CHARACTERIZATION OF UNBLEACHED PULP FROM EMPTY FRUIT BUNCHES OF OIL PALM AS A RAW MATERIAL FOR BROWN PAPER

TRISNO AFANDI, ELVRI MELLIATY SITINJAK, RYCCE SYLVIANA PRATIKHA and FERNANDO NAINGGOLAN

Department of Chemical Engineering, Politeknik Teknologi Kimia Industri, Medan-20228, Indonesia
✉ *Corresponding author: F. Nainggolan, fernando.nainggolan@ptki.ac.id*

Received December 21, 2023

Improper disposal of palm biomass wastes resulting from industrial palm oil production may contribute to the environmental issues in Indonesia. However, given their abundance and availability, empty fruit bunches (EFB) can be potentially considered as a raw material for unbleached pulp. In this study, unbleached pulp was produced from oil palm EFB by a pulping process with alkaline pretreatment. FT-IR analysis confirmed the presence of cellulose in the pulp, with absorption peaks at 3332 cm^{-1} corresponding to the O-H stretching and at 1029 cm^{-1} assigned to the stretching of the C-O-C bond, respectively. SEM images revealed the aspect of individual fibers, with a rigid appearance, in the pulp obtained from EFB biomass. The major crystalline peak was observed at 2θ of 22.41°, indicating the presence of cellulose. Brown paper was made from the unbleached pulp (A4 size, with a grammage of 134 g/m^2 and a thickness of 219.3 μm) and proved to have excellent mechanical strength. Therefore, unbleached pulp from oil palm EFB can be recommended to be used in the manufacture of brown paper.

Keywords: EFB, biomass, pulp, cellulose, brown paper

INTRODUCTION

As edible oil is produced from oil palm, oil palm (*Elaeis guineensis*) has become one of the most commercially important plants in the world.[1-3] Many everyday things are made from oil palm.[4,5] Indonesia is well known as the world's top producer of crude palm oil and palm kernel oils.[6,7] As a result, a significant quantity of agricultural waste is produced by the oil palm plantation sector.[8] The biomass obtained from the palm oil mill consists of palm oil mill effluent (POME) (60%), empty fruit bunches (EFB) (23%), mesocarp fiber (MF) (12%), and palm kernel shell (PKS) (5%).[9,10]

EFB represents a fairly large amount of solid waste, but its utilization is still limited. The decomposition of EFB takes around 3 weeks. Continuous palm oil production means EFB biomass waste continues to pile up and becomes a problem in palm oil processing factories. Issues, such as greenhouse gas emissions, rising temperatures, anomalous weather patterns, and inefficiencies in the energy sector, have been exacerbated by the landfills of palm oil biomass residues.[10] With great potential for producing biofuels,[11,12] as well as other essential materials, like cellulose, for adsorbents,[13,14,15] bio-charcoal,[16] bio-aerogel,[17] bioethanol,[18] as well as succinate,[19] the use of palm biomass may offer a viable way for solving environmental issues.

EFB are composed of 54-60% holocellulose and 22-27% lignin.[20,21] The high cellulose content in EFB, as well as its abundance and easy availability, can be an opportunity for utilizing EFB biomass for making EFB pulp, which can serve as a raw material for paper manufacturing.[22] Erwinsyah *et al*. have used EFB pulp in making industrial paper, such as liner, medium and duplex cardboard.[23] Dina *et al*. have also used EFB biomass as raw material in making EFB pulp in preparing biodegradable paper bags.[24] EFB fibers appear to have favorable thermal and physical properties, they are inexpensive, biodegradable and sustainable.[25]

In this research, EFB biomass was subjected to alkaline pretreatment overnight. Then, a semi-mechanical process was applied using a digester reactor to produce unbleached pulp. The obtained pulp was then used to prepare brown paper, and its properties were evaluated. The findings allowed concluding that EFB biomass residues can be processed for obtaining unbleached pulp by this affordable method, and the pulp obtained can serve as an alternative raw material for manufacturing brown paper.

EXPERIMENTAL

Pulping process

EFB were chopped into small pieces. An amount of 30 g of the chopped EFB was added into a solution of 300 mL of 5M NaOH and soaked for 24 hours. After filtration, 30 g of the soaked EFB with 300 mL of 5 wt% NaOH solution was treated using a digester reactor, with a maximum speed of 70 rpm and a pressure of 7 bar. Then, the same procedure was carried out, varying the concentration of the NaOH solution (10 wt% and 15 wt%) and the treatment temperature (100 °C and 160 °C).

Brown paper was prepared from the unbleached pulp that was considered optimum (A4 size, with a grammage of 134 g/m^2 and a thickness of 219.3 µm) and was then subjected to standard tests in order to determine its mechanical properties and other characteristics.

RESULTS AND DISCUSSION

Pulping process of EFB

The pulping process uses a semi-mechanical process using a digester reactor and alkaline treatment using NaOH, with varying concentrations of 5 wt%, 10 wt% and 15 wt%. The procedure followed for obtaining unbleached pulp and the other process steps are shown in Figure 1, while the reaction conditions are listed in Table 1.

The lignin and hemicelluloses in EFB were partially removed by the NaOH treatment at high pressure and temperature. Under the treatment conditions, lignin creates a lignin-alkali complex.[26] Additionally, NaOH is also able to break hydrogen bonds, especially the bonds between cellulose molecules. This causes cellulose to loosen both its bonds with the non-cellulosic components and the cellulose itself.[27]

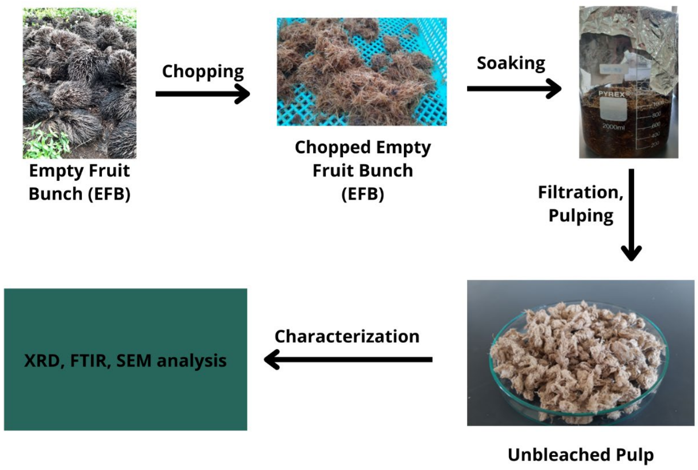

Figure 1: Process steps of preparing unbleached pulp from oil palm EFB

Table 1
Processing conditions and yield of unbleached pulp from oil palm empty fruit bunches

No	Sample name	Conditions		Mass of pulp (g)	Yield (%)
		NaOH solution (wt%)	Temperature (°C)		
1	Pulp 1	5	100	13.69	45.63
2	Pulp 2	5	160	10.01	33.37
3	Pulp 3	10	100	12.05	40.17
4	Pulp 4	10	160	9.51	31.70
5	Pulp 5	15	100	11.29	37.63
6	Pulp 6	15	160	6.71	22.37

As a result, lignin and hemicelluloses dissolved in the NaOH solution, which turned black, while cellulose did not dissolve, but rather swelled.[28] The pulp yield ranged from 22.37% to 45.63%. Higher yields were obtained at lower pulping temperatures. The cellulosic pulp obtained was still brown, because it still contained pigments and lignin residues.

FT-IR spectra analysis

The pulps obtained under various pulping conditions were then subjected to FT-IR analysis. The FT-IR spectra shown Figure 2 reveals several characteristic peaks. As can be observed, the peak at 3332 cm^{-1} can be assigned to the stretching of O-H bonds, the peak at 2914 cm^{-1} corresponds to the stretching of -CH- alkane group, the peak at 1029 cm^{-1} belongs to the stretching of the C-O-C bond on the pyranose ring,[29,30] and the peak at 1416 cm^{-1} indicates the vibrations from bending of O-H groups in polysaccharides.[31] Based on the peak characteristics observed, it can be concluded that the pulping process yielded a product consisting mostly of cellulose.

XRD analysis

The recorded XRD patterns of unbleached pulps showed peaks at 2θ = 15.70°, 22.41°, and 35.05°, which are peak characteristics of cellulose, corresponding to the lattice planes (101), (002), and (040). The major crystalline peak was observed at 22.41°.

As may be noted in Figure 3, the XRD patterns of pulp 1, pulp 2, pulp 3, and pulp 4 show better crystallinity than pulp 5 and pulp 6. In addition, pulp 5 and pulp 6, which were subjected to the highest concentration of NaOH in this study – 15 wt% NaOH, do not show strong peaks at 15° and 35°, as do other pulps. On other hand, the strongest peaks were measured for pulp 3. Based on these results, we can conclude that high alkaline concentrations significantly affected the crystallinity of these pulps,[32,33] while pulp 3 can be considered as the optimum.

SEM

Figure 4 shows SEM micrographs of the products obtained after each pulping process. According to the micrographs in Figure 4, each pulp appeared as separate fibers.[30,34] Also, it was observed that the surface morphology of the fibers revealed the rigid appearance of individual fibers, with particles of smaller dimension.

Mechanical testing of brown paper

To make brown paper, we chose samples from pulp 3, which was considered as optimal. Then, mechanical properties of the paper were tested. Unbleached pulp was molded and pressed using a hydraulic press, then dried at room temperature. The manufacturing process of brown paper from unbleached pulp is shown in Figure 5. The mechanical properties of paper comprised: grammage, thickness, Bendtsen porosity, tensile strength, dry tensile energy absorption, wet tensile strength, wet tensile index, wet tensile energy absorption, tearing resistance, tearing index, bursting strength, water absorbency Cobb60, moisture content, and ash content. Each of these properties was assessed according to the corresponding standard procedure shown in Table 2.

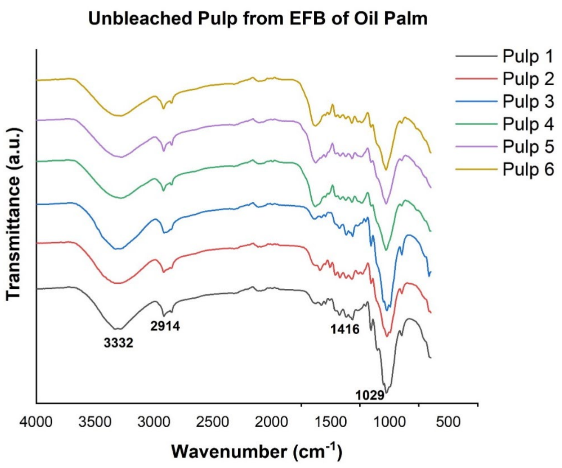

Figure 2: IR spectra of unbleached pulps from oil palm EFB

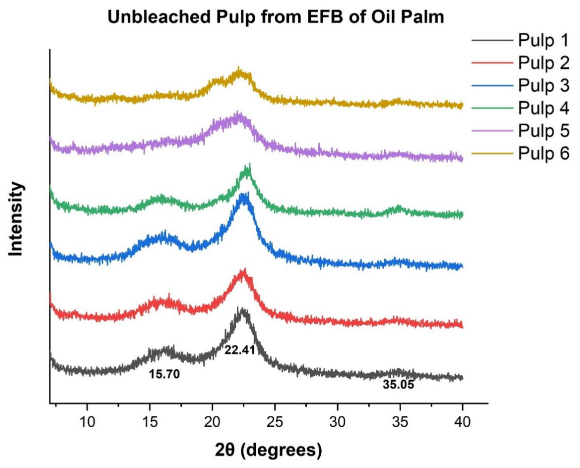

Figure 3: XRD patterns of unbleached pulps from oil palm EFB

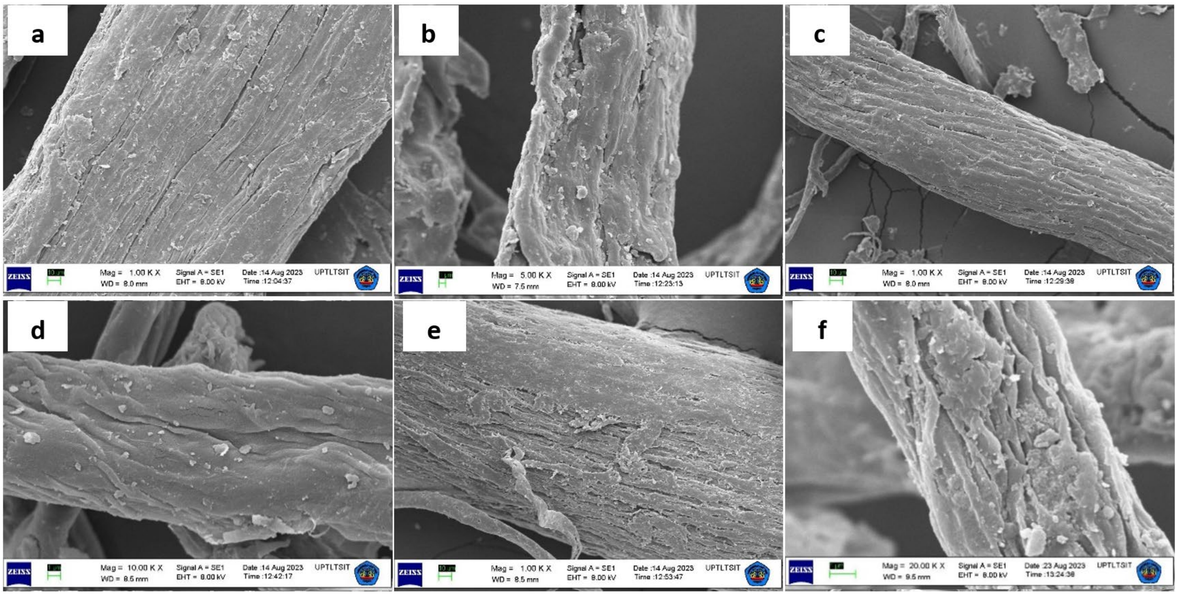

Figure 4: SEM images of unbleached pulps from oil palm EFB: (a) pulp 1, (b) pulp 2, (c) pulp 3, (d) pulp 4, (e) pulp 5, and (f) pulp 6

The paper sheet (A4 size) prepared from unbleached EFB pulp showed a grammage of 134 gsm and a thickness of 219.3 µm. According to Taipale *et al*. (2010) and Ismail *et al*. (2020), the tensile strength is related to fiber strength, bonding strength, and bonding degree of the fiber network.[35,36] The tensile strength found in this study had a value of 5.78 kN/m. The higher value of tensile strength might be caused by the beating treatment. This treatment caused external fibrillation to happen. This improves fiber bonding, and as a result, the tensile strength of the paper is enhanced. Tear resistance is related to felting power, which has a comparable value. Long fibers, which have a high tear resistance, are conducive to the formation of fiber contact on a wider surface area. Long fibers also improve the tear resistance of paper through good internal fiber bonding.[37]

A comparison of the mechanical properties of oil palm EFB pulp with those from other sources, such as pineapple leaf,[38] *Agave americana* L. fibers,[39] palmyra palm fruit fibers,[40] and sweet sorghum bagasse[37] is displayed in Table 3. As may be seen, some characteristics, such as the tensile index, tearing index, bursting index, grammage and Bendtsen porosity, have outstanding values, making oil palm EFB a promising and affordable raw material for paper production. The remarkable results obtained for brown paper made from unbleached EFB pulp in this study thus reveal a potential route of valorizing this agricultural residue, turning it into a promising alternative paper material.

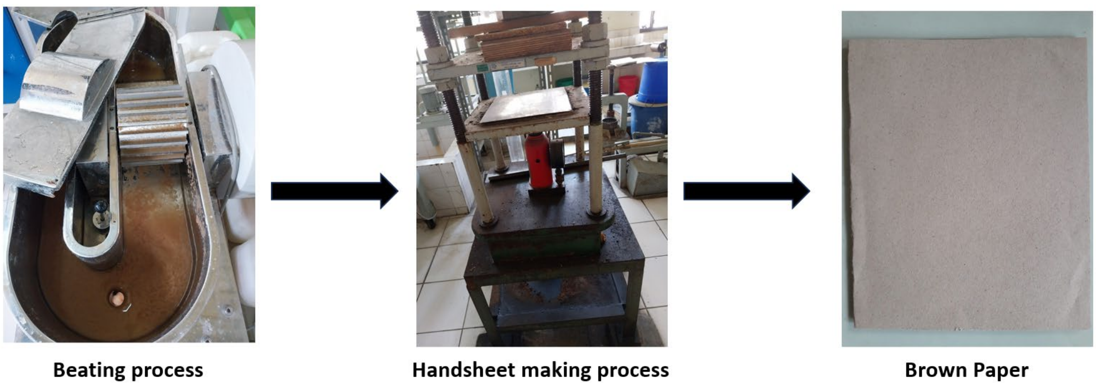

Figure 5: Process steps of making brown paper from unbleached pulp in a conventional manufacturing process

Table 2
Mechanical properties of brown paper from unbleached pulp

No	Mechanical tests	Standards	Pulp 3
1	Grammage (g/m^2)	TAPPI T 410 om-88	134
2	Thickness (µm)	TAPPI T 411 om-15	219.3
3	Bendtsen porosity (mL/min)	ISO 5636/8791/2	1217
4	Tensile strength (kN/m)	TAPPI T 494	5.78
5	Tensile index (Nm/g)	TAPPI T 494	43.07
6	Dry tensile energy absorption (J/m^2)	TAPPI T 494	71.18
7	Wet tensile strength (kN/m)	TAPPI T 456 om-15	0.53
8	Wet tensile index (Nm/g)	ISO 3781	3.91
9	Wet tensile energy absorption (J/m^2)	TAPPI T 494	9.39
10	Tearing resistance (kN/m)	TAPPI T 414 om-12	791
11	Tearing index (mN m^2/g)	TAPPI T 414 om-88	5.89
12	Bursting strength (kPa)	TAPPI T 403 om-22	296
13	Bursting index (kPa m^2/g)	TAPPI T 403 om-91	2.20
14	Water absorbency Cobb60 (g/m^2)	TAPPI T 432	24
15	Moisture content (%)	TAPPI T 412	7.29
16	Ash content (%)	TAPPI T 211 om-02	8.87

Table 3
Comparison of mechanical properties of pulp from different sources

Sample	Pulp yield (%)	Tensile index (Nm/g)	Tearing index (mN m^2/g)	Bursting index (kPa m^2/g)	Grammage (g/m^2)	Bendtsen porosity (mL/min)
Pineapple leaf[38]	79.26	2.03	7.92	1.28	n.a.	n.a.
Agave americana L. fibers[39]	51.45±3	n.a.	5.93±0.55	3.48±0.7	n.a.	n.a.
Palmyra fruit[40]	40.70	13.80	1.12	n.a	n.a.	n.a.
Sweet sorghum bagasse[37]	55	5.31	2.62	0.22	82.72	n.a.
Oil palm EFB (this study)	42.93	43.07	5.89	2.20	134	1217

*n.a. – not available

CONCLUSION

Empty fruit bunches (EFB) are one of the largest contributors of biomass by-products generated by oil palm plantations, and have been considered in this study as an alternative raw material in the production of brown paper. The semi-mechanical pulping process was conducted using a digester reactor and alkali treatment at NaOH concentrations of 5 wt%, 10 wt% and 15 wt%, and temperatures of 100 °C and 160 °C for 2 hours. The optimum conditions of the pulping process were determined as 10 wt% NaOH concentration and a constant temperature of 100 °C. The pulp obtained demonstrated noteworthy mechanical characteristics, when used as a raw material for the manufacture of brown paper.

ACKNOWLEDGMENT: This work was supported by the Department of Chemical Engineering, Politeknik Teknologi Kimia Industri. The authors would also like to acknowledge the support and suggestions from Sari Farah Dina, Justaman Arifin Karo Karo, Fauzatu Arabica Yatasya, and Krissandarta Tarigan.

REFERENCES

[1] M. Choudhary and K. Grover, in "Fruit Oils: Chemistry and Functionality", edited by Md. Fawzy Ramadan Hassanien, Springer-Nature, 2019, pp. 789-802

[2] K. O. Purnama, D. Setyaningsih, E. Hambali and D. Taniwiryono, *Int. J. Oil Palm*, **3**, 40 (2020), https://doi.org/10.35876/ijop.v3i2.47

[3] N. Hastuti, H. Setiawan, K. Kanomata and T. Kitaoka, *Cellulose Chem. Technol.*, **56**, 737 (2022), https://doi.org/10.35812/CelluloseChemTechnol.2022.56.65

[4] S. Handayani, *IOP Conf. Ser.: J. Phys.*, **1763**, 012086 (2021), https://doi.org/10.1088/1742-6596/1763/1/012086

[5] P. Hariyadi, *IOP Conf. Ser.: Earth Environ. Sci.*, **418**, 012003 (2020), https://doi.org/10.1088/1755-1315/418/1/012003

[6] J. Junaedi, *Int*. *J*. *Social Sci*., **2**, 1779 (2022), https://doi.org/10.53625/ijss.v2i4.4137
[7] D. A. F. Zuhdi, M. F. Abdullah, M. S. W. Suliswanto and S. T. Wahyudi, *Jurnal Ekonomi Pembangunan*, **19**, 111 (2021), https://doi.org/10.29259/jep.v19i1.13193
[8] V. Subramaniam, S. K. Loh and A. A. Aziz, *Sustain*. *Prod*. *Cons*., **28**, 1552 (2021), https://doi.org/10.1016/j.spc.2021.09.004
[9] E. Hambali and M. Rivai, *IOP Conf*. *Ser*.: *Earth Environ*. *Sci*., **65**, 012050 (2017), https://doi.org/10.1088/1755-1315/65/1/012050
[10] H. Umar, S. Sulaiman, M. M. Said, A. Gungor, M. Shahbaz *et al*., *Biomass Bioenerg*., **151**, 106179 (2021), https://doi.org/10.1016/j.biombioe.2021.106179
[11] T. M. I. Mahlia, N. Ismail, N. Hossain, A. S. Silitonga and A. H. Shamsuddin, *Environ*. *Sci*. *Pollut*. *Res*., **26**, 14849 (2019), https://doi.org/10.1007/s11356-019-04563-x
[12] M. Zulqarnain, H. M. Yusoff, M. Ayoub, M. Hamza Nazir *et al*., *ChemBioEng Rev*., **8**, 439 (2021), https://doi.org/10.1002/cben.202100007
[13] Y. Wu, M. Fei, T. Chen, R. Qiu and W. Liu, *Ind*. *Crop*. *Prod*., **170**, 113744 (2021), https://doi.org/10.1016/j.indcrop.2021.113744
[14] K. M. Salleh, S. Zakaria, M. S. Sajab, S. Gan and H. Kaco, *Int*. *J*. *Biol*. *Macromol*., **131**, 50 (2019), https://doi.org/10.1016/j.ijbiomac.2019.03.028
[15] K. M. Salleh, S. Zakaria, M. S. Sajab, S. Gan, C. H. Chia *et al*., *Int*. *J*. *Biol*. *Macromol*., **118**, 1422 (2018), https://doi.org/10.1016/j.ijbiomac.2018.06.159
[16] S. Savitri, F. Reguyal and A. K. Sarmah, *Environ*. *Pollut*., **318**, 120879 (2023), https://doi.org/10.1016/j.envpol.2022.120879
[17] E. B. Yahya, H. A. Khalil, M. I. Ahmad, S. Rizal and S. Muhammad, *Ind*. *Crop*. *Prod*., **191**, 115897 (2023), https://doi.org/10.1016/j.indcrop.2023.116500
[18] E. Derman, R. Abdulla, H. Marbawi and M. K. Sabullah, *Renew*. *Energ*., **129**, 285 (2018), https://doi.org/10.1016/j.renene.2018.06.003
[19] P. Khunnonkwao and C. Phosiran, *Biomass Convers*. *Biorefin*., **14**, 17149 (2023), https://doi.org/10.1007/s13399-023-03888-5
[20] T. Kume, S. Matsuhashi, S. Hashimoto, M. R. Awang, H. Hamdini *et al*., *Radiat*. *Phys*. *Chem*., **42**, 727 (1993), https://doi.org/10.1016/0969-806X(93)90361-W
[21] S. Gea, M. Surga, S. Rahayu, M. Marpongahtun, Y. A. Hutapea *et al*., in Procs. *3rd International Seminar on Chemistry: Green Chemistry and Its Role for Sustainability*, *ISOC 2018* - Surabaya, Indonesia, AIP Publishing, 2018, https://doi.org/10.1063/1.5082468
[22] C. L. Yiin, S. Ho, S. Yusup, A. T. Quitain, Y. H. Chan *et al*., *Bioresour*. *Technol*., **290**, 121797 (2019), https://doi.org/10.1016/j.biortech.2019.121797
[23] Erwinsyah, S. Sugesty and T. Hidayat, *Jurnal Selulosa*, **2**, 8 (2012), http://jurnalselulosa.org/index.php/jselulosa/article/view/27/27
[24] S. F. Dina, L. Indriati, N. Elyani and M. A. Zamzami, *Jurnal Selulosa*, **11**, 9 (2021), http://dx.doi.org/10.25269/jsel.v11i01.330
[25] N. A. Ramlee, J. Naveen and M. Jawaid, *Construct*. *Build*. *Mater*., **271**, 121519 (2021), https://doi.org/10.1016/j.conbuildmat.2020.121519
[26] B. E. Dale and M. J. Moreira, in *Procs*. *Biotechnol*. *Bioeng*. *Symp*., United States, Colorado State University, Fort Collins, 1982
[27] W. L. Marsden, P. P. Gray and M. Mandels, *Crit*. *Rev*. *Biotechnol*., **3**, 235 (1985), https://doi.org/10.3109/07388558509150785
[28] Muryanto, Y. Sudiyani and H. Abimanyu, *Jurnal Kimia Terapan Indonesia*, **18**, 27 (2016)
[29] A. Adewuyi and F. V. Pereira, *Makara Journal of Science*, **22**, 121 (2018)
[30] I. Y. A. Fatah, H. Abdul Khalil, M. S. Hossain, A. A. Aziz, Y. Davoudpour *et al*., *Polymers*, **6**, 2611 (2014), https://doi.org/10.3390/polym6102611
[31] V. Hospodarova, E. Singovszka and N. Stevulova, *Am*. *J*. *Anal*. *Chem*., **9**, 303 (2018), https://doi.org/10.4236/ajac.2018.96023
[32] S. M. Razali and K. F. Kasim, *Sains Malaysiana*, **51**, 1061 (2022), http://doi.org/10.17576/jsm-2022-5104-09
[33] E. Xu, D. Wang and L. Lin, *Forests*, **11**, 87 (2020), https://doi.org/10.3390/f11010087
[34] M. A. Guancha-Chalapud, J. Gálvez, L. Serna-Cock and C. N. Aguilar, *Sci*. *Rep*., **10**, 11637 (2020), https://doi.org/10.1038/s41598-020-68368-6
[35] T. Taipale, M. Österberg, A. Nykänen, J. Ruokolainen and J. Laine, *Cellulose*, **17**, 1005 (2010), https://doi.org/10.1007/s10570-010-9431-9
[36] F. S. Ismail, A. Z. M. Asa'ari, N. A. M. Yussof, L. Chin Hao, F. N. M. Padzil *et al*., *J*. *Nat*. *Fibers*, **19**, 999 (2022), https://doi.org/10.1080/15440478.2020.1779896
[37] W. Fatriasari and A. H. Iswanto, *J*. *Eng*. *Technol*. *Sci*., **47**, 149 (2015), https://doi.org/10.5614/j.eng.technol.sci.2015.47.2.4
[38] Z. Daud, M. Z. Mohd Hatta, A. S. Mohd Kassim and H. Awang, *Appl*. *Mech*. *Mater*., **773**, 1215 (2015), https://doi.org/10.4028/www.scientific.net/AMM.773-774.1215
[39] M. Jaouadi, S. Msahli and F. Sakli, *Mater*. *Manuf*. *Processes*, **26**, 567 (2011), https://doi.org/10.1080/10426910903124878
[40] W. Sridach, *Songklanakarin Journal of Science and Technology*, **32**, 201 (2010)