



Preparation and Characterization of Pineapple Leaf-Derived purified Microcrystalline Cellulose and Nanocellulose as liquid Absorbent Materials for Healthcare Applications

Dang Thi Thanh Quyen¹, Le Mai Anh², Le Quang Dien^{1*}, Le Minh Hai¹, Doi Thi Ngoc Anh¹,
 Le Thi Duong¹, Nguyen Thi Ha Anh¹, Nguyen Thi Hong Duc¹, Do Minh Hoa¹

¹ School of Chemistry and Life Sciences, Hanoi University of Science and Technology, 1 Dai Co Viet Road, Hanoi, VIETNAM

² Hanoi-Amsterdam High School for the Gifted, Hoang Minh Giam Road, Hanoi, VIETNAM

* Email: dien.lequang@hust.edu.vn

ARTICLE INFO

Received: 05/09/2026

Accepted: 29/09/2026

Published: 30/09/2026

Keywords:

Pineapple leaf fiber;
 cellulose; nanocellulose;
 permeable adsorbent

ABSTRACT

Pineapple production in Vietnam creates large amounts of organic residues, primarily in the form of pineapple leaves, which contain the cellulose fibers with unique properties and represent a potential raw material to produce environmentally friendly and safe materials for human and animal healthcare. In this study, the pineapple leaf-derived fibers were processed into several useful cellulose-based absorbents via a multistage process. First, the extracted fibers were cooked with sodium hydroxide solution to obtain the unbleached cellulose pulp, which then was treated with a mixed solution of sodium hydroxide and hydrogen peroxide followed sulfuric acid treatment to obtain the purified cellulose. Subsequently, the purified cellulose was converted into microcrystalline cellulose (MCC) and nanocellulose (NC) via acid hydrolysis. The resulting MCC and NC were modified into absorbents with absorption capacity of 4 and 12 g/g for water and 5 and 17 g/g for oil. The new micro- and nanomaterials could be developed for applications as absorbent materials in human and animal healthcare, and these results promise to enhance the effectively utilization of agricultural residues in Vietnam.

Introduction

Amidst rapid industrialization and modernization, which have driven remarkable progress in the economy and quality of life, a consumption boom has led to the increasing use of fossil-based materials, such as synthetic plastics and non-biodegradable fibers, thereby contributing to persistent and difficult-to-control environmental issues [1]. Therefore, the development of green and sustainable alternative materials has become a global imperative. Among these, bio-based absorbent materials, particularly cellulose, stand out as a

promising solution due to their biodegradability, superior mechanical and physical properties, and versatility across various sectors [2]. Cellulose is widely used in the production of textile fibers, food packaging, potential biomedical materials, water filtration systems, thermal insulation materials, healthcare products, and plastic substitutes. Among these, areas that have recently garnered significant interest include potential biomedical materials, water filtration, and healthcare applications [3], as well as modified cellulose used as adsorbent materials and for liquid absorption in the medical and environmental applications [3,4].

In everyday life, high-purity wood-derived cellulose, which is known as "fluff cellulose", is widely used as an absorbent layer in medical dressings and diapers, boasting an absorbency of 10–15 g/g. In recent years, an eco-friendly, biodegradable absorbent material known as "Cat litter", which is produced from protein-based by-products has emerged as an alternative to traditional litter. These products have attracted the attention of researchers exploring the use of agricultural lignocellulosic biomass to supplement or replace conventional cellulose materials [5,6].

Pineapples are a key crop in Vietnam, with approximately 52,000 hectares under concentrated cultivation. Pineapple leaf waste amounts to an estimated 1.7 million tons annually. Currently, only a small portion is collected for production of long fibers used in handicrafts, while the majority is discarded, resulting in waste, cultivation obstacles, and environmental impact. Pineapple leaves contain cellulose fibers with the potential for high liquid absorption, making them a promising raw material for the development of absorbent materials. However, raw pineapple leaf fibers are stiff and contain cellulose and other compounds, therefore, purification and modification of the fibers are essential to improve their absorption and other properties, thereby enabling expanded and advanced applications.

Investigations into the processing of pineapple leaf fibers for applications in various fields have attracted significant interest in recent years. Published findings cover the use of pineapple leaves to produce nanocellulose [7, 9, 10] and aerogels [8], the development and application of functional nanocellulose [10] and bleached cellulose [11, 12], and the use of pineapple leaf-derived cellulose for heavy metal adsorption in wastewater [13] and oil absorption [22]. While various sources of pineapple leaves and fibers have been utilized in research, there have been no studies focusing on the purification and characterization of cellulose and nanocellulose from pineapple leaves specifically for applications as absorbent materials in hygiene and healthcare products.

This study utilizes pineapple leaf fibers extracted via mechanical processing in Vietnam and employs sequential alkali and acid treatments to remove impurities, yielding high-purity, highly absorbent cellulose and nanocellulose suitable for use as absorbent materials in pet hygiene and human healthcare.

Experimental

Pineapple Leaf Fibers and Chemicals

Pineapple leaf fibers (PLF) were sampled from Nghe An province, Vietnam. The fibers were extracted from the leaves using a decorticating machine, sun-dried, cut into 2–3 cm lengths, and subsequently used in experiments.

All chemicals were of high-purity, analytical PA grade were purchased from Merck or other commercial suppliers in China.

The soda cooking of PLF, cellulose bleaching, cellulose alkaline purification, and microcrystalline cellulose (MCC) preparation were carried out with 1.0 L stainless steel reactors, which were heated in a glycerin bath equipped with a temperature controller. Each cooking batch was conducted with 30 g of oven-dried PLF at 100°C, solid-to-liquid ratio of 1:10. Chemical dosage and treatment time were adjusted according to the goals of each experiment. Upon completion, the reaction mixture was filtered to separate into the solid and liquid fractions. The solid fraction, consisting of unbleached cellulose pulp, was thoroughly washed, dried at 103±2°C and stored in a closed container at room temperature for further analysis.

Cellulose bleaching was conducted by one step hydrogen peroxide treatment at 80°C for 90 min using dosages NaOH and H₂O₂ of 1.5% and 3% of oven-dried unbleached cellulose pulp respectively. Pulp consistent was 10%.

Cellulose purification was carried at room temperature for 60 min using NaOH solution. The solid to liquor ratio was 1:10. After alkaline treatment, cellulose pulp was thoroughly washed until neutral pH was reached, dewatered, dried at 103±2°C.

The acid treatment was conducted for MCC preparation: 30 g of oven-dried cellulose was treated 300 mL of a 10% H₂SO₄ in 1.0-L reactor at 100°C for 60 min using glycerin heating bath. The solid fraction of MCC was thoroughly washed until neutral pH was reached, dewatered, dried at 103±2°C and refined into powder, and stored in a close container at room temperature for further analysis and investigation.

Nanocellulose (NC) was prepared by hydrolyzing 30 g oven-dried (OD) purified cellulose with 300 mL of a 0.5% H₂SO₄ and 1 mL of 30% H₂O₂ in a 1.0-L reactor at 140°C for 90 min using glycerin heating bath. The resulting suspension was thoroughly washed until neutral pH was reached, dewatered, and treated with 200 mL water contain 0.075 g NaOH and 0.5 mL 30% H₂O₂ at 80°C for 60 min. Obtained NC suspension then thoroughly washed until neutral, dewatered, and was mechanically refined using a laboratory cutter at 2500 rpm, for 3 – 5 min to obtain NC. The nanocellulose gel (~20% solids) was stored in a sealed container at 10°C and

subsequently submerged freeze drying at -40°C to obtain nanocellulose powder.

Chemical composition and α -cellulose content of the purified cellulose were determined according to TAPPI standards as follows: Cellulose (T17 wd070), Lignin (T222), Pentosan (T223), Ash content (T211 om-93), Ethanol extractives (T204 cm-07), Water solubility (T 207), α -cellulose (T203 cm-09).

The morphology of the cellulose samples was examined using a field-emission SEM (FEI Nova NanoSEM 450, USA). Images were recorded under different conditions to capture both overall structure and fine surface details. Low-magnification images were obtained at 10 kV accelerating voltage and a working distance of ~ 5 mm using an Everhart-Thornley detector (ETD), while higher-magnification images were acquired at 5 kV accelerating voltage and ~ 8.6 mm working distance using the in-lens secondary electron (SE(UL)) detector.

The water absorption capacity of the cellulose samples was determined in accordance with TCVN 10584:2014 – Baby diapers – to evaluate absorbency: Filter tea bags (2x3 cm) were first soaked in 0.9% NaCl solution for 1 min, centrifuged them for 3 min, and weighed to determine their mass. Approximately 0.25 g of dried cellulose material was then placed into each filter bag. The bags were soaked in the NaCl solution for 5 min, centrifuged for 5 min, and weighed again. The water absorption capacity was subsequently calculated based on the mass difference.

The determination of oil absorption was carried out using a similar procedure: Filter tea bags (2x3 cm) were first soaked in a diesel oil (DO) for 2 min at room temperature (25 – 32°C), centrifuged for 3 min using centrifuge LC-04R with speed 3000 rpm, and weighed to determine their mass. Approximately 0.25 g of dried cellulose material was then added into the filter bag. The bags were soaked in the oil solution for 5 min, centrifuged for 5 min, and weighed again. The oil absorption capacity was subsequently calculated based on the mass difference.

Results and discussion

Cellulose preparation

The chemical composition of PLF was determined as follows: cellulose content of 59.36%; lignin content of 5.64%; pentosane 8.47%, ash of 5.05%; ethanol extractives of 4.96 %; water solubility was 16.52%. Pineapple leaf fibers were characterized by high cellulose content and low lignin content. Therefore, a low-temperature soda cooking method can be employed to produce high-purity cellulose.

PLF were treated with a NaOH solution at dosages of 5–10 % w/w OD mass. The results (Table 1) showed that approximately 90.31 % of the initial lignin was removed during cooking. At alkali dosages of 8–10%, the lignin removal rate exceeded 99.1%. The amount of residual lignin in the cellulose pulp was negligible.

An examination of the effect of cooking time at a constant temperature (Table 2) also indicated that the optimal cooking time was 90 minutes.

Table 1: Influence of NaOH dosage to cellulose yield and delignification of Pineapple leaf fibers (Cooking temperature: 100°C ; Cooking time: 120 min)

Dosage of NaOH (% w/w)	Cellulose yield (% w/w)	Lignin content of cellulose pulp (% w/w)
5	75.84 ± 1.24	0.72 ± 0.16
7	67.35 ± 0.86	0.24 ± 0.08
8	59.87 ± 0.92	0.08 ± 0.02
10	57.59 ± 0.74	0.021 ± 0.004

Table 2: Influence of cooking time dosage to cellulose yield and delignification of Pineapple leaf fibers (Cooking temperature: 100°C ; NaOH dosage: 8 % w/w)

Time of cooking (min)	Cellulose yield (% w/w)	Lignin content of cellulose pulp (% w/w)
30	82.61 ± 1.37	2.08 ± 0.23
60	78.35 ± 0.74	1.94 ± 0.11
90	75.84 ± 1.24	0.72 ± 0.16
120	58.36 ± 0.56	0.015 ± 0.003

A pilot-scale batch cooking of 1.5 kg of PLF was processed in a 20 L pilot-scale reactor at 100°C for 90 minutes with NaOH dosage of 8 %, which yielded 1,134.7 g of OD cellulose pulp with a cellulose content of 96.04 % and an ash content of 0.67 %. The pulp was bleached using hydrogen peroxide at 80°C for 90 minutes, with an H_2O_2 and NaOH dosage of 3 % w/w and 0.5 % w/w. The total yield of bleached cellulose pulp was 1,106.2 g, with a cellulose content of 97.18 % w/w and an ash content of 0.46 % w/w; lignin was not detected. Thus, the bleached cellulose pulp had a high cellulose content but still contained the pentosan and inorganic compounds. Therefore, further purification was necessary to enhance its purity and suitability for material applications.

Cellulose purification

In the next stage, the bleached cellulose was treated with a 6–12% NaOH solution.

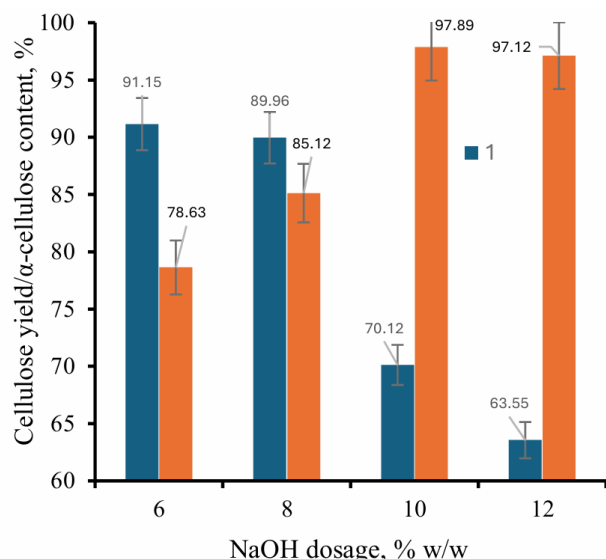


Fig 1: Influence of NaOH dosage on the yield and α -cellulose content of purified cellulose

The results (Figure 1) indicated that the yield of purified cellulose was approximately 70% w/w of bleached cellulose, lower than acacia-derived cellulose, which was purified using the same method [14]. However, the purified cellulose from pineapple fibers achieved an α -cellulose content of 97–98%, which was higher than that of cellulose from acacia wood or non-wood cellulose from mulberry bark, which exhibited cellulose yields of

86–88% w/w and α -cellulose contents of 92–93% [15]. These findings demonstrated the potential of pineapple leaf fibers derived purified cellulose for various applications, such as the production of microcrystalline cellulose (MCC) and material derivatives.

The analysis of SEM images (Figure 2) of the cellulose samples showed that the untreated PLF exhibited an agglomerated structure containing various impurities. After the bleaching, distinct fibrillation was observed. This indicated that the bleaching and alkaline purification processes removed impurities and amorphous regions of the cellulose, resulting in separated cellulose fibers with diameters of approximately 5 μm .

Characteristics and liquid absorption of pineapple leaf fiber derived cellulose materials

The SEM image of microcrystalline cellulose (Figure 3A) showed that the acid hydrolysis primarily caused the cellulose fibers to be shortened, resulted in fiber diameters of less than 5 μm , consistent with previously published results [15,16,20,21]. The nanocellulose fibers have diameters of less than 100 nm, average <50 nm, smaller than the size of nanocellulose derived from straw [17] or sugarcane bagasse [18]. The acid treatment process reduced the ash content of MCC and nanocellulose to 0.27 % and 0.18 %, respectively.

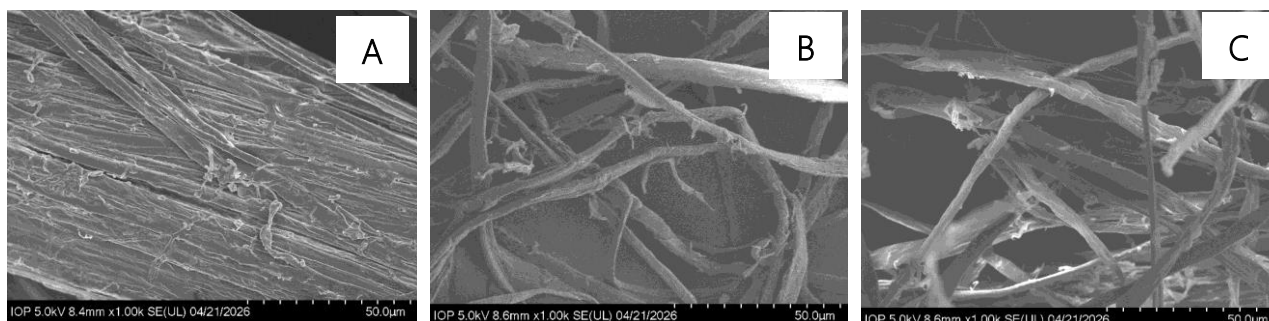


Fig 2: SEM images of PLF (A), bleached cellulose (B), and purified cellulose(C) at x 1,000 magnification

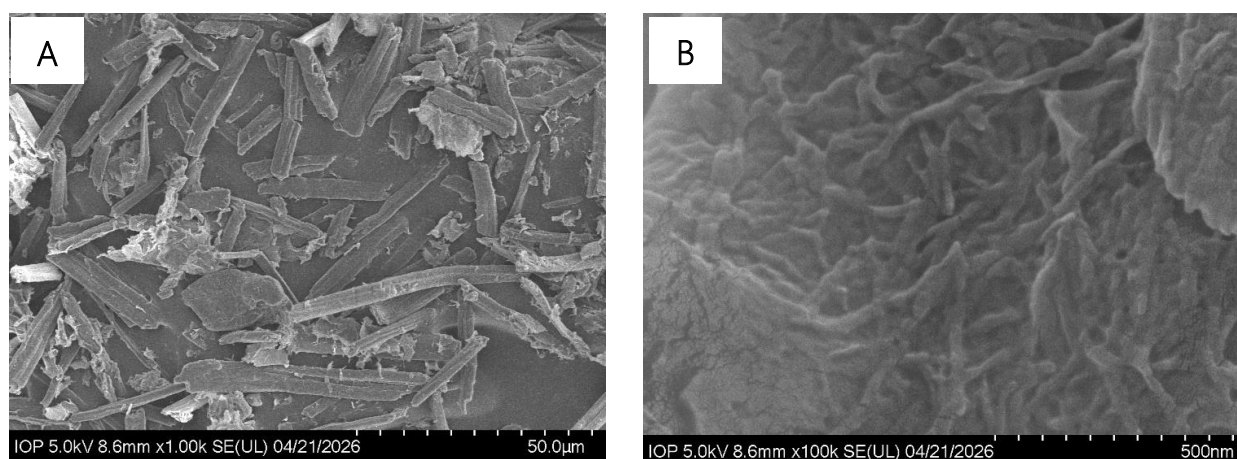


Fig 3: SEM of MCC (A) and nanocellulose (B) at x1,000 and x100,000 magnification

An analysis of water and oil absorption for the pineapple leaf-derived cellulose material samples (Table 3) revealed that pure fiber (PLB) exhibited low water and oil absorption, whereas purified cellulose showed relatively high absorption capacities (about 9 g/g), which was comparable or higher than water absorption of some types of alkaline treated fibers, such as cotton (8.9–6 g/g), banana fiber (2.4–4.8 g/g), pineapple fiber (1.7–3.0) [19] and fluff pulp [21]. MCC demonstrated the water absorption only slightly higher than that of pure fiber but significantly lower than that of purified cellulose. Possibly, as the small particle size of powdered MCC may have impeded water penetration. Nevertheless, the oil absorption of MCC remained substantially higher than that of pure fiber.

Freeze-dried nanocellulose exhibited superior water and oil absorption capacities compared to the above mentioned cellulose materials, reaching approximately 12 g/g for the water and 17 g/g for the oil. While freeze-dried nanocellulose powder possessed high liquid absorption capabilities, its production process is costly. The oil absorption capacity of virgin cellulose materials was equivalent to commercial fluff cellulose pulp and lower than that of modified cellulose aerogel, which had an oil absorption capacity of >40 g/g [22].

An assessment of the potential application of the obtained cellulose materials revealed that the purified cellulose, MCC, and nanocellulose hold significant promise for use as absorbent materials in hygiene and healthcare applications. While purified cellulose can be readily processed into absorbent materials in the form of pressed sheets or pellets, nanocellulose is typically limited to use as a filler layer. However, the composite materials can be fabricated by combining purified cellulose or MCC with nanocellulose using cellulose nanogel as a binder to create a cellulose-based nanomaterial with excellent absorption properties.

Table 3: Water and oil absorption of PLF derived cellulose and other cellulose materials

Cellulose samples	Water absorption, g/g	Oil absorption, g/g
Untreated leaf fiber (PLF)	2.15±0.14	2.88±0.19
Purified cellulose	8.96±0.96	9.73±1.02
Microcrystalline cellulose	4.76±0.31	4.89±0.27
Nanocellulose	11.89±0.18	17.06±0.31
Commercial fluff pulp	9.18±0.32	9.76±0.17

Preliminary fabrication tests of MCC pellets with diameters of 2–3 mm and purified cellulose sheets with

thicknesses of 5–6 mm demonstrated water absorption capacities of 4.02 g/g and 8.67 g/g, respectively. These values exceeded the water absorption capacities of commercial soybean-based cat litter and cotton-based patient underpads, and are comparable to the absorbent layer of sanitary pads (9.18 g/g), thereby confirming the potential for the development and application of these materials.

Conclusion

Pineapple leaf-derived purified cellulose, microcrystalline cellulose, and nanocellulose exhibited high water and oil absorption capacities.

Alkaline and acid treatments, together with the conversion of cellulose into microcrystalline cellulose and nanocellulose, reduced the ash content and improved liquid absorption capacities and cellulose purify to levels comparable with those of commercial fluff pulp. These results indicate that pineapple leaf-derived cellulose materials have potential for use as absorbents in hygiene and healthcare applications.

The research findings represented the fundamental scientific contributions toward developing technologies that utilize lignocellulosic agricultural residues for green production of new high purity cellulose fiber and agricultural development.

References

1. P. Rajput, A. Warrish, J.S. Chauhan, J. Hazard. Mater. Plast., 1 (2025) 100012. <https://doi.org/10.1016/j.hazmp.2025.100012>
2. A.H. Behrooz, T.H. Mekonnen, EcoMat, 8(4) (2026) e70063. <https://doi.org/10.1002/eom.2.70063>
3. N. Chandel, K. Jain, A. Jain, T. Raj, A.K. Patel, Y.-H. Yang, S.K. Bhatia, Ind. Crops Prod., 201 (2023) 116929. <https://doi.org/10.1016/j.indcrop.2023.116929>
4. A. Nogayev, K. Kudaibergenov, A. Togasheva, A. Zholbasarova, R. Bayamirova, B. Burkanov, A. Abdygaliyeva, N. Zhumagaliyeva, Polysaccharides, 7 (2026) 66. <https://doi.org/10.3390/polysaccharides7020066>
5. M.E. Winkler, M. Brosche, B. Kosan, K. Römhild, K. Thümmel, S. Fischer, Carbohydr. Polym., 388 (2026) 125420. <https://doi.org/10.1016/j.carbpol.2026.125420>
6. K.M. Salleh, M.E. Selamat, N.A. Nordin, Q. Zuo, Int. J. Biol. Macromol., 308 (2025) 142455. <https://doi.org/10.1016/j.ijbiomac.2025.142455>
7. M. Esquivel-Alfaro, B. Sulbarán-Rangel, O. Rojas-Carrillo, J. Chen, L. Rodríguez-Quesada, G. Sáenz-Arce, O.J. Rojas, Polymers, 17 (2025) 2671. <https://doi.org/10.3390/polym17192671>

8. L. Nguyen, G.C. Tu, T.P. Le, N.H.N. Do, V.T. Tran, T.P. Mai, T.V. Le, K.A. Le, P.T.K. Le, *Chem. Eng. Trans.*, 97 (2022) 61–66. <https://doi.org/10.3303/CET2297011>
9. M. Esquivel-Alfaro, O. Rojas-Carrillo, B. Sulbarán-Rangel, L. Rodríguez-Barquero, H. Palacios-Hinestroza, O.J. Rojas, *J. Compos. Sci.*, 9 (2025) 652. <https://doi.org/10.3390/jcs9120652>
10. K. Pornbencha, S. Sringam, S. Piyanirund, A. Seubsai, P. Prapainainar, C. Niumnuy, S. Roddecha, P. Dittanet, *RSC Adv.*, 13 (2023) 15311–15321. <https://doi.org/10.1039/d3ra02693k>
11. D.M. Chaves, J.C. Araújo, C.V. Gomes, S.P. Gonçalves, R. Figueiro, D.P. Ferreira, *Heliyon*, 10(4) (2024) e26698. <https://doi.org/10.1016/j.heliyon.2024.e26698>
12. M.S. Abdul Karim, N. Zainol, N.I.A. Abu Hassan As'ari, N. Abu Talip Yusof, N.H. Aziz, *Biocatal. Agric. Biotechnol.*, 42 (2022) 102339. <https://doi.org/10.1016/j.bcab.2022.102339>
13. A. Rahman, *Processes*, 14 (2026) 159. <https://doi.org/10.3390/pr14010159>
14. L.Q. Dien, N.V. Huu, T.D. Cuong, *J. Sci. Technol.*, 4 (2025) 83–86. <https://tapchicongthuong.vn/an-pham/read/khoa-hoc-cong-nghe-so-4-thang-12-nam-2025-407.htm>
15. S.W. Kweon, T.J. Lee, Y.J. Lee, J.H. Seo, H.J. Kim, *Ind. Crops Prod.*, 235 (2025) 121824. <https://doi.org/10.1016/j.indcrop.2025.121824>
16. N. Chanka, W. Mondach, P. Dittanet, S. Roddecha, C. Niamnuy, P. Prapainainar, A. Seubsai, *Chemosphere*, 266 (2021) 129000. <https://doi.org/10.1016/j.chemosphere.2020.129000>
17. L.Q. Dien, T.D. Cuong, N.T.M. Phuong, P.H. Hoang, D.N. Truyen, N.T.M. Nguyet, *Energy Sources, Part A*, 46(1) (2024) 1458–1467. <https://doi.org/10.1080/15567036.2019.1687617>
18. N.H. Chung, L.Q. Dien, *Iran. J. Chem. Chem. Eng.*, 42(1) (2022) 27–37. <https://doi.org/10.30492/jicce.2022.543220.5024>
19. H. Begum, T. Tanni, M. Shahid, *J. Text. Sci. Technol.*, 7 (2021) 152–160. <https://doi.org/10.4236/jtst.2021.74013>
20. M.H. Sainorudin, N.A. Abdullah, M.S. Asmal Rani, M. Mohammad, M. Mahizan, N. Shadan, N.H. Abd Kadir, Z. Yaakob, A. El-Denglawey, M. Alam, *Nanotechnol. Rev.*, 10(1) (2021) 793–806. <https://doi.org/10.1515/ntrev-2021-0053>
21. S. Rebola, J. Ferreira, D.V. Evtuguin, *J. Eng. Fibers Fabr.*, 15 (2020) 1–13. <https://doi.org/10.1177/1558925020980146>
22. H.T. Nguyen, C.D. Pham, N.H. Do, C.V. Truong, L.T. Nguyen, V.T. Tran, K.A. Le, P.K. Le, *Biomass Convers. Biorefin.*, 15 (2025) 10453–10464. <https://doi.org/10.1007/s13399-024-05836-3>