PENGARUH *CHAIN EXTENDER* TERHADAP PERFORMA BIOPLASTIK *POLY*(*BUTYLENE ADIPATE-CO-TEREPHTHALATE*) (PBAT) DAN PATI TERMOPLASTIK

SKRIPSI

diajukan untuk memenuhi sebagian syarat untuk memperoleh
gelar Sarjana Sains Program Studi Kimia

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UNIVERSITAS PENDIDIKAN INDONESIA
BANDUNG
2024

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PENGARUH *CHAIN EXTENDER* TERHADAP PERFORMA BIOPLASTIK *POLY*(*BUTYLENE ADIPATE-CO-TEREPHTHALATE*) (PBAT) DAN PATI TERMOPLASTIK

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ABSTRAK

Bioplastik merupakan alternatif pengganti kemasan polimer sintetis yang ramah lingkungan, bersifat *biodegradable*, dan terbuat dari bahan alam, salah satunya adalah pati singkong. *Thermoplastic starch* (TPS) memiliki sifat mekanik yang buruk, sehingga perlu dicampur dengan polimer terdegradasi lain, seperti *poly*(*butylene adipate-co-terephthalate*) (PBAT). Namun, TPS dan PBAT tidak tercampur secara baik, maka dari itu pemanjang rantai (*chain extender*) perlu ditambahkan. Dalam penelitian ini, pemanjang rantai 4,4'-*methylene diphenyl diisocyanate* (MDI) digunakan sebagai *compatibilizer* untuk meningkatkan performa bioplastik TPS/PBAT. Tujuan penelitian ini adalah mengetahui pengaruh *chain extender* terhadap karakteristik dan kemampuan degradasi bioplastik TPS/PBAT-MDI. Metode penelitian yang digunakan adalah pencampuran leleh antara pati singkong, gliserol, PBAT, dan MDI, kemudian pencetakan injeksi dan tekan, serta karakterisasi. Pengaruh kandungan MDI terhadap bioplastik diselidiki melalui pengujian sifat mekanik, karakterisasi *Scanning Electron Microscope* (SEM), *Thermal Gravimetry Analysis* (TGA), *Fourier Transform Infrared* (FTIR), dan uji biodegradasi. Penambahan 2% MDI dan 1,5% MDI menunjukkan performa terbaik dalam kekuatan dan elastisitas dengan nilai kuat tarik berturut-turut 17,71 MPa dan 17,33 MPa serta perpanjangan putus 623,65% dan 516,34%. Hasil analisis SEM memperlihatkan bahwa permukaan bioplastik tanpa MDI terdapat retakan dan sedikit gumpalan, sedangkan bioplastik dengan MDI permukaannya lebih halus, homogen, tidak ada aglomerasi, serta adanya pori-pori kecil yang terdistribusi merata. Hasil TGA menunjukkan stabilitas termal yang kurang memadai. Hasil FTIR mengkonfirmasi adanya gugus O-H, -CH, -NCO, dan C=O. Hasil uji biodegradasi selama 21 hari, menunjukkan nilai optimum pada penambahan 1,5% MDI sebesar 4,72% dibandingkan dengan 0% MDI yang hanya 3,27%. Berdasarkan hasil karakterisasi, penambahan *chain extender* dapat meningkatkan performa bioplastik TPS/PBAT-MDI.

Kata kunci: bioplastik, *chain extender*, pati termoplastik

ABSTRACT

Bioplastics serve as a viable substitute for synthetic polymer packaging, characterised by their eco-friendliness, biodegradability, and utilisation of natural resources, like cassava starch. To address the inadequate mechanical characteristics of thermoplastic starch (TPS), it is necessary to combine it with another biodegradable polymer, such poly(butylene adipate-co-terephthalate) (PBAT). Nevertheless, the combination of TPS and PBAT is not compatible, so more chain extenders must be included. The present work employed 4,4'-methylene diphenyl diisocyanate (MDI) chain extender as a compatibilizer to enhance the performance of TPS/PBAT bioplastics. The objective of this work was to investigate the impact of a chain extender on the properties and flowability of TPS/PBAT-MDI bioplastics. The research methodology employed involved the integration of cassava starch, glycerol, PBAT, and MDI by melt mixing, followed by injection and press moulding, and finally characterisation. This study examined the impact of MDI concentration on bioplastics using several analytical techniques including mechanical properties testing, Scanning Electron Microscope (SEM) characterisation, Thermal Gravimetry Analysis (TGA), Fourier Transform Infrared (FTIR), and biodegradation. The incorporation of 2% MDI and 1,5% MDI resulted in the highest strength and elasticity profiles, with tensile strength values of 17,71 MPa and 17,33 MPa, and elongation at break values of 623,65% and 516,34%, respectively. Scanning electron microscopy (SEM) study reveals that bioplastics lacking MDI exhibit cracks and a few clumps on their surface. In contrast, bioplastics with MDI have a smoother and more uniform surface, without any agglomeration and consisting of equally distributed tiny pores. Results from TGA indicate inadequate thermal stability. FTIR analysis verified the existence of O-H, -CH, -NCO, and C=O functional groups. The biodegradation tests conducted over a period of 21 days revealed an optimal figure of 4.72% when 1.5% MDI was added, whereas the corresponding value for 0% MDI was 3.27%. Results from characterisation indicate that including a chain extender can enhance the performance of TPS/PBAT-MDI bioplastics.

Keywords: bioplastics, chain extender, thermoplastic starch

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DAFTAR PUSTAKA

Aditya Nugraha, L., Dewi Triastianti, R., & Prihandoko, D. (2020). Uji Perbandingan Plastik Biodegradabel Pati Singkong Dan Pati Kentang Terhadap Kekuatan Dan Pemanjangan. *Jurnal Rekayasa Lingkungan*, *20*(1), 17–28. https://doi.org/10.37412/jrl.v20i1.38

Al-Itry, R., Lamnawar, K., & Maazouz, A. (2012). Improvement of thermal stability, rheological and mechanical properties of PLA, PBAT and their blends by reactive extrusion with functionalized epoxy. *Polymer Degradation and Stability*, *97*(10), 1898–1914. https://doi.org/10.1016/j.polymdegradstab.2012.06.028

Analysis, T. (2014). *TMA 4000 Installation and Hardware Guide THERMAL ANALYSIS*.

Analysis. (t.t.). Diakses dari https://analysisdoo.com/products/fourier-transform-infrared-ftir-spectroscopy-and-microscopy/

Annisa, N. (2014). *Senyawa Asam Karboksilat Dan Ester*. *January*.

Arruda, L. C., Magaton, M., Bretas, R. E. S., & Ueki, M. M. (2015). Influence of chain extender on mechanical, thermal and morphological properties of blown films of PLA/PBAT blends. *Polymer Testing*, *43*, 27–37. https://doi.org/10.1016/j.polymertesting.2015.02.005

Aversa, C., & Barletta, M. (2022). Addition of Thermoplastic Starch (TPS) to Binary Blends of Poly(lactic acid) (PLA) with Poly(butylene adipate-co-terephthalate) (PBAT): Extrusion Compounding, Cast Extrusion and Thermoforming of Home Compostable Materials. *Chinese Journal of Polymer Science (English Edition)*, *40*(10), 1269–1286. https://doi.org/10.1007/s10118-022-2734-0

Can, S., Karsli, N. G., Yesil, S., & Aytac, A. (2016). Improving the properties of recycled PET/PEN blends by using different chain extenders. *Journal of Polymer Engineering*, *36*(6), 615–624. https://doi.org/10.1515/polyeng-2015-0268

Chauhan, K., Kaur, R., & Chauhan, I. (2024). Sustainable bioplastic: a comprehensive review on sources, methods, advantages, and applications of bioplastics. *Polymer-Plastics Technology and Materials*, *63*(8), 913–938. https://doi.org/10.1080/25740881.2024.2307369

Dammak, M., Fourati, Y., Tarrés, Q., Delgado-Aguilar, M., Mutjé, P., & Boufi, S. (2020). Blends of PBAT with plasticized starch for packaging applications: Mechanical properties, rheological behaviour and biodegradability. *Industrial Crops and Products*, *144*(December 2019). https://doi.org/10.1016/j.indcrop.2019.112061

Desramadhani, R., & Wardhana, B. (2023). *Indonesian Journal of Chemical Science The Effect of Sorbitol Concentration on the Characteristics of Starch-Based Bioplastic*. *12*(2).

Fact.mr. (2023). *Polybutylene Adipate Terephthalate (PBAT) Market*. 6–11. https://www.factmr.com/report/3218/pbat-market

Fianda, A. Y. A., Fandinny, I., Kacaribu, L. N. B., Desyani, N. A., Asyifa, N., & Wijayanti, P. (2021). Eco-friendly packaging: Preferensi dan Kesediaan Membayar Konsumen di Marketplaces. *Jurnal Ilmu Lingkungan*, *20*(1), 147–157. https://doi.org/10.14710/jil.20.1.147-157

Haifaturrahmah, H., Nizaar, M., & Mas'ad, M. (2017). Pemanfataan Botol Plastik Bekas Sebagai Media Tanam Hidroponik Dalam Meningkatkan Kesadaran Siswa Sekolah Dasar Terhadap Lingkungan Sekitar. *JMM (Jurnal Masyarakat Mandiri)*, *1*(1), 10. https://doi.org/10.31764/jmm.v1i1.8

Iman Mujiarto, ST., M. (2023). SIFAT DAN KARAKTERISTIK MATERIAL PLASTIK DAN BAHAN ADITIF Iman Mujiarto. *Repository.Uin-Suska.Ac.Id*. http://repository.uin-suska.ac.id/26740/1/Haki Buku Genealogi Intelektual Melayu Tradisi Pemikiran Islam Abad ke 19 di Kerajaan Riau Lingga.pdf

Ismaya, F. C., Hendrawati, T. Y., & Kosasih, M. (2019). Pemilihan Prioritas Bahan Baku Plastik Biodegradable dengan Metode Analytical Hierarkhi Process (AHP). *Prosiding Seminar Nasional Sains Dan Teknologi*, *19*, 1–5. https://jurnal.umj.ac.id/index.php/semnastek/article/view/5181

Jannah, N. R., Jamarun, N., & Putri, Y. E. (n.d.). *Production of Starch-Based Bioplastic from Durio zibethinus Murr Seed Using Glycerol as Plasticizer*. 159–165.

Jantrawut, P., Chaiwarit, T., Jantanasakulwong, K., Brachais, C. H., & Chambin, O. (2017). Effect of plasticizer type on tensile property and in vitro indomethacin release of thin films based on low-methoxyl pectin. *Polymers*, *9*(7). https://doi.org/10.3390/polym9070289

Jian, J., Xiangbin, Z., & Xianbo, H. (2020). An overview on synthesis, properties and applications of poly(butylene-adipate-co-terephthalate)–PBAT. *Advanced Industrial and Engineering Polymer Research*, *3*(1), 19–26. https://doi.org/10.1016/j.aiepr.2020.01.001

Kamsiati, E., Herawati, H., & Purwani, E. Y. (2017). POTENSI PENGEMBANGAN PLASTIK BIODEGRADABLE BERBASIS PATI SAGU DAN UBIKAYU DI INDONESIA / The Development Potential of Sago and Cassava Starch-Based Biodegradable Plastic in Indonesia. *Jurnal Penelitian Dan Pengembangan Pertanian*, *36*(2), 67. https://doi.org/10.21082/jp3.v36n2.2017.p67-76

Kanwal, A., Zhang, M., Sharaf, F., & Li, C. (2022). Polymer pollution and its solutions with special emphasis on Poly (butylene adipate terephthalate (PBAT)). *Polymer Bulletin*, *79*(11), 9303–9330. https://doi.org/10.1007/s00289-021-04065-2

Lackner, M., Ivanič, F., Kováčová, M., & Chodák, I. (2021). Mechanical properties and structure of mixtures of poly(butylene-adipate-co-terephthalate) (PBAT) with thermoplastic starch (TPS). *International Journal of Biobased Plastics*, *3*(1), 126–138. https://doi.org/10.1080/24759651.2021.1882774

Lang, H., Chen, X., Tian, J., Chen, J., Zhou, M., Lu, F., & Qian, S. (2022). Effect of Microcrystalline Cellulose on the Properties of PBAT/Thermoplastic Starch Biodegradable Film with Chain Extender. *Polymers*, *14*(21). https://doi.org/10.3390/polym14214517

Liu, B., & Xu, Q. (2013). Effects of Bifunctional Chain Extender on the Crystallinity and Thermal Stability of PET. *Journal of Materials Science and*

Chemical Engineering, *01*(06), 9–15. https://doi.org/10.4236/msce.2013.16002

Martinez Villadiego, K., Arias Tapia, M. J., Useche, J., & Escobar Macías, D. (2022). Thermoplastic Starch (TPS)/Polylactic Acid (PLA) Blending Methodologies: A Review. *Journal of Polymers and the Environment*, *30*(1), 75–91. https://doi.org/10.1007/s10924-021-02207-1

Mayasari, H. E., & Yuniari, A. (2016). Karakteristik termogravimetri dan kinetika dekomposisi EPDM dengan bahan pengisi carbon black. *Majalah Kulit, Karet, Dan Plastik*, *32*(2), 125. https://doi.org/10.20543/mkkp.v32i2.1591

Mendes, J. F., Paschoalin, R. T., Carmona, V. B., Sena Neto, A. R., Marques, A. C. P., Marconcini, J. M., Mattoso, L. H. C., Medeiros, E. S., & Oliveira, J. E. (2016). Biodegradable polymer blends based on corn starch and thermoplastic chitosan processed by extrusion. *Carbohydrate Polymers*, *137*, 452–458. https://doi.org/10.1016/j.carbpol.2015.10.093

Merisiyanto, G., & Mawarani, L. J. (2013). Pengembangan plastik Photobiodegradable Berbahan dasar Umbi Ubi Jalar. *Jurnal Teknik Pomits*, *2*(1), 107–111.

Mościcki, L., Mitrus, M., Wójtowicz, A., Oniszczuk, T., Rejak, A., & Janssen, L. (2012). Application of extrusion-cooking for processing of thermoplastic starch (TPS). *Food Research International*, *47*(2), 291–299. https://doi.org/10.1016/j.foodres.2011.07.017

Mukuze, S., Magut, H., & Mkandawire, F. L. (2019). Comparison of Fructose and Glycerol as Plasticizers in Cassava Bioplastic Production. *Advanced Journal of Graduate Research*, *6*(1), 41–52. https://doi.org/10.21467/ajgr.6.1.41-52

Nofar, M., Sacligil, D., Carreau, P. J., Kamal, M. R., & Heuzey, M. (2019). International Journal of Biological Macromolecules Poly (lactic acid) blends : Processing , properties and applications. *International Journal of Biological Macromolecules*, *125*, 307–360. https://doi.org/10.1016/j.ijbiomac.2018.12.002

Nuriyah, L., Saroja, G., Ghufron, M., Razanata, A., Rosid, N. F., Fisika, J., Matematika, F., Ilmu, D., & Alam, P. (2018). Karakteristik Kuat Tarik dan

Elongasi Bioplastik Berbahan Pati Ubi Jalar Cilembu dengan Variasi Jenis Pemlastis. *Natural B*, *4*(4), 177–182.

Nurmanisah. (2015). Prarencana Pabrik Gliserol. *Galang Tanjung*, *2504*, 1–9.

Ogunrinola, T. M., & Akpan, U. (2018). Production of Cassava Starch Bioplastic Film Reinforced with Poly-Lactic Acid (PLA). *International Journal of Engineering Research and Advanced Technology*, *4*(8), 56–61. https://doi.org/10.31695/ijerat.2018.3308

Pan, H., Li, Z., Yang, J., Li, X., Ai, X., Hao, Y., Zhang, H., & Dong, L. (2018). The effect of MDI on the structure and mechanical properties of poly(lactic acid) and poly(butylene adipate-co-butylene terephthalate) blends. *RSC Advances*, *8*(9), 4610–4623. https://doi.org/10.1039/c7ra10745e

Perkin Elmer. (t.t.). Diakses dari https://www.perkinelmer.com/product/tga-4000-system-100-240v-50-60hz-n5370210

Phothisarattana, D., Wongphan, P., Promhuad, K., Promsorn, J., & Harnkarnsujarit, N. (2021). Biodegradable poly(Butylene adipate-co-terephthalate) and thermoplastic starch-blended tio2 nanocomposite blown films as functional active packaging of fresh fruit. *Polymers*, *13*(23). https://doi.org/10.3390/polym13234192

POL-EKO. (t.t.). Diakses dari https://www.pol-eko.com.pl/climatic-chambers/climatic-chamber-kk-500/

Powerful process engineering for efficient material and process development. (n.d.).

PT. Andalan Bangun Sejahtera. (t.t.). Diakes dari https://www.pt-abs.com/product/ohaus-pioneer-pa214c-p470793.aspx

Raffa, P., Coltelli, M. B., Savi, S., Bianchi, S., & Castelvetro, V. (2012). Chain extension and branching of poly(ethylene terephthalate) (PET) with di- and multifunctional epoxy or isocyanate additives: An experimental and modelling study. *Reactive and Functional Polymers*, *72*(1), 50–60. https://doi.org/10.1016/j.reactfunctpolym.2011.10.007

Rahmayetty, Kanani, N., & Yudo, E. (2018). Pengaruh Penambahan PLA pada Pati Terplastisasi Gliserol Terhadap Sifat Mekanik Blend Film. *Jurnal Umj*, 1–9.

Rodziewicz, P., & Goclon, J. (2014). Structural flexibility of 4,4′-methylene diphenyl diisocyanate (4,4′-MDI): Evidence from first principles calculations. *Journal of Molecular Modeling*, *20*(2). https://doi.org/10.1007/s00894-014-2097-8

Romli, M., Suryani, A., Yuliasih, I., & Johan, S. (2013). The Characterization of Morphology, Thermal, Physic-Mechanic, and Barrier of Biodegradable Plastic from Thermoplastic Starch-LLDPE/HDPE Blends. *Agritech*, *33*(2), 197–207.

Sandra Fitriany, D., Annaziha, S., Sains Assajuly Syamsuddin, H., & Khumaira, A. (2023). Bio-Pack : Biodegradable Packaging Pati Singkong Sebagai Solusi Pencemaran Limbah Plastik Konvensional. *Journal of Comprehensive Science (JCS)*, *2*(1), 430–437. https://doi.org/10.59188/jcs.v2i1.229

Saputra, A., Lutfi, M., & Masruroh, E. (2015). Studi Pembuatan dan Karakteristik Sifat Mekanik Plastik Biodegradable Berbahan Dasar Ubi Suweg (Amorphophallus campanulatus) Study of Manufacturing and Mechanical Characteristic of Biodegradable Plastics Made From Suweg (Amorphophallus campanulatus). *Jurnal Keteknikan Pertanian Tropis Dan Biosistem*, *3*(1), 1–6.

Saputra, M. R. B., & Supriyo, E. (2020). Pembuatan Plastik Biodegradable Menggunakan Pati Dengan Penambahan Katalis ZnO dan Stabilizer Gliserol. *Pentana*, *1*(1), 41–51.

Scientific, T. F. (2012). Safety Data Sheet . قم سلا تانايب ةرشن Safety Data Sheet. *Material Safety Data Sheet*, *4(2)*(1), 8–10. https://us.vwr.com/assetsvc/asset/en_US/id/16490607/contents

Setyaningrum, C. C., Hayati, K., & Fatimah, S. (2020). Optimasi Penambahan Gliserol sebagai Plasticizer pada Sintesis Plastik Biodegradable dari Limbah Nata de Coco dengan Metode Inversi Fasa. *Jurnal Teknik Kimia Dan Lingkungan*, *4*(2), 96–104. https://doi.org/10.33795/jtkl.v4i2.140

Shafqat, A., Al-Zaqri, N., Tahir, A., & 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. https://doi.org/10.1016/j.sjbs.2020.12.015

Shijiazhuang Tuya Technology Co ., Ltd Address : No . 18 Ping ' an North Street , Chang ' an District , Shijiazhuang City , China Email : lisa@sjztuya.com. (n.d.). *18*, 85539531.

Shimadzu Corporation. (2013). *C224-E057E Autograph AGS-X Series*.

Siddiqui, S. A., Sundarsingh, A., Bahmid, N. A., Nirmal, N., Denayer, J. F. M., & Karimi, K. (2023). A critical review on biodegradable food packaging for meat: Materials, sustainability, regulations, and perspectives in the EU. *Comprehensive Reviews in Food Science and Food Safety*, *22*(5), 4147–4185. https://doi.org/10.1111/1541-4337.13202

Steven, S., Mardiyati, M., Dyota, A., & Widyanto, B. (2018). Pembuatan dan Karakterisasi Bioplastik Pati-Kitosan dengan Menggunakan Metode Dialisis-Solution Casting. *Mesin*, *27*(1), 32–42. https://doi.org/10.5614/mesin.2018.27.1.4

Suminto, S. (2017). Ecobrick: solusi cerdas dan kreatif untuk mengatasi sampah plastik. *PRODUCTUM Jurnal Desain Produk (Pengetahuan Dan Perancangan Produk)*, *3*(1), 26. https://doi.org/10.24821/productum.v3i1.1735

Susanti, A. (2021). Pembuatan dan Karakterisasi Biodegradable plastic Berbasis Campuran Pati dan Selulosa Dari Limbah Jagung. *Eksergi*, *18*(2), 49. https://doi.org/10.31315/e.v18i2.5341

Teknik, J., & Fakultas, M. (n.d.). *Perumusan Laju Reaksi dan Sifat-Sifat Pirolisis Lambat Sekam Padi Menggunakan Metode Analisis Termogravimetri*. 12–18.

Thermo Fisher Scientific. (t.t.). Diakses dari https://www.thermofisher.com/order/catalog/product/PRISMAESEM

Thermo Scientific. (2008). Thermo Scientific Haake MiniJet II. *Thermo Scientific HAAKE MiniJet II*, *1*, 1–2. http://www.unipace.de/fileadmin/user_upload/Laborausstattung/UNIpace_MiniJet_II.pdf

Utami, Meilina, R., Latifah, L., & Widiarti, N. (2014). Sintesis Plastik Biodegradable dari Kulit Pisang dengan Penambahan Kitosan dan Plasticizer Glisero. *IJCS - Indonesia Journal of Chemical Science*, *3*(2252), 163–167.

Van Soest, J. J. G., & Borger, D. B. (1997). Structure and properties of compression-molded thermoplastic starch materials from normal and high-amylose maize starches. *Journal of Applied Polymer Science*, *64*(4), 631–644. https://doi.org/10.1002/(SICI)1097-4628(19970425)64:4<631::AID-APP2>3.0.CO;2-O

Wu, B., Sufi, A., Ghosh Biswas, R., Hisatsune, A., Moxley-Paquette, V., Ning, P., Soong, R., Dicks, A. P., & Simpson, A. J. (2020). Direct Conversion of McDonald's Waste Cooking Oil into a Biodegradable High-Resolution 3D-Printing Resin. *ACS Sustainable Chemistry and Engineering*, *8*(2), 1171–1177. https://doi.org/10.1021/acssuschemeng.9b06281

Yasuda Seiki. (t.t.). Diakses dari https://yasudaseiki.com/product/plastic_rubber/heating-minitest-press/

Yustisi, K. C., Wulandari, K., & Utami, I. (2024). Pembuatan Plastik Biodegradable Berbahan Pati Dari Limbah Kulit Pisang Raja Dengan Penambahan Kitosan Dan Plasticizer Sorbitol. *Inovasi Teknik Kimia*, *9*(1), 31–36.

Zeolite Products. (2021). Material Safety Data Sheet Induex-25 MATERIAL SAFETY DATA SHEET. *Material Safety Data Sheet*, *1907*, 1–5. https://fscimage.fishersci.com/msds/60250.htm

Zhao, Z., Wu, Y., Wang, K., Xia, Y., Gao, H., Luo, K., Cao, Z., & Qi, J. (2020). Effect of the Trifunctional Chain Extender on Intrinsic Viscosity, Crystallization Behavior, and Mechanical Properties of Poly(Ethylene Terephthalate). *ACS Omega*, *5*(30), 19247–19254. https://doi.org/10.1021/acsomega.0c02815

Zulisma Anita, Fauzi Akbar, & Hamidah Harahap. (2013). Pengaruh Penambahan Gliserol Terhadap Sifat Mekanik Film Plastik Biodegradasi Dari Pati Kulit Singkong. *Jurnal Teknik Kimia USU*, *2*(2), 37–41. https://doi.org/10.32734/jtk.v2i2.1437