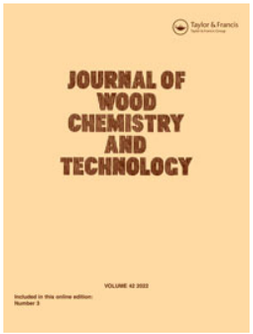

Journal of Wood Chemistry and Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/lwct20

Investigation of the potentiality of five bamboo species in biorefinery through analysis of chemical profiles

Mohammad Jakir Hossain, Rupak Kumar Ghosh, Atanu Kumar Das, Shambhu Chandra Nath, Md. Rakibul Islam, Shaheen Akhter & Md. Saidur Rahman

To cite this article: Mohammad Jakir Hossain, Rupak Kumar Ghosh, Atanu Kumar Das, Shambhu Chandra Nath, Md. Rakibul Islam, Shaheen Akhter & Md. Saidur Rahman (2022) Investigation of the potentiality of five bamboo species in biorefinery through analysis of chemical profiles, Journal of Wood Chemistry and Technology, 42:3, 204-210, DOI: 10.1080/02773813.2022.2055770

To link to this article: https://doi.org/10.1080/02773813.2022.2055770

Published online: 28 Mar 2022.

JOURNAL OF WOOD CHEMISTRY AND TECHNOLOGY
2022, VOL. 42, NO. 3, 204–210
https://doi.org/10.1080/02773813.2022.2055770

Taylor & Francis
Taylor & Francis Group

NOTE

Investigation of the potentiality of five bamboo species in biorefinery through analysis of chemical profiles

Mohammad Jakir Hossain[a], Rupak Kumar Ghosh[a], Atanu Kumar Das[b], Shambhu Chandra Nath[a], Md. Rakibul Islam[a], Shaheen Akhter[a], and Md. Saidur Rahman[a]

[a]Forest Chemistry Division, Bangladesh Forest Research Institute, Chittagong, Bangladesh; [b]Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Umeå, Sweden

ABSTRACT

Determination of the chemical composition of biomaterial is important for their valued utilization in biorefinery. In this study, the chemical composition of five bamboo species, i.e., mitinga (*Bambusa tulda*), borak (*Bambusa balcooa*), rengoon (*Thyrsostachys oliveri*), orah (*Dendrocalamus longispathus*), and bajja (*Bambusa vulgaris*) were determined. The chemical characterization of these bamboo species can expedite a further study on the extraction of cellulose and lignin. α-cellulose content was in the range of 42.7–45.7% and Klason lignin content was 22.4–28.2%. The ash content was 1.8–4.3% for the studied five bamboo species. The α-cellulose and lignin content were similar to other non-timber spices. The ash content was lower than other non-timber species. Therefore, these species can be a potential source of raw material for biorefinery.

KEYWORDS

Bamboo; chemical characterization; biorefinery

Introduction

Sustainability and environmental conservation are the most emergent and dominated affairs that are related to the use of renewable resources, which are devoted worldwide.[1–3] The use of raw materials and products that are renewable, sustainable, and biocompatible has emerged a sturdy interest in the world. In this context, the demand for a substitute to resources, which mitigated the environmental problems, has been populated.[4] Over the past few decades, bamboo has received ever more attention as a renewable, fast-growing resource.[1,5] Research has progressed rapidly due to its wide availability and material characteristics comparable to wood. Non-timber forest products (NTFP) like bamboo play a major role in mitigating the pressure on slow-growing forest resources and the growing demand for qualitative timber.[1] Recently, there are also growing interested in the utilization of bamboo for pulp production,[6,7] nanofiber extraction,[8] composite materials,[5,9–13] biofuel production,[14–16] and wastewater treatment.[17]

Bamboo, a perennial woody grass, plays a significant role as a material for consumer products. With its high growth rate, awide range of applications, and renewability, bamboo resources occupy a noteworthy position in the twenty-first century as a versatile and vital raw material.[18] It attains maturity in 3 years as compared to wood, which takes almost more than 20 years.[19] It is one of the fastest-growing plants that grow in the unproductive area. New shoots are generated from harvested clum as root structure remains alive after harvest.[20,21] Bamboo grows in plains, hilly, and high altitude mountainous regions, and in most kinds of soils, except alkaline soils, desert, and marsh.[22] It is widely distributed in Asian countries and has become one of the most potential renewable non-woody cellulosic materials because of its high productivity, rapid growth, and easy propagation.[8,16,20] The annual production of bamboo is approximately 20 million tons globally.[23]

Chemical characterization of raw material is vital in determining its suitability for various applications and treatments. The accurate compositional analysis enables the evaluation of potential conversion yields and process economics.[24] Knowledge of the physico-chemical properties of bamboo is essential for effective utilization of bamboo since Information regarding basic properties is very confined. In Bangladesh, there are many

CONTACT Atanu Kumar Das atanu.kumar.das@slu.se Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, SE- 90183, Umeå, Sweden.

This article has been republished with minor changes. These changes do not impact the academic content of the article.

bamboo species, which are widely used as a household material. However, due to advanced processing technology and increased market demand, it has been extended to industrial applications, i.e., pulp and paper, furniture, and construction. Since many bamboo species remain unutilized, research is needed to determine their properties so that appropriate technologies can be developed to exploit them.

Therefore, the proposed study was undertaken for the chemical characterization of five bamboo species. Their proper end uses were discussed based on the results obtained from chemical analysis.

Material and methods

Raw materials

The mature (3–4 years) culms of five bamboo species, namely mitinga (*Bambusa tulda*), borak (*Bambusa balcooa*), rengoon (*Thyrsostachys oliveri*), orah (*Dendrocalamus longispathus*), and bajja (*Bambusa vulgaris*), were sourced from Keucia silvicultural research station, Bangladesh Forest Research Institute (BFRI), Satkania, Chattogram (92°24′E and 93°15′E longitude and 24°22′N and 25°8′N latitude), Bangladesh.

Reagent grade (≥95% purity) sodium hydroxide (NaOH), acetic acid (CH_3COOH), sodium chlorite ($NaClO_2$), and sulfuric acid (H_2SO_4) were received from Carolina Biological Supply Company, New York City, USA. Analytical grade (≥95% purity) benzene and ethanol were sourced from Merck KGA, Darmstadt, Germany.

Preparation of raw material

The bamboo culms were cut at 15 cm above ground level and then subdivided equally into the top, middle and basal portions according to their total length. The internodes of each portion were cut into small strips and chipped by a hammer mill. The chips were dried in the sun and milled by a Wiley mill to get fine particles and the powder of three portions mixed thoroughly to obtain a representative sample of a whole bamboo. The powders were then sieved to obtain in the range of <40 mesh to >60 mesh. This procedure was applied for all five species used in this study. The powders were stored in an air-tight container for further analysis. The sample preparation is presented in Figure 1.

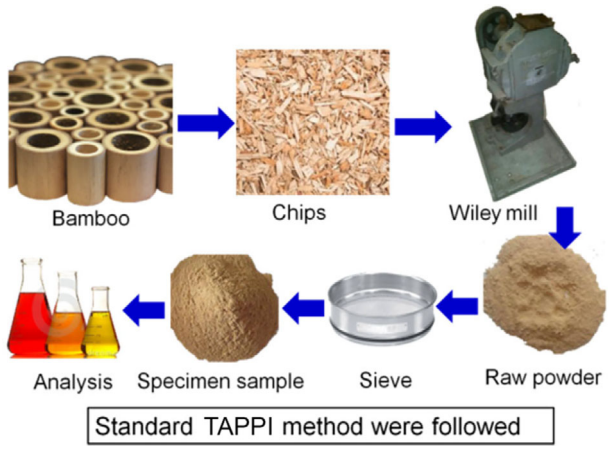

Figure 1. Preparation procedure of bamboo powder for chemical analysis.

Chemical analysis

Chemical analysis of five bamboo species was conducted based on TAPPI standards. Solubility, extractive content, cellulose content, lignin content, and ash content were analyzed in this study.

Solubility

Water and alkaline solubility were measured. For water solubility, both cold and hot water solubility was studied. T-207 cm-99 standard was used to analyze cold and hot water solubility and alkaline solubility was determined by T-212 om-02 standard.

Cold water solubility

The sample (2 g) was placed in a 500 ml beaker, and 300 ml of distilled water was added to the beaker. After completely wetting the sample, extraction was carried out with constant stirring at room temperature (23 °C) for 48 h. The mixture was then transferred to a tared filtering crucible and washed with 200 ml of cold distilled water. After that, it was dried at 105 °C to a constant weight. The following equation was used to calculate the cold water solubility.

$$\text{Cold water solubility } (\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the test specimen, respectively.

Hot water solubility

The sample (2 g) was put in a 250 ml conical flask, and 100 ml of hot distilled water was poured into the flask. The mixture was placed in a boiling water bath and digested by the reflux condenser for 3 h. Then,

the mixture was transferred to a tared filtering crucible and washed with 200 ml of hot distilled water. It was dried at 105 °C until reaching constant weight. The calculation of hot water solubility was done using the following equation.

$$\text{Hot water solubility } (\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the test specimen, respectively.

Alkaline solubility

The sample was (2 g) kept in a 500 ml conical flask, and 100 ml of 1% NaOH solution was added. The mixture was stirred with a glass rod, and it was then placed in a water bath at 97–100 °C for a period of 60 min. After that, it was transferred to a tared filtering crucible and washed with 100 ml of hot water. In the next, it was soaked in 25 ml of 10% CH_3COOH for 1 min followed by soaking in 15 ml of 10% CH_3COOH for 1 min. Finally, it was washed with hot water until the complete removal of the remaining acid. Alkaline solubility was calculated using the following equation.

$$\text{Alkaline solubility } (\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the test specimen, respectively.

Extractive

Extractive content was determined following the T-204 cm-97 standard a 5 g sample was used for this analysis. The solvent was a mixture of benzene and ethanol in the ratio of 2:1 and kept in a flask. Soxhlet apparatus was used to extract extractive for a period of a period of 4–5 h. The solvent was evaporated and the flask was dried at 105 ± 3 °C for 1 h followed by cooling in a desiccator and weighing. The extractive content was determined using the following equation

$$\text{Extractive content } (\%) = \left[(W_e - W_b)/W_p\right] \times 100$$

where W_e, W_p, and W_b are the weight (dry mass) of the flask with the extractive, bamboo powder, and flask, respectively.

Cellulose

Holocellulose and α-cellulose were determined to identify the cellulose content of five bamboo species for this study. Holocellulose and α-cellulose were analyzed by following the standard of T 249-75 and T 203 cm-99, respectively.

Holo-cellulose

A two-gram extractive-free sample, 160 ml of distilled water, 0.2 ml of cold CH_3COOH, and 1 g of $NaClO_2$ were placed in a 250 ml flask. It was then placed into a water bath at 70–80 °C for 5 h. One gram of $NaClO_2$ and 0.2 ml of cold CH_3COOH were added to the mixture with continuous stirring in a 1 h interval. At the end of 5 h, the flasks were placed in an ice water bath and filtered into a known weight of coarse porosity fritted-glass crucible. The residue was washed with acetone followed by ethanol. The crucibles were then oven-dried at 105 °C and weighed until a constant weight was reached. The following equation was used to determine the holocellulose content.

$$\text{Holo} - \text{cellulose content in bamboo } (\%) = (W_3 - W_4)/(100 \times W_2) \times (100 - W_1)$$

Where W_1 is alcohol-toluene extractive content (percent), W_2, W_3, and W_4 were weight (dry mass) of samples, residue and crucible, and crucible, respectively.

α-Cellulose

A 3 g of oven-dried holocellulose sample was placed in a 250 ml Erlenmeyer flask and it was then put in a water bath maintaining a temperature of 20 °C. Then, 50 ml of 17.5% NaOH solution was poured into the flask and mixed thoroughly for one minute. After that, the specimen was allowed to react with the solution for 29 min followed by adding 50 ml of distilled water and mixing for another minute. The mixture was kept for another 5 min to complete the reaction, and it was filtered using a known weight of fritted-glass crucible with the aid of vacuum suction. The residue was washed with 50 ml of 8.3% NaOH followed by 40 ml of 10% CH_3COOH, and 1000 ml of hot distilled water. The crucible was oven-dried in an oven at 103 ± 2 °C until obtaining a constant weight. α-Cellulose was determined using the following formula.

$$\alpha - \text{cellulose } (\%) = (W_3 - W_4)/(100 \times W_2) \times W_1$$

where W_1 is holocellulose content (percent), W_2, W_3, and W_4 were weight (dry mass) of holo-cellulose sample, residue and crucible, and crucible, respectively.

Lignin

Klason lignin content was analyzed based on the T-222 cm-02 standard. A 2 g of extractive free bamboo

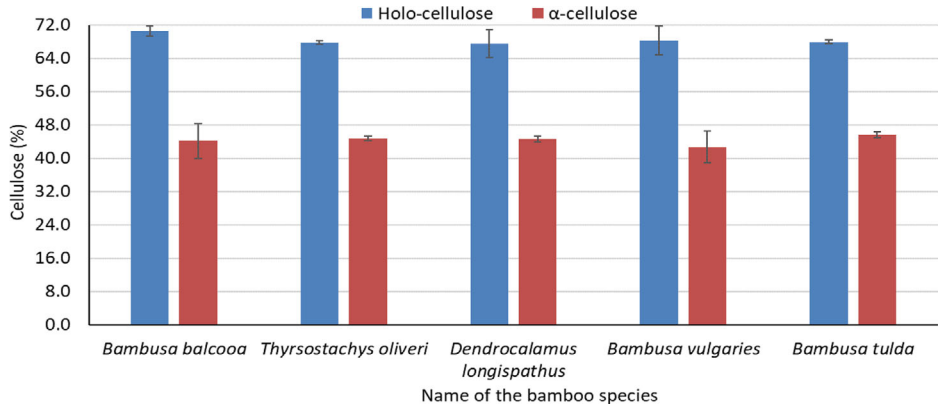

Figure 2. Cellulose content of five bamboo species.

powder was placed in a beaker and 40.0 ml of 72% H_2SO_4 was added and stirred with a glass rod continuously until complete dispersion of the sample. It was then transferred to the flask and 1540 ml of hot water was added to the mixture. The mixture was boiled for 4 h, maintaining constant volume by the addition of hot water frequently. After that, it was kept overnight. Then, it was filtered using a known weight of fritted-glass crucible by the aid of vacuum suction and washed with hot water to remove the residual acid from the lignin. The residue containing the crucible was oven-dried at 103 ± 2 °C until obtaining a constant weight. Klason lignin content was calculated using the following equation.

$$\text{Klason lignin content}(\%) = \left[(W_2 - W_3)/W_1\right] \times 100$$

where W_1, W_2, and W_3 were the weight (dry mass) of the sample, residue and crucible, and crucible, respectively.

Ash content

The ash content was determined according to the standard of T211om-93. A 5 g of bamboo powder was put in the known oven-dry weight of the crucible. Then, it was ignited at a temperature of 575 ± 25 °C for 5 h. The crucible containing residue was placed in a desiccator to cool down and weighed. The ash content was calculated based on the following equation.

$$\text{Ash content } (\%) = \left[(W_2 - W_3)/W_1\right] \times 100$$

where W_1, W_2, and W_3 were the weight (dry mass) of the sample, residue and crucible, and crucible, respectively.

Results and discussions

Cellulose

Holo-cellulose and α-cellulose content of five bamboo species are presented in Figure 2. *B. balcooa* showed the highest amount (70.5%) of holo-cellulose and it was significantly higher than that of *B. tulda*, *T. oliveri*, *D. longispathus*, *and B. vulgaris*. α-Cellulose content was in the range of 42.7–45.7% and *B. tulda* had the highest content (45.7) of α-cellulose. The α-cellulose content of five bamboo species was similar to *Neosinocalamus affinis* (44.9%) observed in the previous study.[15] It was higher than non-wood species, i.e., *M. sapientum* (39.4%), *E. crassipes* (35.2%), and a frond of *C. nucifera* (40.2%).[25,26] In comparison to wood and other bamboo species, five bamboo species showed more or less similar content of cellulose in the present study.

Lignin

The measured Klason lignin content of five bamboo species has been shown in Figure 3. The lowest Klason lignin content (22.4%) was observed for *B. balcooa*. It was significantly lower than the other four bamboo species. The range of Klason lignin content was 27.5–28.2 for *B. tulda*, *T. oliveri*, *D. longispathus*, and *B. vulgaris*. It was the lower and similar value of *N. affinis* (28.2%) obtained from the previous study. In other studies, *M. sapientum* (14.2%), *E. crassipes* (15.3%), and a frond of *C. nucifera* (19.9%) showed the lower value of Klason lignin content.[25,26] The Klason lignin content of five bamboo species was comparatively similar to other bamboo and wood species.

Solubility

Figure 4 represents the solubility of five bamboo species. *B. tulda* showed the highest solubility (26.30%) in 1% NaOH solution. *B. vulgaries* was more susceptible to both cold (10.56%) and hot water (16.28%)

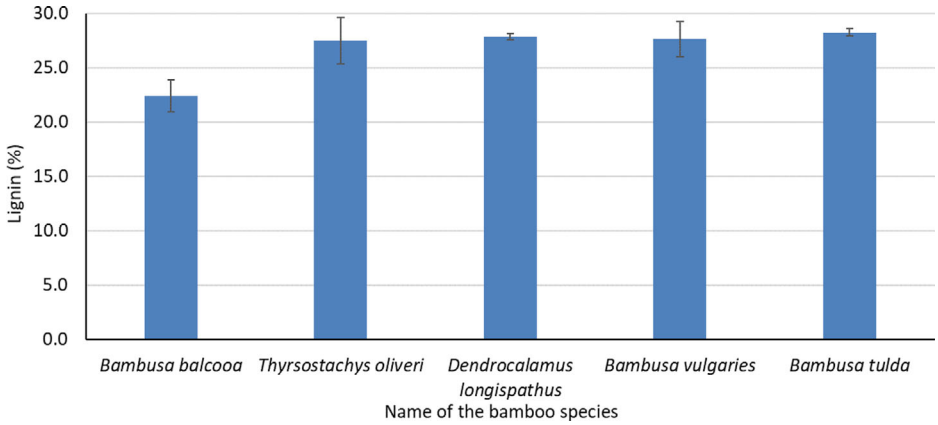

Figure 3. Klason lignin content of five bamboo species.

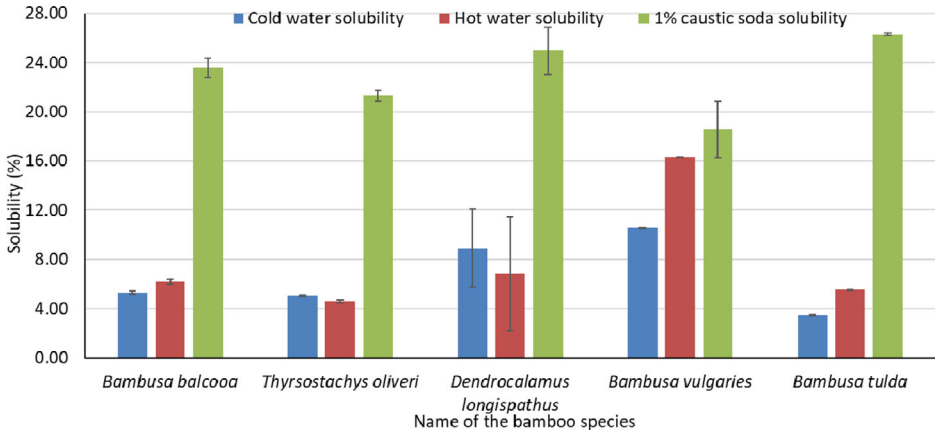

Figure 4. Solubility of five bamboo species.

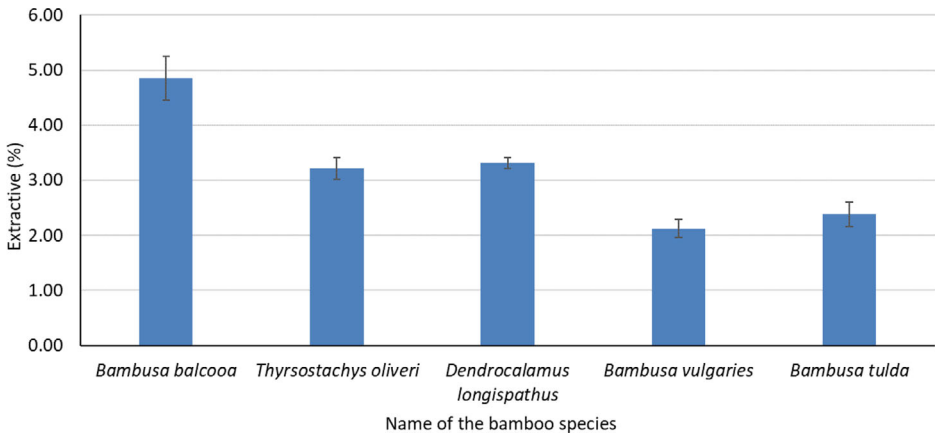

Figure 5. Extractive content of five bamboo species.

than other species in this study. Cellulose is more resistant but xylan is soluble to NaOH,[27] which may cause the higher solubility in 1% NaOH solution.

Extractive

The benzene-ethanol extractive content of five bamboo species is shown in Figure 5. The highest extractive content (4.85%) was found for *B. balcooa* and it was the lowest (2.12%) for *B. vulgaris*. The hexane extractive of *M. sapientum*, *E. crassipes*, and a frond of *C. nucifera* was 1.1, 2.4, and 3.4%, respectively and acetone extractive of them was 2.6, 3.8, and 4.4, respectively.[25] The extractive content of five bamboo species of this study was in the range of other non-wood species.

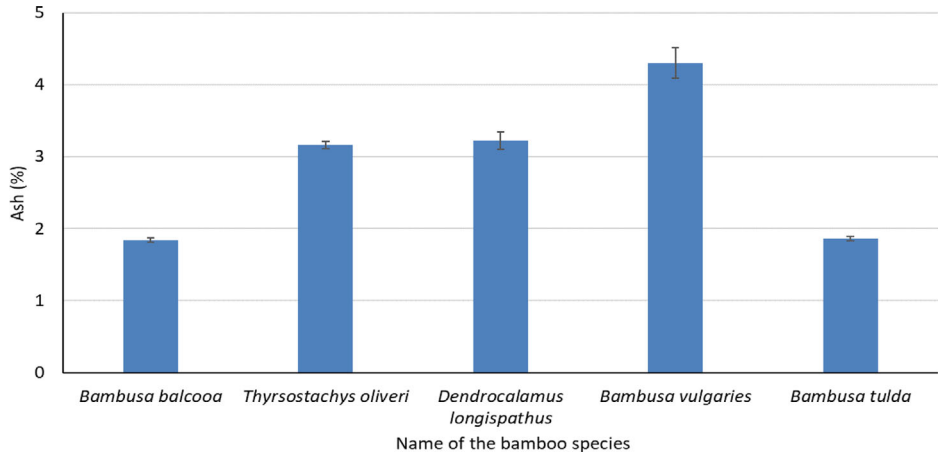

Figure 6. Ash content of five bamboo species.

Ash

Ash content of five bamboo species has been presented in Figure 6. The ash content was 1.8–4.3% for five bamboo species. The determined ash content was the highest (4.3%) for *B. vulgaris* and it was the lowest (1.8%) for *B. balcooa*. The ash content of *M. sapientum*, *E. crassipes,* and a frond of *C. nucifera* was 18.3, 10.2, and 5.6%, respectively.[25] The bamboo species had a lower amount of ash content compared to other non-wood species obtained from previous studies.

Future prospective of five bamboo species

Cellulose and lignin are the most valuable resources for developing value-added products. The forest is the main source of cellulose and lignin leading to deforestation. Considering the environmental issues and sustainability of biorefinery, alternative resources are crucial. Non-timber forest resources can contribute to mitigating the problem of raw material shortage. Bamboo is fast-growing, and it can harvest in three years. The significant content of cellulose and lignin and less amount of ash of five bamboo species compared to other non-wood species can appeal to consider them as an alternative source of cellulose and lignin.

Conclusions

Chemical analysis has been conducted for five bamboo species in this study. Cellulose and lignin content was more or less close to the wood and other non-timber species. The ash content was lower than other non-timber species. Lower ash content and higher cellulose and lignin content of these bamboo species indicate the potential source of raw material for the biorefinery. Further studies are needed to develop a suitable cellulose and lignin extraction method for these new raw materials. It can help contribute as an alternative source of raw material in biorefinery.

Acknowledgments

The authors would like to express their gratitude to Bangladesh Forest Research Institute (BFRI) and Forest Chemistry Division for their logistic support, sincere assistance and encouragement.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Authors' contributions

Mohammad Jakir Hossain: Conceptualization, data acquisition, visualization, literature review, writing—original draft, writing—review & editing. Rupak Kumar Ghosh: Data acquisition, writing—review & editing. Atanu Kumar Das: Conceptualization, literature review, writing—original draft, writing—review & editing, visualization. Shambhu Chandra Nath: Visualization, writing—review & editing. Md. Rakibul Islam: Writing—review & editing. Shaheen Akhter: Writing—review & editing. Md. Saidur Rahman: Writing—review & editing.

Funding

Financial support from the Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh, Building#8, Level#13, Bangladesh Secretariat, Dhaka 1000, Bangladesh.

References

[1] Lugt, P.; Vogtländer, J.; Brezet, H. *Bamboo, a Sustainable Solution for Western Europe: Design Cases LCAs and Land-Use*; VSSD, Elsevier B.V., **2009**.

[2] Tarabanko, V. E.; Kaygorodov, K. L.; Vigul, D. O.; Tarabanko, N.; Chelbina, Y. V.; Smirnova, M. A. Influence of Acid Prehydrolysis on the Process of Wood Oxidation into Vanillin and Pulp. *J. Wood Chem. Technol.* **2020**, *40*, 421–433. DOI: 10.1080/02773813.2020.1835984.

[3] Tarabanko, V. E.; Kaygorodov, K. L.; Skiba, E. A.; Tarabanko, N.; Chelbina, Y. V.; Baybakova, O. V.; Kuznetsov, B. N.; Djakovitch, L. Processing Pine Wood into Vanillin and Glucose by Sequential Catalytic Oxidation and Enzymatic Hydrolysis. *J. Wood Chem. Technol.* **2017**, *37*, 43–51. DOI: 10.1080/02773813.2016.1235583.

[4] Liu, D. G.; Song, J. W.; Anderson, D. P.; Chang, P. R.; Hua, Y. Bamboo Fiber and Its Reinforced Composites: Structure and Properties. *Cellulose* **2012**, *19*, 1449–1480. DOI: 10.1007/s10570-012-9741-1.

[5] Tong, J.; Ma, Y. H.; Chen, D. H.; Sun, J. Y.; Ren, L. Q. Effects of Vascular Fiber Content on Abrasive Wear of Bamboo. *Wear* **2005**, *259*, 78–83. DOI: 10.1016/j.wear.2005.03.031.

[6] Sridach, W. The Environmentally Benign Pulping Process of Non-Wood Fibers. *Suranaree J. Sci. Technol.* **2010**, *17*, 105–123.

[7] Rasheed, M.; Jawaid, M.; Karim, Z.; Abdullah, L. C. Morphological, Physiochemical and Thermal Properties of Microcrystalline Cellulose (MCC) Extracted from Bamboo Fiber. *Molecules* **2020**, *25*, 2824. DOI: 10.3390/molecules25122824.

[8] Visakh, P. M.; Thomas, S.; Oksman, K.; Mathew, A. P. Effect of Cellulose Nanofibers Isolated from Bamboo Pulp Residue on Vulcanized Natural Rubber. *Bioresources* **2012**, *7*, 2156–2168. DOI: 10.15376/biores.7.2.2156-2168.

[9] Amada, S.; Untao, S. Fracture Properties of Bamboo. *Compos. B. Eng.* **2001**, *32*, 449–457. DOI: 10.1016/S1359-8368(01)00022-1.

[10] Chiu, H. H.; Young, W. B. Characteristic Study of Bamboo Fibers in Preforming. *J. Compos. Mater.* **2020**, *54*, 3871–3882. DOI: 10.1177/0021998320923144.

[11] Jain, S.; Kumar, R.; Jindal, U. C. Mechanical-Behavior of Bamboo and Bamboo Composite. *J. Mater. Sci.* **1992**, *27*, 4598–4604. DOI: 10.1007/BF01165993.

[12] Muhammad, A.; Rahman, M. R.; Hamdan, S.; Sanaullah, K. Recent Developments in Bamboo Fiber-Based Composites: A Review. *Polym. Bull.* **2019**, *76*, 2655–2682. DOI: 10.1007/s00289-018-2493-9.

[13] Viel, Q.; Esposito, A.; Saiter, J. M.; Santulli, C.; Turner, J. A. Interfacial Characterization by Pull-out Test of Bamboo Fibers Embedded in Poly(Lactic Acid). *Fibers* **2018**, *6*, 7. DOI: 10.3390/fib6010007.

[14] Sindhu, R.; Kuttiraja, M.; Binod, P.; Sukumaran, R. K.; Pandey, A. Bioethanol Production from Dilute Acid Pretreated Indian Bamboo Variety (*Dendrocalamus* sp.) by Separate Hydrolysis and Fermentation. *Ind. Crops Prod.* **2014**, *52*, 169–176. DOI: 10.1016/j.indcrop.2013.10.021.

[15] Yang, H. Y.; Shi, Z. J.; Xu, G. F.; Qin, Y. J.; Deng, J.; Yang, J. Bioethanol Production from Bamboo with Alkali-Catalyzed Liquid Hot Water Pretreatment. *Bioresour. Technol.* **2019**, *274*, 261–266. DOI: 10.1016/j.biortech.2018.11.088.

[16] Sun, S. L.; Wen, J. L.; Ma, M. G.; Sun, R. C. Enhanced Enzymatic Digestibility of Bamboo by a Combined System of Multiple Steam Explosion and Alkaline Treatments. *Appl. Energy* **2014**, *136*, 519–526. DOI: 10.1016/j.apenergy.2014.09.068.

[17] Yuan, J.; Zhu, Y.; Wang, J.; Liu, Z.; Wu, J.; Zhang, T.; Li, P.; Qiu, F. Agricultural Bamboo Leaf Waste as Carbon Precursor for the Preparation of Cu-Al/Biomass Fiber Adsorption and Its Application in the Removal of Ammonia Nitrogen Pollutants from Domestic Wastewater. *J. Wood Chem. Technol.* **2021**, *41*, 137–149. DOI: 10.1080/02773813.2021.1914110.

[18] Salam, K. *Bamboo for Economic Prosperity and Ecological Security*; Facets of the North-East 2, **2008**.

[19] Khalil, H.; Bhat, I. U. H.; Jawaid, M.; Zaidon, A.; Hermawan, D.; Hadi, Y. S. Bamboo Fibre Reinforced Biocomposites: A Review. *Mater. Des.* **2012**, *42*, 353–368. DOI: 10.1016/j.matdes.2012.06.015.

[20] Kleinhenz, V.; Midmore, D. J. Aspects of Bamboo Agronomy. *Adv. Agron.* **2001**, *74*, 99–153. DOI: 10.1016/S0065-2113(01)74032-1.

[21] Vogtlander, J. G.; Lugt, P. *The Environmental Impact of Industrial Bamboo Products: Life-cycle Assessment and Carbon Sequestration*; **2015**. http://resolver.tudelft.nl/uuid:2b1f58e2-2a72-4247-bf57-49eb7d5646a1 (accessed October 20, 2021).

[22] Kumar, S.; Dobriyal, P. B. Treatability and Flow Path Studies in Bamboo Part I. *Dendrocalamus strictus* Nees. *Wood Fiber Sci.* **2007**, *24*, 113–117.

[23] Hu, Y.; Tang, L. R.; Lu, Q. L.; Wang, S. Q.; Chen, X. R.; Huang, B. Preparation of Cellulose Nanocrystals and Carboxylated Cellulose Nanocrystals from Borer Powder of Bamboo. *Cellulose* **2014**, *21*, 1611–1618. DOI: 10.1007/s10570-014-0236-0.

[24] Sluiter, J. B.; Ruiz, R. O.; Scarlata, C. J.; Sluiter, A. D.; Templeton, D. W. Compositional Analysis of Lignocellulosic Feedstocks. 1. Review and Description of Methods. *J. Agric. Food Chem.* **2010**, *58*, 9043–9053. DOI: 10.1021/jf1008023.

[25] Das, A. K.; Nakagawa-Izumi, A.; Ohi, H. Evaluation of Pulp Quality of Three Non-Wood Species as Alternative Raw Materials for Paper Production. *Jpn. Tappi J.* **2015**, *69*, 548–554. DOI: 10.2524/jtappij.1501.

[26] Das, A. K.; Nakagawa-Izumi, A.; Ohi, H. Quality Evaluation of Dissolving Pulp Fabricated from Banana Plant Stem and Its Potential for Biorefinery. *Carbohydr. Polym.* **2016**, *147*, 133–138. DOI: 10.1016/j.carbpol.2016.03.103.

[27] Horvath, A. L. Solubility of Structurally Complicated Materials: I. Wood. *J. Phys. Chem. Ref. Data* **2006**, *35*, 77–92. DOI: 10.1063/1.2035708.