The primary functional groups of the bioplastics were investigated using Fourier Transform Infrared (FTIR) (Shimadzu IR Prestige-21). In this analysis, the spectra of bioplastics have been compared.

3 RESULT AND DISCUSSION

3.1 Effect of Glycerol Addition on Bioplastic Characteristics

Biodegradable films made from cellulose fibers are suitable. Additional plasticizers should be introduced to increase the film's elasticity. Plasticizers are commonly used to enhance the flexibility and stretchability of cellulose substrates [14, 24]. In this study, glycerol was used as a plasticizer.

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The swelling degree was evaluated by measuring the change in the weight of the bioplastic in the aquadest. The results are shown in Fig 1(A). The addition of glycerol can increase the swelling degree of the bioplastic. These results imply that adding glycerol enhances the bioplastics hydrophilicity. Glycerol has three hydroxyls, which are hydrophilic and hygroscopic; therefore, it easily absorbs water [27]. Bioplastics are said to be good when they have water-resistant properties. The decreasing swelling degree value indicates that bioplastics have lower heritability (ability to absorb water). Therefore, a low swelling degree of bioplastics is desirable [32].

The tensile strength test aims to determine the maximum stress a material can withstand before breaking. From Fig. 1(B), it can be seen that with the increase in the glycerol concentration added, the bioplastic's tensile strength value decreases. Increasing the glycerol concentration leads to a decrease in tensile strength because it reduces intermolecular interactions by allowing more shear chains and increasing the elongation of the bioplastic. Increasing glycerol concentration resulted in a significant reduction in tensile strength [4]. The hygroscopic nature of glycerol contributes more to the plasticizing effect than other plasticizers, thus increasing the mobility of the polymer chains and increasing the flexibility of bioplastics [9].

The elongation test determines the maximum change in bioplastic length before breaking (plastic elasticity). The elongation test was carried out by comparing the increase in length before and after the tensile test was taken. The effect of the glycerol addition on the elongation break value presented in Fig. 1(C). The addition of glycerol at low concentrations can increase elongation at breaks. However, the elongation at break value decreases at a concentration of glycerol addition above 1%. The glycerol addition can break hydrogen bonds in adjacent polymer molecules, increasing the intermolecular distance [28]. As a result, the stiffness of the polymer molecular chains will decrease, and the flexibility of bioplastics will increase [16]. However, if the addition of the glycerol concentration exceeds the saturation value, the glycerol will be in its phase outside the cellulose-chitosan phase. This condition causes the elongation break value to decrease [6].

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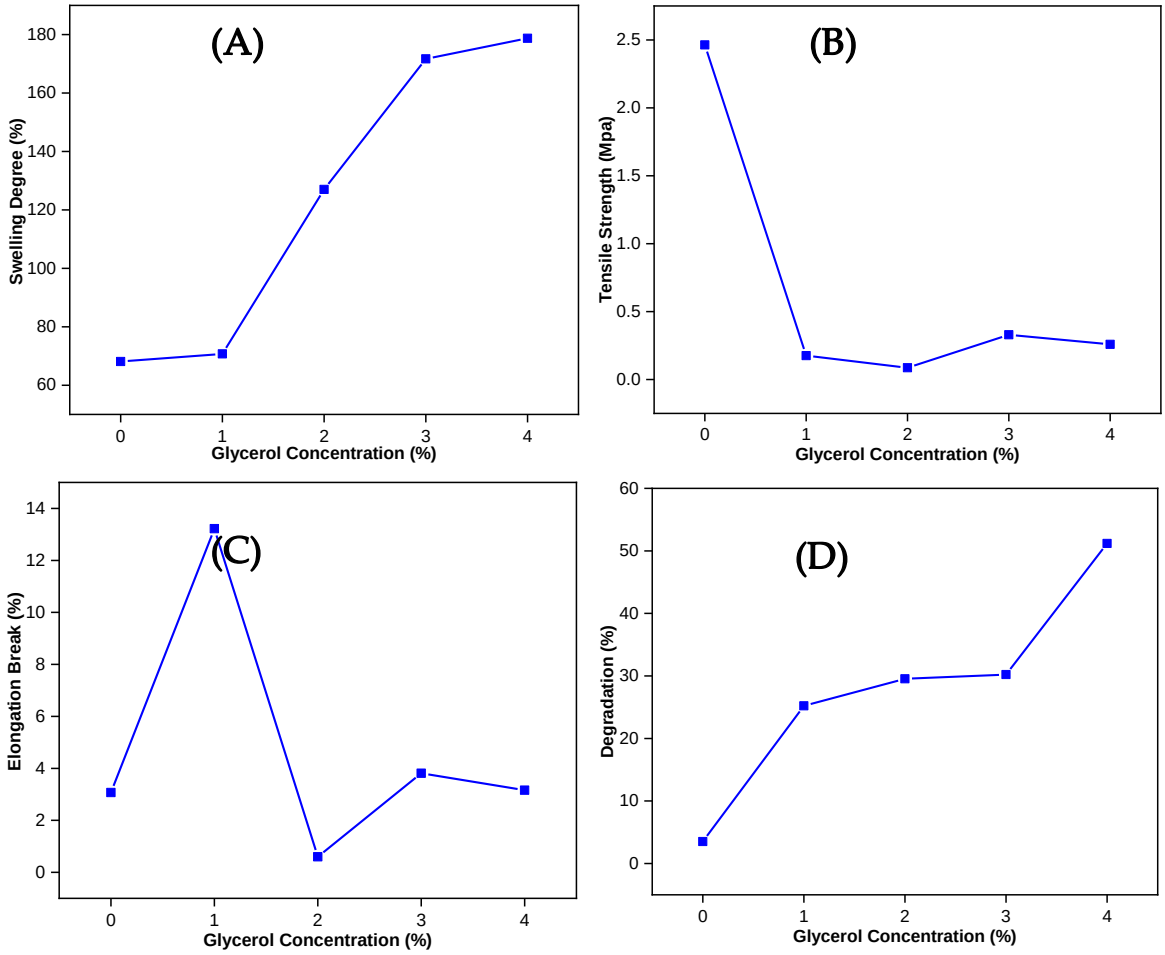

Figure 1. Effect of glycerol addition on bioplastic characteristics: swelling degree (A), tensile strength (B), elongation break (C), degradation (D)

The primary raw material of bioplastics is biopolymer. The hydroxyl groups in biopolymers, which are hydrophilic, cause water to be easily absorbed by bioplastics and then microorganisms in the environment to quickly enter the plastic matrix. The addition of glycerol which is hydrophilic, can increase the free volume between the cellulose polymer chains and increase the free hydroxyl groups that will form hydrogen bonds with the liquid. Thus, increasing glycerol addition increased the ability of bioplastics to absorb liquids and increased the biodegradability of bioplastic (Fig. 1(D)) [2].

According to SNI 7188.7:2016, the elongation at break of biodegradable plastic is 10-20% [22]. In this study, the elongation at break of bioplastics by adding 1% glycerol was 13.2%. Besides that, based on the

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international plastic standard (ASTM5336), the overall biodegradability for PLA (Polylactic Acid) plastic from Japan and PCL (Polycaprolactone) from England takes 60 days [23]. In this study, the percentage of bioplastic degradation by adding 1% glycerol for seven days reached 25%. Therefore, the optimum addition of glycerol to bioplastics is 1%.

3.2 Effect of Cellulose/Chitosan Ratio on Bioplastic Characteristics

To improve the characteristics of bioplastics, the study of the effect of the cellulose/chitosan ratio on bioplastic products has been carried out. Fig. 2 shows that decreasing the cellulose/chitosan ratio causes the increase swelling degree of the resulting bioplastic. On the other hand, the decrease of cellulose/chitosan ratio reduce, the tensile strength and degradation of bioplastics. The hydrophilicity of chitosan is higher than cellulose, so the rise of chitosan content in bioplastics enhances the swelling degree and reduces the tensile strength [13, 15].

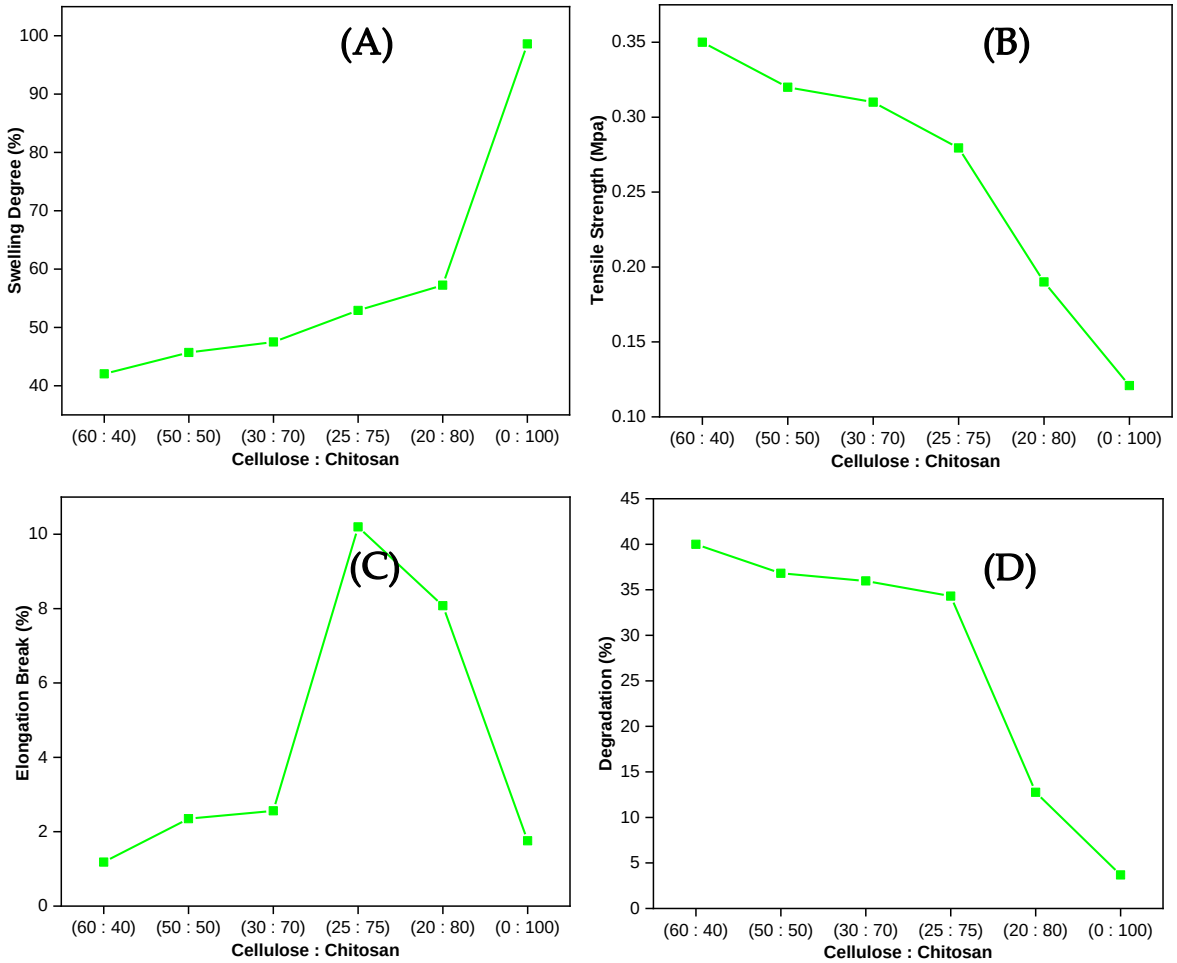

Figure 2. Effect of cellulose: chitosan ratio on bioplastic characteristic: swelling degree (A), tensile

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strength (B), elongation break (C), degradation (D)

The decrease in the cellulose/chitosan ratio up to 25:75 (w/w) increases the elongation break value. However, the elongation at break value declines at the lower cellulose/chitosan ratio. The amine group (NH_2) in the chitosan compound, which is protonated to NH_3^+, will form hydrogen bonds with the hydroxyl group (OH^-) in cellulose. These hydrogen bonds create an interactive network between polymer chains, making the material more elastic. The higher elongation at break value indicates that bioplastics are more flexible. [7].

The chitosan excess causes a reduction in the distance of intermolecular bonds because there are no free OH groups in cellulose that bind to groups on chitosan. This causes the availability of movement at the bioplastic interface to be low so that it becomes more rigid and less elastic [29].

Fig. 2(A) also shows that decreasing the cellulose/chitosan ratio decreases the biodegradability of bioplastics, and the percentage value of degradation decreases significantly when the raw material of bioplastic approaches pure chitosan. Hydrophilic polymer bioplastics exhibit rapid biodegradation [10]. The reduced weight of bioplastics during soil burial shows the natural environment's degradation due to the activity of microorganisms [11]. Chitosan has antimicrobial properties that can prevent microbial attack. Thus, more chitosan content in bioplastics leads to reduced weight loss than in bioplastics with lower chitosan concentrations [3].

3.3 Effect of Glutaraldehyde Crosslinking on Bioplastic Characteristics.

Fig. 3(A) shows that the swelling degree decrease with the increase of glutaraldehyde concentration. Crosslinking cause interconnections between chitosan polymer chains and reduce the mobility of the material, thereby reducing the swelling degree [17]. Glutaraldehyde increases the crosslinking density of the polymer chains. When the concentration of glutaraldehyde increases, the hydroxyl and amino groups, which have hydrophilic properties, are crosslinked to weaken the sample's heritability (ability to absorb water) [32].

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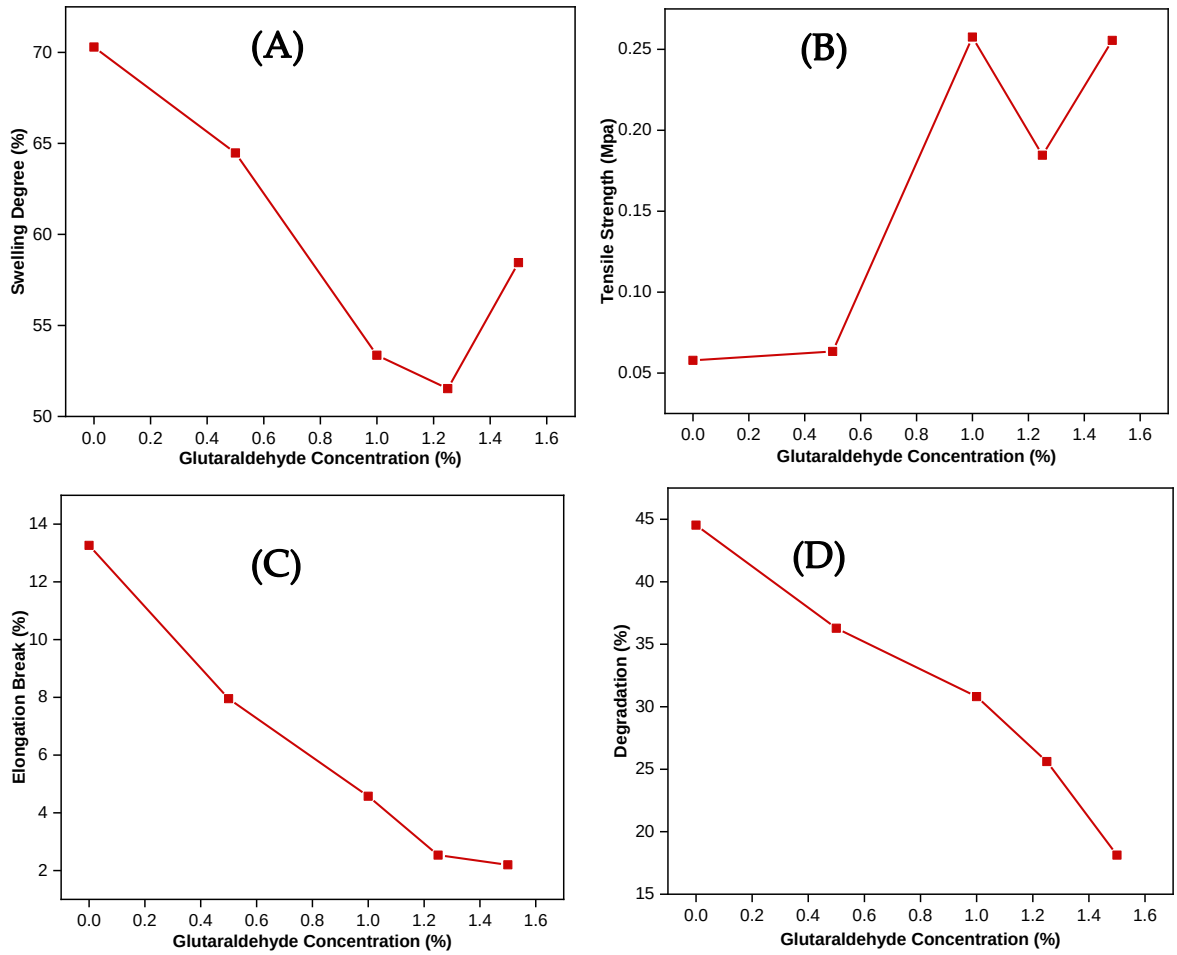

Figure 3. Effect of glutaraldehyde crosslink on bioplastic characteristic: swelling degree (A), tensile strength (B), elongation break (C), degradation (D)

The rise of glutaraldehyde concentration increases the tensile strength value of the bioplastic (Fig. 3(B)). Tensile strength shows the resistance of a material to break. The addition of glutaraldehyde causes the formation of crosslinks between the amine group and the hydroxyl group with the aldehyde group in glutaraldehyde. The crosslinking in chitosan are highly reactive, particularly between the aldehyde and free amino groups. When incorporating glutaraldehyde above a concentration of 2%, the tensile strength value tends to be constant because no free amine and hydroxyl groups could bind to glutaraldehyde [1].

The increasing glutaraldehyde concentration reduces the elongation at break of bioplastic (Fig. 3(C)). The formation of crosslinked networks between amine groups and hydroxyl groups with aldehyde groups in glutaraldehyde causes the matrix to become more compact and stiffer, thereby reducing the mobility of the polymer chains. Therefore, an increase in the amount of glutaraldehyde will result in a decrease in the elongation break value [8].

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Fig. 3(C) shows that the increasing glutaraldehyde concentration decreases the degradation of bioplastics (Fig. 3(C)). The cross-linking between the active groups in the polymer and the aldehyde groups in glutaraldehyde enhances the structural strength of bioplastics, rendering them less susceptible to water absorption, thus inhibiting the biodegradation process of bioplastic [30].

3.4 Bioplastic Product

The results indicated that the optimum conditions to produce bioplastics were the glycerol addition of 1%, the cellulose/chitosan ratio of 25:75, and the glutaraldehyde addition of 1%. The product appearance and FT-IR Spectrum of bioplastic that was produced from optimum conditions are shown in Fig. 4

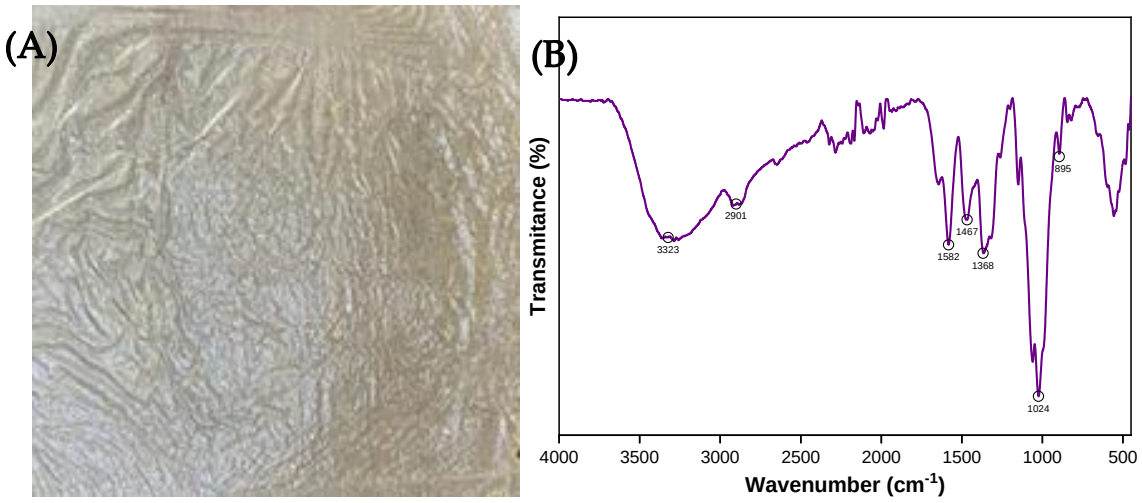

Figure 4. (A) Physical appearance and (B) FT-IR Spectrum of bioplastic product (optimum condition)

The chemical structure of bioplastic products from raw chitosan and corn-stalk fiber under the optimum conditions was analyzed by FTIR spectroscopy. Fig. 4 showed that at wavenumber 3323 cm^{-1}, indicating the presence of an OH group from cellulose and chitosan [21]. Absorption of CH groups (CH_3 asymmetric stretching) was observed at a wavenumber of 2901 cm^{-1}, amine groups from chitosan at 1582 cm^{-1} [20], and cellulose CH groups (-CH_2- bending asymmetric) at 1400-1500 cm^{-1} [6]. The wavenumber of 1368 cm^{-1} indicates the C=N group due to the interaction of chitosan with glutaraldehyde. The CO glycosidic bond is shown in wavenumber 1024 cm^{-1} [31]. The wavenumber of 895 cm^{-1} indicates the presence of CO strain from the cellulose component [12].

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CONCLUSION

The introduction of glycerol can increase the swelling degree, elongation at break, and the rate of bioplastic degradation. However, the addition of glycerol can reduce the tensile strength of bioplastic. Increasing the cellulose concentration in cellulose/chitosan bioplastics can cause a decrease in the swelling degree, an increase in tensile strength, an increase in elongation break, and enhanced biodegradability. The crosslinking agent of glutaraldehyde causes a reduction in the degree of swelling, an increase in the value of tensile strength, a decrease in the value of elongation break, and a decrease in the biodegradability of bioplastic. The optimum conditions to produce the best bioplastics were the glycerol addition of 1%, the cellulose: chitosan ratio of 25:75, and the glutaraldehyde addition of 1%.

ACKNOWLEDGMENTS

The authors would like to thank Diponegoro University for the research funding through the *Riset Publikasi Internasional No 569-171/UN7.D2/PP/VII/2022*. Integrated Laboratory Diponegoro University, and Membrane Research Center (MeR-C) for the supporting facilities while conducting this project

REFERENCES

1. Arianita, A., Cahyaningtyas, Amalia, B., Pudjiastuti, W., Melanie, S., Fauzia, V., dan Imawan, C. 2019. Effect of Glutaraldehyde on the Mechanical Properties of Chitosan/Nanocellulose. Journal of Physics: Conference Series. 1317: 1-8.
2. Bella, F. R., Widiyanti, P., dan Aminatun. 2020. The Effect of Glycerol Concentration on Biocomposite Bacterial Cellulose-Chitosan Characterization as Dura Mater Artificial. Journal of Biomimetics, Biomaterials, and Biomedical Engineering. 45: 40-48.
3. Chie, S. C. dan Wahab, M. K. A. 2019. Morphology and Biodegradability of Micro-Crystalline Cellulose/Chitosan Films. IOP Conference Series: Materials Science and Engineering. 701: 1-9.
4. Debandi,M.V., Bernal,C., and Francois,N.J. 2016. Development of Biodegradable Films Based on Chitosan/Glycerol Blends Suitable for Biomedical Applications. Journal of Tissue Science & Engineering,7:3, 1-9.
5. Dewanti, D. P. (2018). Potensi Selulosa dari Limbah Tandan Kosong Kelapa Sawit untuk Bahan Baku Bioplastik Ramah Lingkungan. Jurnal Teknologi Lingkungan. 19(1): 81-87.
6. Febrianti, T., Septiriana, I., Ariyanto, V. K., Rizky, R. 2017. Engineering of Cassava Stem Cellulose as a Filler for Manufacturing Plastic Biodegradable. World Chemical Engineering Journal. 1(5): 58 – 64.
7. Gabriel, A. A., Solikhah, A. F., dan Rahmawati, A. Y. 2021. Tensile Strength and Elongation Testing for Starch-Based Bioplastic Using Melt Intercalation Method: A Review. Journal of Physics: Conference Series. 1858: 1-10.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 51-62

8. Gan, P. G., Sam, S. T., Omar, M F., dan Abdullah, M. F. 2020. Effect of Glutaraldehyde as Crosslinker on the Properties of Cellulose Nanocrystals/Chitosan Films. IOP Conference Series: Materials Science and Engineering. 957: 1-5.
9. Helmy, B., Windarta, J. and Giovanni, E.H., 2020. Konversi Limbah Plastik Menjadi Bahan Bakar. Jurnal Energi Baru dan Terbarukan, 1(1), pp.1-7.
10. Indumathi, M. P., Sarojini, K. S., dan Rajarajeswari, G. R. 2019. Antimicrobial and Biodegradable Chitosan/Cellulose Acetate Phthalate/ZnO Nano Composite Films with Optimal Oxygen Permeability and Hydrophobicity for Extending the Shelf Life of Black Grape Fruits. International Journal of Biological Macromolecules. 132: 1112–1120.
11. Jangong, O. S., Gareso, P. L., Mutmainna, I., dan Tahir, D. 2019. Fabrication and Characterization Starch/Chitosan Reinforced Polypropylene as Biodegradable. Journal of Physics: Conference Series. 1341: 1-6.
12. Kampeerapappun, P. 2015. Extraction and Characterization of Cellulose Nanocrystals Produced by Acid Hydrolysis from Corn Husk. Journal of Metals, Materials, and Minerals. 25(1): 19-26.
13. Khan, A., Khan, R. A., Salmieri, S., Tien, C. L., Riedl, B., Bouchard, J., Chauve, G., Tan, V., Kamal, M. R., dan Lacroix, M. 2012. Mechanical and Barrier Properties of Nanocrystalline Cellulose Reinforced Chitosan Based Nanocomposite Films. Carbohydrate Polymers. 90: 1601:1608.
14. Kumar, V., Bollström, R., Yang, A., Chen, Q., Chen, G., Salminen, P., Bousfield, D. and Toivakka, M., 2014. Comparison of nano-and micro-fibrillated cellulose films. Cellulose, 21, pp.3443-3456.
15. Li, Q., Zhou, J. and Zhang, L., (2009). Structure and properties of the nanocomposite films of chitosan reinforced with cellulose whiskers. Journal of Polymer Science Part B: Polymer Physics, 47(11), 1069–1077.
16. Lubis, M., Harahap, M. B., Ginting, M. H. S., Sartika, M., dan Azmi, H. 2018. Production of Bioplastic from Avocado Seed Starch Reinforced with Microcrystalline Cellulose from Sugar Palm Fibers. Journal of Engineering Science and Technology. 13(2): 381 - 393.
17. Pavoni, J., dos Santos, N., May, I., Pollo, L. and Tessaro, I., 2020. Impact of acid type and glutaraldehyde crosslinking in chitosan films' physicochemical and mechanical properties and biodegradability. Polymer Bulletin, 78(2), pp.981-1000
18. Prakoso, P. and Udjiana, S. S. 2020. Pembuatan dan Karaterisasi Material Kontruksi dari Limbah Plastik LDPE (Low Density Polyethylene) dan PP (Polypropylene) dengan Penambahan Kalsium Karbonat (CaCO3). Jurnal Teknologi Separasi. 6(2): 439-444.
19. Rinaudo, M., (2006). Chitin and chitosan: Properties and applications. Progress in polymer science, 31(7), pp.603–632.
20. Sawalha, S., Ma'ali, R., Surkhi, O., Sawalha, M., Dardouk, B., Walwel, H., dan Ahmad, D. H.. 2018. Reinforcing of Low-Density Polyethylene by Cellulose Extracted from Agricultural Wastes. Journal of Composite Materials. 53(2): 219-225.

ISSN: 2582-6271

Vol. 5, Issue.2, March-April 2024, page no. 51-62

21. Shafqat, A., Al-Zaqri, N., Tahir, A., dan Alsalme, A. 2021. Synthesis and Characterization of Starch-Based Bioplatics Using Varying Plant-Based Ingredients, Plasticizers, and Natural Fillers. Saudi Journal of Biological Sciences. 28(3): 1739–1749.
22. Sisnayati, Hatina, S., dan Rahmi, A. 2019. Pengaruh Aditif Bawang Putih Terhadap Karakteristik dan Biodegradasi Bioplastik dari Biji Durian. Jurnal Ilmiah TEKNIKA. 6(1): 56-67.
23. Situmorang, F. U., Hartiati, A., dan Harsojuwono, B. A. 2019. Pengaruh Konsentrasi Pati Ubi Talas (Colocasia esculenta) dan Jenis Plasticizer Terhadap Karakteristik Bioplastik. Jurnal Rekayasa dan Manajemen Agroindustri. 7(3): 457-467.
24. Sun, Y., Meng, C., Zheng, Y., Xie, Y., He, W., Wang, Y., Qiao, K. & Yue, L. (2018). The effects of two biocompatible plasticizers on dry bacterial cellulose membrane performance: a comparative study. Cellulose, 25, pp.5893–5908.
25. Sutan, S. M., Maharani, D. M., dan Febriari, F. 2018. Studi Karakteristik Sifat Mekanik Bioplastik Berbahan Pati - Selulosa Kulit Siwalan (Borassus flabellifer). Jurnal Keteknikan Pertanian Tropis dan Biosistem. 6(2): 157-171.
26. Syafri, E., Kasim, A., Abral, H., Asben, A., dan Sudirman. 2018. Pembuatan dan Karakterisasi Komposit Bioplastik Berbasis Filler Cellulose Micro Fibers Rami. Jurnal Sains Materi Indonesia. 19(2): 66-71.
27. Van Nguyen, S. & Lee, B.K. (2021). Microfibrillated cellulose film with enhanced mechanical and water-resistant properties by glycerol and hot-pressing treatment. Cellulose, 28(9), 5693–5705.
28. Wahyuni, L. S., Putri, D., Nurazizah, I. Z., dan Bahruddin. 2019. Bioplastic Properties of Sago-PVA Starch with Glycerol and Sorbitol Plasticizers. Journal of Physics: Conference Series. 1351 (1): 1-8.
29. Yadav, M., Behera, K., Chang, Y. H., dan Chiu, F. C. 2020. Cellulose Nanocrystal Reinforced Chitosan Based UV Barrier Composite Films for Sustainable Packaging. Polymers. 12: 1-22.
30. Yang, W., Qi, G., Kenny, J. M., Puglia, D., dan Ma, P. 2020. Effect of Cellulose Nanocrystals and Lignin Nanoparticles on Mechanical, Antioxidant, and Water Vapour Barrier Properties of Glutaraldehyde Crosslinked PVA Films. Polymers. 12: 1-15.
31. Yeng, C. M., Husseinsyah, S., dan Ting, S. S. 2013. Chitosan/Corn Cob Biocomposite Films by Crosslinking with Glurataldehyde. Bioresources. 8(2): 2910-2923.
32. Yu, Q., Song, Y., Shi, X., Xu, C. and Bin, Y., 2011. Preparation and properties of chitosan derivative/poly (vinyl alcohol) blend film crosslinked with glutaraldehyde. Carbohydrate Polymers, 84(1), pp.465-470.