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Characterization of Eco-Friendly Straw Based on Chitosan from Pupae Exuviae of Black Soldier Fly (*Hermetia illucens*)

Rico Sulaeman[1], Raden Roro Zakiah Diva Wisnu Putri[2], Regita Damayanti[3], Fathan Fauzan[3], Muhammad Ribhan Hadiyan[4] and Yani Maharani[5*]

[1]Department of Agrotechnology, Faculty of Agriculture, Universitas Padjadjaran, Bandung, Indonesia; [2]Department of Marine Science, Faculty of Fisheries and Marine, Universitas Padjadjaran, Bandung, Indonesia; [3]Department of Fisheries, Faculty of Fisheries and Marine, Universitas Padjadjaran, Bandung, Indonesia; [4]Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Bandung, Indonesia; [5]Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Padjadjaran, Bandung, Indonesia

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Abstract

Utilizing materials with high natural degradation capabilities is viable for managing a sustainable environment. Chitosan derived from the exuvia of black soldier flies-BFS (*Hermetia illucens*) offers a potential alternative to chitosan sourced from crustaceans and food plants. It can be used to create straws and other chitosan-based products. The research aimed to analyze the characterization of chitosan from BSF exuvia as an environmentally friendly raw straw material. This study began by collecting BSF pupae exuviae, which was cleaned and dried for chitosan extraction. The test was carried out using various levels of chitosan, i.e., 0%, 0.5%, 1%, 1.5%, and 2%, with observation parameters on tensile strength and elongation, biodegradability, water absorption, and contact angle. The research was conducted with 5 repetitions per sample at each chitosan concentration level. The results showed that higher concentrations of chitosan led to increased tensile strength, ranging from 1.38 to 3.65 N mm^{-2}. The contact angle and hydrophobicity values varied between 69.87° and 103.66°, while the elongation at break values ranged from 4.5 to 285%. The 4 formulas on the biodegradability test showed no noticeable difference according to statistical analysis of variance (ANOVA test). Based on the formulation tested, a chitosan concentration of 2% (P4) is the best formulation as an ingredient in making eco-friendly straw.

Keywords: biodegradability; contact angle; insect; tensile strength; water absorption

INTRODUCTION

Waste is an item that is considered unused and discarded by the previous owner or user, but for some people, it can still be used if the proper procedures are followed (Nugroho, 2013). World Bank (2021) stated that each day, Indonesians produce around 105 thousand tons of solid waste, which may increase to 150 thousand tons per day in 2025. According to Indonesian Ministry of Environment and Forestry (2021), more than 50% of waste comes from food and organic waste, followed by plastic waste at 18%. Organic waste can be decomposed naturally by microbes or biodegradable. However, this decomposition takes time, so organic waste that is not

* **Corresponding author**: yani.maharani@unpad.ac.id

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immediately processed can rot and become a source of disease. However, the World Bank also stated that plastic waste in Indonesia reached 7.8 million tons per year, with around 4.9 million tons (62%) of that waste mismanaged and around the estimated range of 201.1 to 552.3 thousand tons per year of plastic waste discharged into the marine environment (World Bank, 2021). According to Divers Clean Action (2018), everyday plastic straw in Indonesia reached 93 million pieces. The waste management crisis requires creating effective cycles to address the degradation of organic waste from food and reduce the use of plastic materials, such as plastic drinking straws.

Chitosan is an alternative material that can be used as a substitute for plastic because it is easily modified into film form (Rizzi et al., 2018). Chitosan can be obtained from crustaceans, mollusks, fungi, and insects (Nwe et al., 2014). Chitosan generally comes from the skin of marine life, such as crabs, shrimps, and lobsters. However, chitosan derived from insects has not been widely disclosed, and it can be used as an alternative source of chitosan. Black soldier fly (BFS) or *Hermetia illucens* is an insect known for its rapid growth, minimal environmental impact, and remarkable ability to efficiently convert organic waste without producing odor (Siddiqui et al., 2024). Maggot or larvae is an active phase used to degrade organic waste in the form of food waste or kitchen material waste. In the BSF cultivation process, maggots produce pupae exuviae waste, which can be processed into chitosan through chitin deacetylation (Waśko et al., 2016). Chitosan-rich maggot exuviae can be used as an innovation in reducing the use of plastic straws.

A straw is a drinking tool shaped like a tube without a lid, flexible, smooth in texture, and typically made of plastic, specifically polypropylene and polystyrene (Anggraini et al., 2022). This tool can reduce the risk of spills and make drinking more convenient. A good straw is flexible, lightweight, water-resistant, and strong (Chintya and Nugraha, 2017). Research on environmentally friendly straws has begun to develop, starting from the types of straws made from sugarcane, rice, cornstarch, wheat, pasta (Jonsson et al., 2021), carrageenan (A'yun et al., 2021) and crab chitosan (Chen et al., 2022). However, most of these ingredients can still be used as human food. The innovation of BSF exuviae straws is an alternative straw that utilizes waste without reducing human food availability.

Several research papers have explored the potential of BSF as a bioplastic source, further highlighting this resource's versatility and sustainability. Le et al. (2023) utilized chitin and chitosan from BSF prepupae as sources for potential bio-packaging films, while Barbi et al. (2019) developed bioplastics from proteins extracted from *H. illucens* prepupae. In foodware applications, chitosan derived from insect exuviae has not been extensively investigated. For this reason, this paper aims to examine the characterization of chitosan from BSF pupae as raw material for making environmentally friendly straws. The results of this research can be used to reduce straw plastic waste and provide additional information on ecologically friendly straw innovations.

MATERIALS AND METHOD

BSF exuviae was obtained from the maintenance of the Maggolab at Universitas Padjadjaran from BSF fed with organic waste, primarily consisting of materials such as leaves, vegetables, or fruit scraps. The chitosan extraction process and straw making are done at the Laboratory of Plant Pests and Diseases, Universitas Padjadjaran.

Chitosan extraction

The extraction method was based on Mirwandhono et al. (2022) with modifications. Exuviae BSF is cleaned using clean water. Then, the exuviae were boiled with boiling water at 100 °C for 10 to 15 minutes and dried for 24 hours in an oven at 60 °C. Next, exuviae are crushed with a grinder. Around 50 g of exuviae powder is dissolved into 500 ml HCl 1 N and heated on a hot plate for 20 minutes at 100 *°C* (demineralization). The residue is washed with distilled water to pH 6.8 to 7. Then, the residue was soaked in 500 ml 3.5% NaOH for 24 hours, heated with a hot plate at 80 °C for 1 hour, and filtered with Whatman No. 40 filter paper (deproteination). The resulting residue is washed with aquadest to neutral pH and pigmented using 500 ml 0.3515% NaOCl. The deacetylation process is done by soaking the residue in NaOH, heating it with a hot plate, and then drying it in an oven at 60 °C for 24 hours.

Table 1. Formulation of eco-friendly straw

Materials	Formulation				
	P0	P1	P2	P3	P4
Chitosan solution					
Chitosan (g)	0	1	2	3	4
Asetic acid (%)	1	1	1	1	1
Glyserol (%)	0.5	0.5	0.5	0.5	0.5
Aquadest (ml)	100	100	100	100	100
CMC solution					
CMC (g)	2	2	2	2	2
Aquadest (ml)	100	100	100	100	100
Coating solution					
Beeswax (%)	1	1	1	1	1
Ethanol (g)	500	500	500	500	500

Formulation of eco-friendly straws

The formulation of straw manufacturing can be seen in Table 1. A total of 0, 1, 2, 3, and 4 g of chitosan were dissolved in a solution containing 1% acetic acid (v/v) and 0.5% glycerol (w/v) at 90 °C for 20 minutes (Singh et al., 2015). In different containers, 1% carboxyl methyl cellulose (CMC) (w/v) is dissolved in 100 ml of aquades and stirred on a hot plate stirrer until homogeneous. The CMC solution is then put into the chitosan solution and stirred again. After that, the chitosan-CMC solution is filtered with a filter cloth (Singh et al., 2015) and poured into a tray. The filtered solution is then dried in the oven at 60 °C for 24 hours.

Manufacture of beeswax coating

The manufacture of beeswax coating is carried out based on the method of Wang et al. (2020) with modifications. In another container, 200 ml ethanol and as much as 1% beeswax (w/v solvent) are incorporated and put into a water bath at 80 °C. The coating solution is stirred at high speed and removed after the beeswax melts, forming tiny particles. The coating solution was cooled at room temperature while being ultrasonicated for 1 hour and then was put into the spray gun. All bioplastic samples were sprayed with a coating solution for 10 seconds per side at a pressure of 4 bar, with a distance of 10 cm.

Making straw shapes

The coated chitosan membrane is cut into rectangular sheets, ensuring consistent dimensions for subsequent handling and processing. These sheets are then carefully rolled onto polytetrafluoroethylene (PTFE) cylindrical rods, which provide a stable framework for forming the sheets into cylindrical shapes while preventing any unwanted chemical interactions. After shaping, the membrane cylinders are dried at room temperature, a gentle process that helps preserve the membrane's structural integrity and functional properties (Chen et al., 2022).

Mechanical test

The mechanical test in this study consisted of tensile strength, contact angle, and water absorption test.

Tensile strength

This test is carried out by giving a load on the same axis to the straw sample to determine the straw's strength level. The mechanical results obtained are data on the strength and elasticity of the straw.

Contact angle

This test is carried out to determine the hydrophobic or hydrophilic properties of the surface of the test material. The test is done by dripping water on the membrane and then measuring the contact angle of water from the surface.

Water absorption

This is a test to determine the solubility of bioplastics at a specific time and temperature. This test is carried out by cutting a sample with a size of 1 cm x 4 cm and then weighing the initial weight of the sample. The sample is then soaked for 3 minutes. The sample is then removed from the water and weighed again.

Biodegradability test

The intention is to determine the level of aerobic degradation of plastics in soil, according to ISO 17556:2019.

Fourier transform infrared spectroscopy (FTIR)

FTIR is a test to determine various functional groups based on the vibration of each functional group in a sample when irradiated by light with a specific wavelength.

Scanning electron microscope (SEM)

SEM is carried out to see an object's surface morphology and cross-section up to the micro or nanoscale and to measure the composition of materials quantitatively. The morphology of bioplastics was observed by scanning an electron microscope (SEM, JEOL JSM-6360LA).

Data analysis

All test results were analyzed using Duncan's multiple range test and further examined with ANOVA through Python programs. All data were presented in graphs for better interpretations. Among several formulations, the optimal 1 was determined based on the best test results, considering both each sample's physical characteristics and biodegradability.

RESULTS AND DISCUSSION

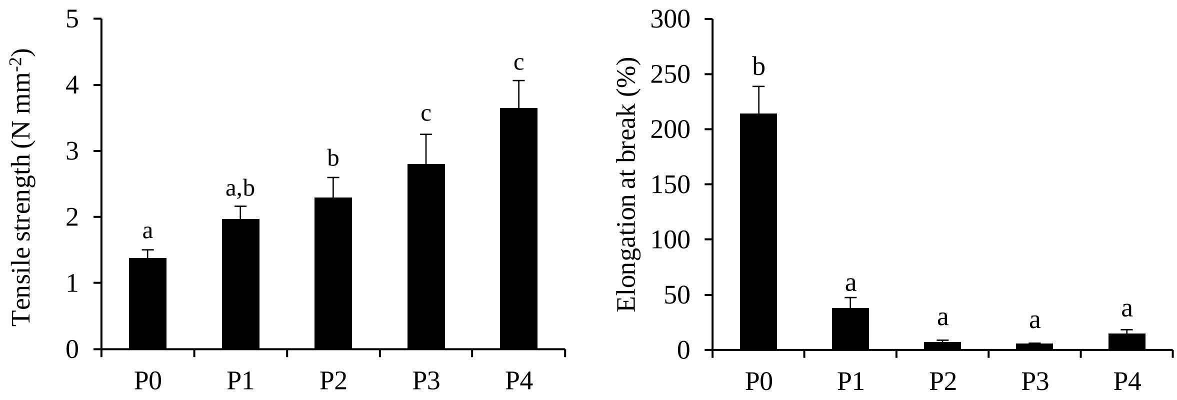
Bioplastic sheets from BSF chitosan exuviae with chitosan concentrations of 0%, 0.5%, 1%, 1.5%, and 2% were made and coated with beeswax. The higher the concentration of chitosan gives a different response to several observational parameters.

The effect of chitosan concentration on bioplastics tensile strength

Based on the test results, it was found that the higher the concentration of chitosan used, the higher the tensile strength obtained. The lowest tensile strength in P0 control bioplastics was 1.38 N mm^{-2} and the highest in bioplastics with a 2% chitosan concentration (P4) of 3.65 N mm^{-2} (Figure 1a). This increase occurs because adding the number of chitosan increases the number of hydrogen bonds in bioplastics, making the bonds between straw molecules stronger (Muchtar et al., 2023). Adding chitosan as a thickener affects the bioplastic chemical bond and increases tensile strength. Chitosan has amine functional groups as well as primary and secondary hydroxyl groups. It causes high chemical reactivity in starch suspension (Ginting et al., 2018). In addition, the addition of chitosan causes the formation of more triple carbon bonds (C≡C) in samples with high bond intensity that are more difficult to stretch or break. Hence, tensile strength increases (Safira and Purbasari, 2023), and elongation at break decreases, as in Figure 1b. Based on this data, the P4 formulation is the best. The addition of chitosan results from a physical interaction of hydrogen bonds between the starch and chitosan solution, so the resulting bioplastic had good tensile strength (Ginting et al., 2017; Lubis et al., 2017).

Effect of chitosan concentration on bioplastic contact angle

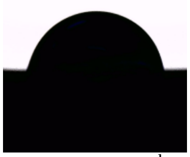
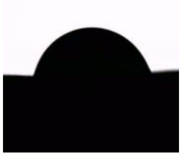
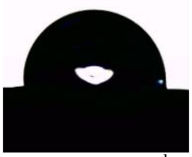
Hydrophobic surfaces have higher contact angles than hydrophilic. The results of the contact angle test (Table 2 and Figure 2) showed that the contact angle at the control (P0) was 80.60° while the sample with the addition of chitosan fluctuated. P1 has a smaller contact angle than the control, which is 69.87°. The sample P4 exhibited the highest contact angle of 103.66°, indicating its superior hydrophobicity.



a. b.

Figure 1. Effect of chitosan concentration (a) effect on tensile strength of bioplastics and (b) effect on elongation at bioplastics break

Table 2. Contact angle in each sample with different chitosan concentrations

Treatment				
P0	P1	P2	P3	P4
				
80.60±2.99[b]	69.87±5.02[a]	96.82±0.65[d]	90.98±1.53[c]	103.66±6.97[e]

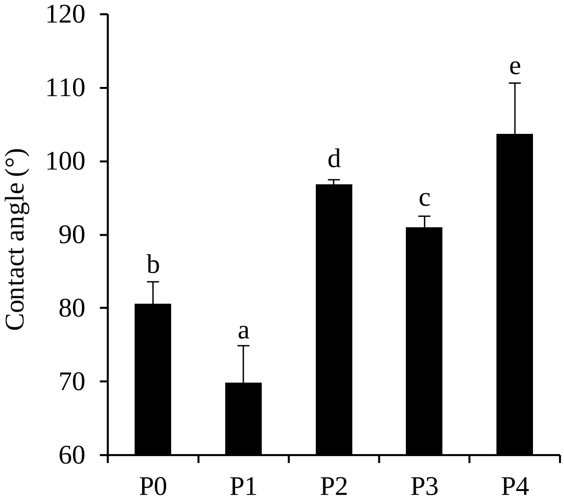


Figure 2. The effect of chitosan addition on the contact angle

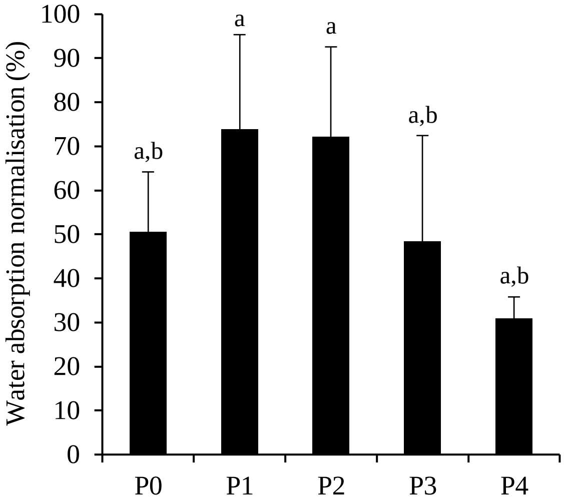


Figure 3. The effect of chitosan concentration on straw water absorption

Based on the data obtained, it was found that the trend of increasing chitosan concentration caused an increase in the contact angle of water. This coincidence may occur because chitosan is relatively hydrophobic (Luchese et al., 2018) due to hydrophobic groups being on the film's surface while hydrophilic groups are on the other side (Cunha et al., 2008). Meanwhile, fluctuations in samples to which chitosan is added can be affected due to the inhomogeneity of the beeswax layer during the coating process, so some parts are not coated with beeswax. This coincidence causes some plastic surfaces to have less waterproof ability and result in lower contact angle values. Therefore, P4 (chitosan 2%) is the formulation with the highest hydrophobicity.

Water resilience (Hydrophobicity)

Based on data from water absorption testing results (Figure 3), it was found that water absorption in samples given chitosan had a downward trend. According to Pasaribu (2021), increasing the chitosan concentration in bioplastic solutions improves the quality of polymer structure and bonds. If the polymer bond gets more robust, the absorption rate of bioplastics to water will be lower.

Based on the results of the ANOVA test, a *p*-value of 0.007 was obtained, which was smaller than the significance level of 0.05. It shows that increasing the concentration of chitosan in bioplastic solutions affects water absorption. Further analysis found that the treatment with a chitosan concentration of 2% had the lowest water absorption value. Therefore, a bioplastic solution with a chitosan concentration of 2% is the optimal solution for straw manufacturing.

Biodegradability

Based on biodegradability testing data, each treatment yielded an average value of biodegradability with a weight loss percentage of 100% after 7 days (Table 3). It shows no effect of chitosan concentration on the biodegradability of bioplastics. Bioplastics are made up of natural components, including chitosan. Under the statement of Utami et al. (2014), bioplastics can be easily decomposed if their components are natural materials. According to Afif et al. (2018),

Table 3. Biodegradability of bioplastics in chitosan concentration treatment

Treatment	Biodegradability (%)
P0	100
P1	100
P2	100
P3	100
P4	100

bioplastics contain hydroxyl groups and carbonyl groups so that they can undergo complete degradation. Based on Indonesian National Standard (SNI) 7818:2014, bioplastics will degrade < 60% for 7 days. It can be concluded that bioplastics from chitosan of BSF exuviae have met SNI 7818:2014. So that all treatments from bioplastics have the potential to be eco-friendly straws.

Fourier transform infrared spectroscopy (FTIR)

In the functional group region, sample P2 found a broad absorbance between 3,250 to 3,650 cm^{-1} followed by absorbance of 1,000 to 1,200 cm^{-1} in the fingerprint region in treatments P2, P3, and P4, which indicates the presence of hydroxyl groups in the treatment with the highest chitosan concentration (Figure 4). Chitosan, which has more hydroxyl groups, makes the absorbance more significant. In addition, absorbance was also found at 2,800 to 2,900 cm^{-1}, indicating mixtures with aliphatic chains.

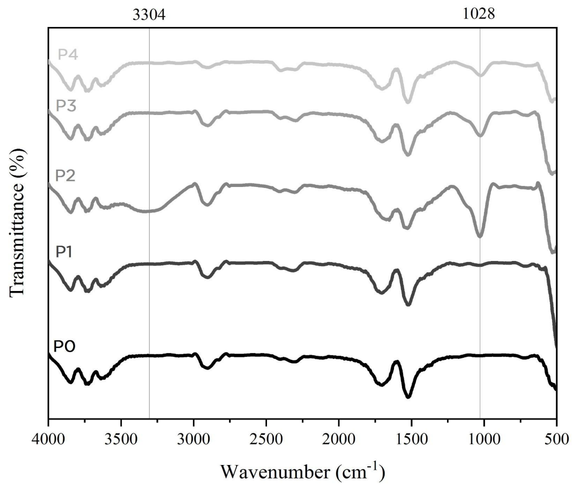


Figure 4. FTIR results of each treatment

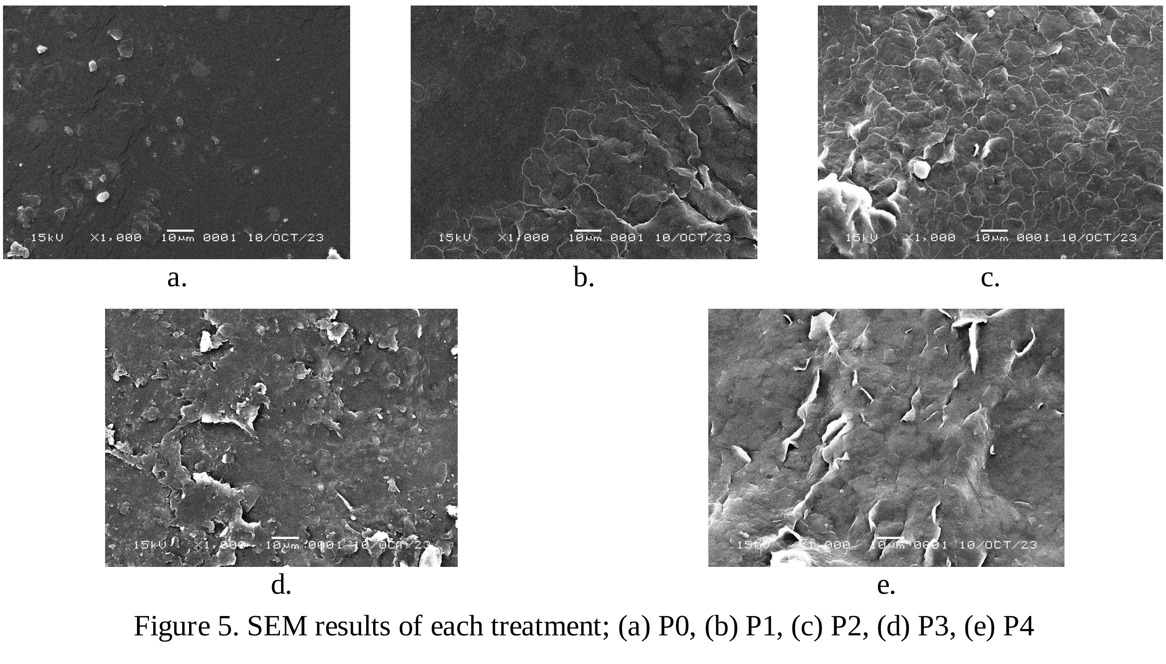


Figure 5. SEM results of each treatment; (a) P0, (b) P1, (c) P2, (d) P3, (e) P4

The group has representatives of the chitosan functional group and a chemical structure similar to cellulose and lignin (Spies and Hoseney, 1982).

Scanning electron microscope (SEM)

SEM results showed that adding chitosan caused structural changes on the film's surface. In Figure 5a, the absence of chitosan in the film sheet forms a flatter and homogeneous surface. In Figure 5b, 5c, 5d, and 5e, chitosan can be seen as piece-shaped particles scattered across the surface. More chitosan particles fill the CMC-glycerol matrix at higher chitosan concentrations, resulting in a wavier surface. In addition, higher chitosan causes chitosan parts to stick out to the outside of the surface, forming cracks and making the surface rougher than lower chitosan concentrations. It can be seen that the distribution of fillers in bioplastics is still not homogeneous, and a buildup of fillers can cause a decrease in mechanical properties in bioplastic products. This filler buildup inhibits the efficient interaction between the filler and the matrix (Ma et al., 2009).

CONCLUSIONS

Chitosan produced from BSF exuviae can be used as a mixture to manufacture environmentally friendly straws. Increasing the concentration of chitosan in the formula of straw-making materials will affect the results regarding tensile strength and elongation, biodegradability, water absorption, and contact angle. The 2% chitosan formula best supports the characterization of eco-friendly straw. Further improvement is required to increase the physical and hydrophobic properties of the straw to ensure its effectiveness for its intended applications.

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REFERENCES

Afif, M., Wijayati, N., & Mursiti, S. (2018). Pembuatan dan karakterisasi bioplastik dari pati biji alpukat-kitosan dengan plasticizer sorbitol. *Indonesian Journal of Chemical Science*, *7*(2), 102–109. https://doi.org/10.15294/ijcs.v7i2.20914

Anggraini, L., Rosida, D. F., & Wicaksono, L. A. (2022). Kemampuan laju transmisi uap dan biodegradasi edible straw dari pati umbi (ganyong, garut, kimpul) dan gelatin ikan. *Jurnal Keteknikan Pertanian Tropis dan Biosistem*, *10*(3), 226–235. https://doi.org/10.21776/ub.jkptb.2022.010.03.06

A'yun, S. N., Triastuti, J., & Saputra, E. (2021). Edible straw formulation from caragenant and gelatin as a solution in reducing plastic waste. *IOP Conference Series: Earth and Environmental Science*, *718*(1), 012007. https://doi.org/10.1088/1755-1315/718/1/012007

Barbi, S., Messori, M., Manfredini, T., Pini, M., & Montorsi, M. (2019). Rational design and characterization of bioplastics from *Hermetia illucens* prepupae proteins. *Biopolymers*, *110*(5), e23250. https://doi.org/10.1002/bip.23250

Chen, C., Wu, Q., Wan, Z., Yang, Q., Xu, Z., Li, D., Jin, Y., & Rojas, O. J. (2022). Mildly processed chitin used in one-component drinking straws and single use materials: Strength, biodegradability and recyclability. *Chemical Engineering Journal*, *442*, 136173. https://doi.org/10.1016/j.cej.2022.136173

Chintya, V., & Nugraha, R. (2017). Eksplorasi material limbah sedotan plastik pada aksesoris fesyen. *eProceedings of Art & Design*, *4*(3), 1067–1086. Retrieved from https://openlibrarypublications.telkomuniversity.ac.id/index.php/artdesign/article/view/4839

Cunha, A. G., Fernandes, S. C. M., Freire, C. S. R., Silvestre, A. J. D., Neto, C. P., & Gandini, A. (2008). What is the real value of chitosan's surface energy? *Biomacromolecules*, *9*(2), 610–614. https://doi.org/10.1021/bm701199g

Divers Clean Action. (2018). *Jumlah sedotan plastik di Indonesia*. Retrieved from www.diverscleanaction.org

Ginting, M. H. S., Hasibuan, R., Lubis, M., Tanjung, D. S., & Iqbal, N. (2017). Effect of hydrochloric acid concentration as chitosan solvent on mechanical properties of bioplastics from durian seed starch (*Durio zibethinus*) with filler chitosan and plasticizer sorbitol. *IOP Conference Series: Materials Science and Engineering*, *180*(1), 012126.

https://doi.org/10.1088/1757-899X/180/1/012126

Ginting, M. H. S., Lubis, M., Sidabutar, T., & Sirait, T. P. (2018). The effect of increasing chitosan on the characteristics of bioplastic from starch talas (*Colocasia esculenta*) using plasticizer sorbitol. *IOP Conference Series: Earth and Environmental Science*, *126*(1), 012147. https://doi.org/10.1088/1755-1315/126/1/012147

Indonesian Ministry of Environment and Forestry. (2021). *Capaian kinerja pengolahan sampah*. Retrieved from https://sipsn.menlhk.go.id/sipsn/

Jonsson, A., Andersson, K., Stelick, A., & Dando, R. (2021). An evaluation of alternative biodegradable and reusable drinking straws as alternatives to single-use plastic. *Journal of Food Science*, *86*(7), 3219–3227. https://doi.org/10.1111/1750-3841.15783

Le, T. M., Tran, C. L., Nguyen, T. X., Duong, Y. H. P., Le, P. K., & Tran, V. T. (2023). Green preparation of chitin and nanochitin from black soldier fly for production of biodegradable packaging material. *Journal of Polymers and the Environment*, *31*(7), 3094–3105. https://doi.org/10.1007/s10924-023-02793-2

Lubis, M., Harahap, M. B., Manullang, A., Alfarodo, Ginting, M. H. S., & Sartika, M. (2017). Utilization starch of jackfruit seed (*Artocarpus heterophyllus*) as raw material for bioplastics manufacturing using sorbitol as plasticizer and chitosan as filler. *Journal of Physics: Conference Series*, *801*, 012014. https://doi.org/10.1088/1742-6596/801/1/012014

Luchese, C. L., Pavoni, J. M. F., Dos Santos, N. Z., Quines, L. K., Pollo, L. D., Spada, J. C., & Tessaro, I. C. (2018). Effect of chitosan addition on the properties of films prepared with corn and cassava starches. *Journal of Food Science and Technology*, *55*(8), 2963–2973. https://doi.org/10.1007/s13197-018-3214-y

Ma, X., Chang, P. R., Yang, J., & Yu, J. (2009). Preparation and properties of glycerol plasticized-pea starch/zinc oxide-starch bionanocomposites. *Carbohydrate Polymers*, *75*(3), 472–478. https://doi.org/10.1016/j.carbpol.2008.08.007

Mirwandhono, E., Nasution, M. I. A., & Yunilas. (2022). Extraction of chitin and chitosan black soldier fly (*Hermetia illucens*) prepupa phase on characterization and yield. *IOP Conference Series: Earth and Environmental Science*, *1114*(1), 012019. https://doi.org/10.1088/1755-1315/1114/1/012019

Muchtar, Z., Sari, S. A., Rahmah, S., Zubir, M., & Sarumaha, G. E. (2023). The effect of chitosan and glycerol mixture on improving biodegradable plastic properties of young coconut husk (*Cocos nucifera* L.). *Oriental Journal of Chemistry*, *39*(1), 95–101. https://doi.org/10.13005/ojc/390111

Nugroho, P. (2013). *Panduan membuat pupuk kompos cair*. Yogyakarta: Pustaka Baru Press. Retrieved from https://scholar.google.co.id/scholar?cluster=5408089592348017865&hl=id&as_sdt=2005&sciodt=0,5

Nwe, N., Furuike, T., & Tamura, H. (2014). Isolation and characterization of chitin and chitosan from marine origin. *Advances in Food and Nutrition Research*, *72*, 1–15. https://doi.org/10.1016/B978-0-12-800269-8.00001-4

Pasaribu, M. (2021). Produksi biodegradable plastic dari limbah kulit pisang dengan penambahan kitosan. *Prosiding Seminar Nasional Teknologi Industri (SNTI)*, *8*(1), 433–435. Retrieved from https://journal.atim.ac.id/index.php/prosiding/article/view/430

Rizzi, V., Longo, A., Placido, T., Fini, P., Gubitosa, J., Sibillano, T., Giannini, C., Semeraro, P., Franco, E., Ferrandiz, M., & Cosma, P. (2018). A comprehensive investigation of dye–chitosan blended films for green chemistry applications. *Journal of Applied Polymer Science*, *135*(10), 45945. https://doi.org/10.1002/app.45945

Safira, A. B., & Purbasari, A. (2023). Optimization and characterization of biodegradable film based on glutinous flour/glycerol/chitosan/ZnO using response surface methodology (RSM)—central composite design (CCD). *Jurnal Kimia Sains dan Aplikasi*, *25*(10), 368–381. https://doi.org/10.14710/jksa.25.10.368-381

Siddiqui, S. A., Süfer, Ö., Çalışkan Koç, G., Lutuf, H., Rahayu, T., Castro-Muñoz, R., & Fernando, I. (2024). Enhancing the bioconversion rate and end products of black soldier fly (BSF) treatment–A comprehensive review. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-04306-6

Singh, T. P., Chatli, M. K., & Sahoo, J. (2015). Development of chitosan based edible films: Process optimization using response surface methodology. *Journal of Food Science and Technology*, *52*(5), 2530–2543. https://doi.org/10.1007/s13197-014-1318-6

Spies, R. D., & Hoseney, R. C. (1982). Effect of sugars on starch gelatinization. *Cereal Chemistry*, *59*(2), 128–131. Retrieved from https://www.cerealsgrains.org/publications/cc/backissues/1982/Documents/chem59_128.pdf

Utami, M. R., Latifah, & Widiarti, N. (2014). Sintesis plastik biodegradable dari kulit pisang dengan penambahan kitosan dan plasticizer gliserol. *Indonesian Journal of Chemical Science*, *3*(2), 163–167. https://doi.org/10.15294/ijcs.v4i2.6166

Wang, D., Huang, J., & Guo, Z. (2020). Tomato-lotus inspired edible superhydrophobic artificial lotus leaf. *Chemical Engineering Journal*, *400*, 125883. https://doi.org/10.1016/j.cej.2020.125883

Waśko, A., Bulak, P., Polak-Berecka, M., Nowak, K., Polakowski, C., & Bieganowski, A. (2016). The first report of the physicochemical structure of chitin isolated from *Hermetia illucens*. *International Journal of Biological Macromolecules*, *92*, 316–320. https://doi.org/10.1016/j.ijbiomac.2016.07.038

World Bank. (2021). *Plastic waste discharges from rivers and coastlines in Indonesia*. The World Bank. Retrieved from https://www.worldbank.org/en/country/indonesia/publication/plastic-waste-discharges-from-rivers-and-coastlines-in-indonesia