Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Characterisation of Axonopus compressus Fibre through Chemical Composition, Thermogravimetric Behaviour, and Moisture Content Evaluation

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ARTICLE INFO

Article history:
Received 10 July 2023
Received in revised form 14 September 2023
Accepted 23 September 2023
Available online 13 October 2023

Keywords:
Axonopus compressus; fibre; moisture content

ABSTRACT

The thermal properties and moisture content of Axonopus compressus, a common grass species used for various purposes, have received insufficient attention. This study aims to investigate these facets, utilising insights from previous research on the plant's numerous applications, such as soil erosion prevention, water purification, and heavy metal pollution treatment. The study extracted Axonopus compressus fibre from Melaka, Malaysia, using the water retting method and analysed its chemical composition using neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) according to ISO standards. The results indicated a chemical composition of 27.28 % cellulose, 22.56 % hemicellulose, and 4.79 % lignin. Thermal gravimetric analysis (TGA) was used to determine the fibre's thermal stability and decomposition behaviour. The initial decomposition temperature of the fibres was 228 °C, with maximum decomposition occurring at 360 °C. In addition, the moisture content was measured at 14.95 %.

1. Introduction

Axonopus compressus is a common grass in warm and tropical areas, as shown in Figure 1. According to research by Azuddin *et al.,* [1] the grass that is also known as lawn grass, tropical carpet grass, blanket grass, broadleaf carpet grass, and savannah grass, is a short-spreading perennial grass. A study conducted by Rahman *et al.,* [2] revealed the Axonopus compressus has creeping stems with long stolons that spread above the ground and root at the nodes. Samarakoon *et al.,* [3] stated that Axonopus compressus is a native grass to America and has spread to numerous tropical and subtropical nations.

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https://doi.org/10.37934/arfmts.110.1.172181

As discussed by Samedani *et al.,* [4] Axonopus compressus is one of the soft grass species that is widely used as ground cover to protect soil erosion and as turf grass for landscaping and for sports fields. It is also utilised in pastures for grazing animals as well as a ground cover in oil palm and rubber plantations. As highlighted by Nawaz *et al.,* [5] Axonopus compressus is a robust and stoloniferous grass with flowering stems that can be up to 45 cm tall. The leaves generally form a dense mat that seldom reaches a height of more than 15 cm leaves according to the findings of He *et al.,* [6].

Fig. 1. Overview of Axonopus compressus

Based on research by Arunbabu *et al.,* [7], Axonopus compressus has been utilised in a horizontal sub-surface flow constructed wetland to treat greywater and tolerate the influent wastewater as well as show impressive removal rates of key contaminants. That study supports the integration of Axonopus compressus into constructed wetlands for environmental protection, water purification, and recycling. The results indicated that constructed wetlands planted with Axonopus compressus performed better than the unplanted control in treating greywater. As outlined by Yu *et al.,* [8] the study demonstrated utilisation of Axonopus compressus in a sulphonated biochar solvothermal method that was conducted at low temperatures for treating heavy metal pollution. Sulphonated biochar derived from Axonopus compressus exhibited rapid and effective adsorption of heavy metals like lead and cadmium.

A detailed study by Rupasinghe and Halwatura [9] identified Axonopus compressus as the optimal plant species for the Vertical Greening Systems (VGS) and showed a marked improvement in thermal performance since there was temperature reduction recorded on the external wall surface and the internal wall surface. A study by Li *et al.,* [10] evaluated Axonopus compressus to have effects on climate indicators such as air temperature and humidity comparable to swimming pools. Axonopus compressus showed the same effect on air temperature, mean radiant temperature, wind velocity, relative humidity, and physiological equivalent temperature as swimming pools, according to the daily variation of climate indicators studied in the research. In similar research done by Zhang *et al.,* [11], Axonopus compressus was used to create a lawn in the center of the square, surrounded by granite and other landscape elements such as arbors, shrubs, pavements, and a pond contributed to the significant night time cooling effects. The thermal properties of Axonopus compressus, in combination with its interaction with other natural and man-made elements, affected the spatiotemporal distribution of air temperature (Ta) within the experimental area.

Based on the findings by Burnley *et al.,* [12], municipal waste assessment involves estimating the volume of waste and subsequently converting it to dry weight values based on the waste proportions. Among the analysed yard waste, grass cuttings were reported to be the second most volumes although their production was seasonal. Similarly, Rahman *et al.,* [13] found that the Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Selangor, generated a significant amount of landscape waste. The primary components of this waste were dry leaves, fresh green leaves, and grass cuttings.The increasing demand for eco-friendly materials increased the thorough investigation of natural fibres for various applications as reported by Jumaidin *et al.,* [14].

According to Berthet *et al.,* [15] for sustainable materials, the moisture content of natural fibres is a crucial factor. According to Taharuddin *et al.,* [16] sugar palm nanofibrillated cellulose had improved the water barrier properties of sugar palm starch based films.This property affected the physical and mechanical properties of fibre, interactions with other substances, durability, and suitability for various applications.

While numerous studies have investigated the plant's physical and mechanical properties and interactions with other substances, a research gap exists in understanding its thermal properties and moisture content. These two aspects are crucial because they influence the fibre's physical and mechanical attributes and its durability and applicability in various contexts. The present study aims to contribute to the field by examining the thermal properties and moisture content of Axonopus compressus fibre. Furthermore, the research sets out to determine its water retention capabilities. By quantifying these specific parameters, the study aims to provide essential data that will serve as a foundation for future research and practical applications. This contribution is intended to facilitate the utilisation of Axonopus compressus in areas requiring materials with specific thermal and moisture-related properties, broadening its scope and increasing its potential for sustainability and environmental conservation.

2. Methodology

2.1 Materials

Axonopus compressus fibre was sourced from Melaka, Malaysia. The extraction process of Axonopus compressus fibre was carried out using the water retting method. The minimum time required for the water retting is 2 weeks depending on the Axonopus compressus grass texture itself. When the leaves of Axonopus compressus grass became soft enough, the leaves were torn into smaller parts to ease the following grinding process. After the tearing, the leaves were dried under the sunshine for a few hours. Then, the leaves were dried at 80 ^{o}C for 12 hours in a drying oven.

The dried leaves of Axonopus compressus grass were cut into smaller pieces before undergoing the grinding process that produced fine Axonopus compressus grass fibre. Next, the fibre was sieved by using sieve shaker into different sizes, and stored in zip-locked bags until further use according to Taharuddin *et al.,* [16].

2.2 Chemical Composition

The chemical composition of Axonopus compressus fiber was evaluated via neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) following the ISO 13906:2008 standard according to Kamaruddin *et al.,* [17].

2.3 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis was carried out to identify the thermal degradation behaviour of the material with respect to weight loss due to temperature increment. TGA was conducted with a Mettler-Toledo AG, Analytical from Schwerzenbach, Switzerland. The specimen weighed around 10±2 mg. The analysis was performed in an aluminium pan under a dynamic nitrogen atmosphere in the temperature range of 30 to 600°C at a heating rate of 10°C min^{-1} according to Hafila *et al.,* [18].

2.4 Moisture Content

Five samples were prepared for the moisture content investigation. The samples were heated in an oven for 24 h at 105 ^oC. The weight of the samples before (Mi) and after (Mf) heating was obtained in order to calculate the moisture content according to Kamaruddin *et al.,* [19]. The moisture content of the samples was calculated from Eq. (1) and summarised in Table 4.

$$\text{Moisture content (\%)} = \frac{Mi-Mf}{Mi} \text{ x } 100 \tag{1}$$

3. Results

3.1 Chemical Composition

According to Table 1, the chemical composition of Axonopus compressus fibre revealed important findings about its fibre content and structural elements. Cellulose, hemicellulose, and lignin were the three primary components analysed in this study following ISO 13906:2008 standard.

Table 1
Comparative composition of natural fibres.

Fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	References
Axonopus compressus	27.28	22.56	4.79	Current study
Pandanus amaryllifolius	48.79	19.95	18.64	Diyana *et al.,* [20]
Cymbopogan citratus	37.56	29.29	11.14	Kamaruddin *et al.,* [17]
Calotropis gigantea	64.47	9.64	13.56	Narayanasamy *et al.,* [21]
Tridax procumbens	32.00	6.80	3.00	Vijay *et al.,* [22]
Ficus religiosa	55.58	13.86	10.13	Moshi *et al.,* [23]
Bamboo	73.83	12.49	10.5	Muhammad *et al.,* [24]
Sugarcane	48.00	14.60	12.10	Fitch-Vargas *et al.,* [25]
Jute	66.00	17.00	12.50	Kumar *et al.,* [26]
Sisal	65.00	12.00	9.90	Kumar *et al.,* [26]
Kenaf	72.00	20.30	9.00	Kumar *et al.,* [26]
Cassava bagasse	27.00	30.00	2.70	Travalini *et al.,* [27]
Arenga pinnata	43.88	7.24	33.24	Ilyas *et al.,* [28]
Pandanus tectorius	37.30	34.40	22.60	Sheltami *et al.,* [29]

The chemical composition of Axonopus compressus fibre in Table 1 was compared to other natural fibres. Axonopus compressus fibre had a cellulose content of 27.28 %, which was significantly lower than those fibres of Pandanus Amarylifolius, sugarcane, and Arenga Pinnata, which stood at 48.79 %, 48 %, and 43.83 %, respectively. In addition, this fibre lagged behind other natural fibres, such as Calotropis gigantea, Ficus Religiosa, bamboo, jute, sisal, and kenaf which have cellulose contents of 64.47 %, 55.58 %, 73.8 %, 66 %, 65 %, and 72 %, respectively. According to Wan Ishak *et al.,* [30], with an increase in its cellulose content, the mechanical properties improved. With decreased cellulose levels, the structural integrity of Axonopus compressus fibre weakened. This increased the likelihood of physical damage as the fibre became less resistant to forces.

As outlined by Subash *et al.,* [31], hemicellulose was discovered to strengthen plant cell walls through its interaction with cellulose, playing a vital biological role. Hemicellulose content of Axonopus compressus fibre at 22.56 % was equivalent to kenaf fibre at 20.3 % and Pandanus amaryllifolius fibre at 19.95 %. Relatively lower hemicellulose content of Axonopus compressus compared to Cymbopogan citratus fibre at 29.29 %, Cassava bagasse at 30.00 %, and Pandanus tectorius at 34.40 % was observed. According to Diyana *et al.,* [32], the presence of hydrophobic substances such as lignin in Axonopus compressus fibre confers moisture resistance, enhancing fibre stability and rigidity of tensile strength. Axonopus compressus fibre had a lower lignin content at 4.79 % than Arenga pinnata at 33.24 %, Pandanus tectorius at 22.6% and Pandanus amaryllifolius at 18.64 %. In addition, it contained less lignin than bamboo, sugarcane, jute, sisal, and kenaf, which had respective lignin contents of 10.5 %, 12.1 %, 12.5 %, 9.9 %, and 9 %.

3.2 Thermogravimetric Analysis (TGA)

The decomposition and thermal stability of Axonopus compressus fibre were thoroughly investigated using Thermogravimetric Analysis (TGA) and derivative thermogravimetric (DTG) curves, as shown in Figure 2.

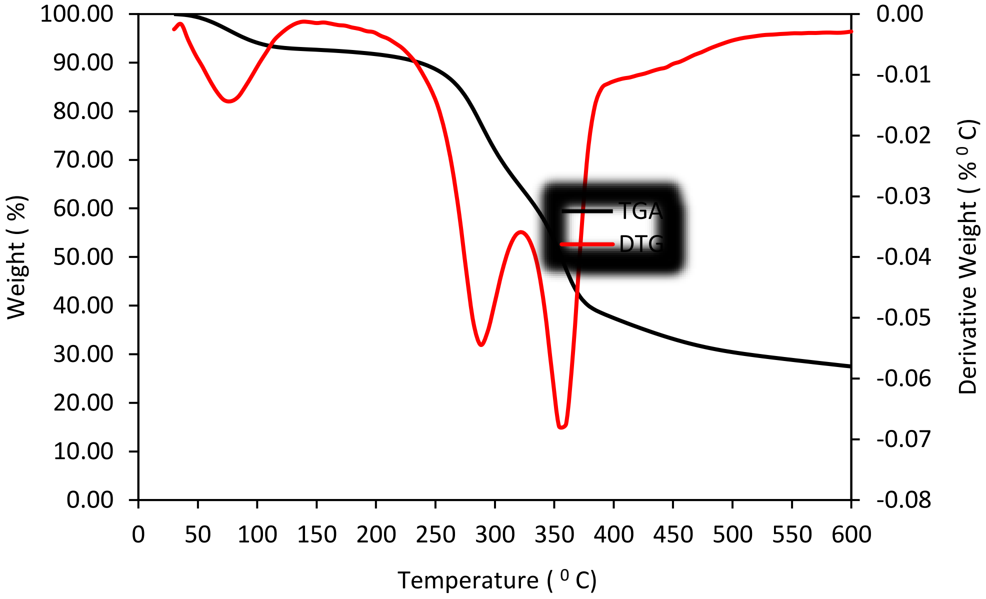

Fig. 2. TGA and DTG curves of Axonopus compressus fibre

Beginning at 30 °C and ending at 78 °C, the first phase involved evaporation of the fibre's moisture content and other volatile components. Then, hemicellulose was thermally decomposed between 78 and 228°C during the second degradation phase. A study conducted by Yang *et al.,* [33] stated that hemicellulose decomposition typically begins around 220 °C. The second peak occurred at 228 °C. At this temperature, the rate of weight loss during this phase of thermal degradation was at its maximum, signifying the maximum rate of hemicellulose decomposition. The final phase of degradation lasted from 228 to 360°C. Throughout this phase, cellulose and lignin decomposed. This phase exhibited a prominent peak at 360 °C, representing the maximum cellulose and lignin degradation rates.

The thermal degradation analysis of Axonopus compressus fibre is shown in Table 2. The first phase resulted in a weight loss of 3.57 %, from an initial weight of 100 to 96.43 %. Ilyas *et al.,* [28] have previously reported that such a loss is typically the result of water evaporation or inherent moisture in natural fibres. In many natural fibres, including Axonopus compressus, water was often trapped within the microscopic structure. As the temperature rose, this moisture was driven off, leading to an initial loss in mass. Then in the second phase of thermal degradation, hemicellulose was degraded, resulting in a 6.06 % reduction in fibre weight from 96.43 to 90.59 %. Throughout the final phase, cellulose and lignin decomposed. The weight of the fibre decreased from 90.59 % at 228 °C to 47.50 % at 360 °C as a result of this process, indicating a significant weight loss of approximately 47.57 %. The final phase involved a significant weight loss, where cellulose and lignin decomposed. Cellulose generally broke down at higher temperatures than hemicellulose, and lignin was degraded over a wide temperature range. After complete thermal degradation at 600 °C, the final residual mass amounted to 27.49 % of the material's weight after thermal decomposition, composed primarily of inorganic components resistant to thermal decomposition. According to Pattnaik *et al.,* [34], the residual mass refers to the remaining material after completely degrading lignin.

Table 2
Thermal Degradation Analysis of Axonopus compressus fibre

Sample	1st Thermal Degradation			2nd Thermal Degradation			3th Thermal Degradation			Residue (wt%)
Axonopus compressus	T_1 (°C)	Weight Loss (%)	T_{peak} (°C)	T_2 (°C)	Weight Loss (%)	T_{peak} (°C)	T_3 (°C)	Weight Loss (%)	T_{peak} (°C)	27.49
	30 to 78	3.57	78	78 to 228	6.06	228	228 to 360	47.57	360	

In Table 3, the thermal behavior of various natural fibres was compared. The fibres included in the table were Axonopus compressus, Cymbopogan citratus, roselle, and kenaf. The table provides information on the initial decomposition temperature and the maximum decomposition temperature for each fibre. For Axonopus compressus, the initial decomposition temperature was recorded as 228 °C. This indicated that the fibre started to degrade when exposed to temperatures above this temperature. Furthermore, the highest temperature of decomposition observed for Axonopus compressus was 360 °C. The result revealed that Axonopus compressus fibre experienced its highest rate of degradation at 360 °C, implying significant chemical changes and weight loss within this temperature range. The result showed that the temperature at which each fibre degraded at its fastest rate was unique. The initial decomposition temperature of Axonopus compressus was 228 °C, which was lower than the initial decomposition temperatures of Cymbopogan citratus at 230 °C indicated by Kamaruddin *et al.,* [17]. These differences in decomposition temperatures were attributed to variations in the chemical composition and structural properties of the different fibres. Factors such as fibre morphology, cellulose content, lignin content, and other organic compounds could affect the thermal stability and decomposition behavior of the fibres.

Table 3
Temperatures of degradation comparison

Natural Fibre	Initial Decomposition (°C)	Maximum Decomposition (°C)	References
Axonopus compressus	228	360	Current study
Cymbopogan citratus	230	338	Kamaruddin *et al.,* [17]
Roselle	210	366	Razali *et al.,* [35]
Kenaf	219	284	De Rosa *et al.,* [36]

3.3 Moisture Content

The moisture content of this specific fibre has been studied and presented in Table 4. When a comparative analysis was undertaken between Axonopus compressus and a range of other natural fibres including those detailed in Table 4, the moisture content of Axonopus compressus showed a higher value than the other fibres examined. When a comparative analysis was initiated, the focus was not only on Axonopus compressus but also encompassed a broad range of other natural fibres. These fibres, known for their applications in various industrial sectors, were carefully selected to represent a diversity of material characteristics.

Table 4
Comparative moisture content of natural fibres

Fibre	Moisture (%)	References
Axonopus compressus	14.95	Current study
Hylocereus polyrhizus	9.70	Taharuddin *et al.,* [16]
Pandanus amaryllifolius	6.00	Diyana *et al.,* [20]
Cymbopogan citratus	5.20	Kamaruddin *et al.,* [17]
Calotropis gigantea	7.27	Narayanasamy *et al.,* [21]
Tridax procumbens	11.20	Vijay *et al.,* [37]
Ficus Religiosa	9.33	Moshi *et al.,* [38]
Coccinia grandis	9.14	Abera *et al.,* [39]
Cissusquadrangularis root	7.30	Indran *et al.,* [40]
Bamboo	7.00	Muhammad *et al.,* [24]
Axacia tortilis	6.47	Dawit *et al.,* [41]
Arenga pinnata	8.36	Ilyas *et al.,* [28]

The result of moisture content for Axonopus compressus showed 14.95 %, which was the highest among other natural fibres studied. Such a high moisture content revealed significant hydrophilic properties of Axonopus compressus. This could have indicated a chemical composition that led to a greater affinity for water. Such a characteristic may make it particularly suitable for applications where high moisture retention is beneficial. In contrast, fibres like Cymbopogan citratus exhibited a significantly lower moisture content of 5.20 %, as reported by Kamaruddin *et al.,* [42] indicating different interactions with water molecules.

4. Conclusions

In conclusion, the comprehensive analysis of Axonopus compressus fibre has revealed a detailed insight into its chemical composition, thermal behaviour, and moisture content. The cellulose content of Axonopus compressus fibre was significantly lower than other natural fibres. The equivalent hemicellulose content of Axonopus compressus fibre with certain fibres like kenaf and Pandanus amaryllifolius strengthening plant cell walls. The lower lignin content of Axonopus compressus has implications for moisture resistance. The thermal degradation analysis indicated distinct decomposition phases of hemicellulose, cellulose, and lignin. The final residual mass pointed to inorganic components resistant to thermal decomposition. Comparative analysis with other fibres also showed a significant decomposition temperature range for Axonopus compressus. The higher moisture content of Axonopus compressus uncovered its unique hydrophilic properties, potentially opening avenues for specific applications where high moisture retention is advantageous.

Acknowledgement

The study was funded by a grant from the Ministry of Higher Education (MOHE) of Malaysia through the Short Term Research Grant, No: S01815 PJP/2021/FTKMP/S01815. The Authors also would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for all the support.

References

[1] Azuddin, Nurul Farizah, Mohamad Syahril Mohamad Noor Azmy, and Latiffah Zakaria. "Molecular identification of endophytic fungi in lawn grass (Axonopus compressus) and their pathogenic ability." *Scientific Reports* 13, no. 1 (2023): 4239. https://doi.org/10.1038/s41598-023-31291-7

[2] Rahman, FM Mustafizur, SM Fuad Kabir, Md Nurnabi, AM Sarwaruddin Chowdhury, and Md Al Amin Sikder. "Chemical and Biological Investigations of Axonopus compressus (Sw.) P. Beauv." *Bangladesh Pharmaceutical Journal* 17, no. 1 (2014): 113-115. https://doi.org/10.3329/bpj.v17i1.22345

[3] Samarakoon, S. P., J. R. Wilson, and H. M. Shelton. "Growth, morphology and nutritive quality of shaded Stenotaphrum secundatum, Axonopus compressus and Pennisetum clandestinum." *The Journal of Agricultural Science* 114, no. 2 (1990): 161-169. https://doi.org/10.1017/S0021859600072154

[4] Samedani, B., A. S. Juraimi, M. P. Anwar, M. Y. Rafii, S. H. Sheikh Awadz, and A. R. Anuar. "Competitive interaction of Axonopus compressus and Asystasia gangetica under contrasting sunlight intensity." *The Scientific World Journal* 2013 (2013). https://doi.org/10.1155/2013/308646

[5] Nawaz, Mohsin, Liao Li, Farrukh Azeem, Samina Shabbir, Ali Zohaib, Umair Ashraf, Hubiao Yang, and Zhiyong Wang. "Insight of transcriptional regulators reveals the tolerance mechanism of carpet-grass (Axonopus compressus) against drought." *BMC Plant Biology* 21, no. 1 (2021): 1-14. https://doi.org/10.1186/s12870-021-02844-7

[6] He, Li, Li Teng, Xiaomin Tang, Wanwan Long, Zhiyong Wang, Yang Wu, and Li Liao. "Agro-morphological and metabolomics analysis of low nitrogen stress response in Axonopus compressus." *AoB Plants* 13, no. 4 (2021): plab022. https://doi.org/10.1093/aobpla/plab022

[7] Arunbabu, V., S. Sruthy, Ignatius Antony, and E. V. Ramasamy. "Sustainable greywater management with Axonopus compressus (broadleaf carpet grass) planted in sub surface flow constructed wetlands." *Journal of Water Process Engineering* 7 (2015): 153-160. https://doi.org/10.1016/j.jwpe.2015.06.004

[8] Yu, Weibin, Jiwen Hu, Yichang Yu, Dongdong Ma, Wenting Gong, Hongxuan Qiu, Zhangjun Hu, and Hong-wen Gao. "Facile preparation of sulfonated biochar for highly efficient removal of toxic Pb (II) and Cd (II) from wastewater." *Science of The Total Environment* 750 (2021): 141545. https://doi.org/10.1016/j.scitotenv.2020.141545

[9] Rupasinghe, H. T., and R. U. Halwatura. "Benefits of implementing vertical greening in tropical climates." *Urban Forestry & Urban Greening* 53 (2020): 126708. https://doi.org/10.1016/j.ufug.2020.126708

[10] Li, Jiayu, Bohong Zheng, and Komi Bernard Bedra. "Evaluating the improvements of thermal comfort by different natural elements within courtyards in Singapore." *Urban Climate* 45 (2022): 101253. https://doi.org/10.1016/j.uclim.2022.101253

[11] Zhang, Xiang, Lihua Zhao, Lingye Yao, Xue Zhong, and Peng Ren. "Investigating the micro-scale thermal effects of natural underlying surfaces on adjacent spaces in a subtropical zone with an optimized method." *Building and Environment* 222 (2022): 109382. https://doi.org/10.1016/j.buildenv.2022.109382

[12] Burnley, S. J., J. C. Ellis, R. Flowerdew, A. J. Poll, and H. Prosser. "Assessing the composition of municipal solid waste in Wales." *Resources, Conservation and Recycling* 49, no. 3 (2007): 264-283. https://doi.org/10.1016/j.resconrec.2006.03.015

[13] Rahman, Mohammad Hariz Abdul, Tosiah Sadi, Aimi Athirah Ahmad, Intan Nadhirah Masri, Masnira Mohammad Yusoff, Hasliana Kamaruddin, Nur Alyani Shakri, Mohamad Abhar Akmal Hamid, and Rashidah Ab Malek. "Inventory and composting of yard waste in Serdang, Selangor, Malaysia." *Heliyon* 6, no. 7 (2020). https://doi.org/10.1016/j.heliyon.2020.e04486

[14] Jumaidin, R., S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari. "Characteristics of thermoplastic sugar palm Starch/Agar blend: Thermal, tensile, and physical properties." *International Journal of Biological Macromolecules* 89 (2016): 575-581. https://doi.org/10.1016/j.ijbiomac.2016.05.028

[15] Berthet, M-A., Nathalie Gontard, and H. Angellier-Coussy. "Impact of fibre moisture content on the structure/mechanical properties relationships of PHBV/wheat straw fibres biocomposites." *Composites Science and Technology* 117 (2015): 386-391. https://doi.org/10.1016/j.compscitech.2015.07.015

[16] Taharuddin, Nurul Hanan, Ridhwan Jumaidin, Muhd Ridzuan Mansor, Fahmi Asyadi Md Yusof, and Roziela Hanim Alamjuri. "Characterization of Potential Cellulose from Hylocereus Polyrhizus (Dragon Fruit) peel: A Study on Physicochemical and Thermal Properties." *Journal of Renewable Materials* 11, no. 1 (2023). https://doi.org/10.32604/jrm.2022.021528

[17] Kamaruddin, Zatil Hafila, Ridhwan Jumaidin, Ahmad Ilyas Rushdan, Mohd Zulkefli Selamat, and R. Hanim Alamjuri. "Characterization of natural cellulosic fiber isolated from Malaysian Cymbopogan citratus leaves." *BioResources* 16, no. 4 (2021): 7729. https://doi.org/10.15376/biores.16.4.7729-7750

[18] Hafila, K. Z., R. Jumaidin, R. A. Ilyas, M. Z. Selamat, and Fahmi Asyadi Md Yusof. "Effect of palm wax on the mechanical, thermal, and moisture absorption properties of thermoplastic cassava starch composites." *International Journal of Biological Macromolecules* 194 (2022): 851-860. https://doi.org/10.1016/j.ijbiomac.2021.11.139

[19] Kamaruddin, Zatil Hafila, Ridhwan Jumaidin, Rushdan Ahmad Ilyas, Mohd Zulkefli Selamat, Roziela Hanim Alamjuri, and Fahmi Asyadi Md Yusof. "Biocomposite of cassava starch-cymbopogan citratus fibre: Mechanical, thermal and biodegradation properties." *Polymers* 14, no. 3 (2022): 514. https://doi.org/10.3390/polym14030514

[20] Diyana, Z. N., R. Jumaidin, M. Z. Selamat, R. H. Alamjuri, and Fahmi Asyadi Md Yusof. "Extraction and characterization of natural cellulosic fiber from pandanus amaryllifolius leaves." *Polymers* 13, no. 23 (2021): 4171. https://doi.org/10.3390/polym13234171

[21] Narayanasamy, P., P. Balasundar, S. Senthil, M. R. Sanjay, Suchart Siengchin, Anish Khan, and Abdullah M. Asiri. "Characterization of a novel natural cellulosic fiber from Calotropis gigantea fruit bunch for ecofriendly polymer composites." *International Journal of Biological Macromolecules* 150 (2020): 793-801. https://doi.org/10.1016/j.ijbiomac.2020.02.134

[22] Vijay, R., D. Lenin Singaravelu, A. Vinod, M. R. Sanjay, Suchart Siengchin, Mohammad Jawaid, Anish Khan, and Jyotishkumar Parameswaranpillai. "Characterization of raw and alkali treated new natural cellulosic fibers from Tridax procumbens." *International Journal of Biological Macromolecules* 125 (2019): 99-108. https://doi.org/10.1016/j.ijbiomac.2018.12.056

[23] Moshi, A. Arul Marcel, D. Ravindran, SR Sundara Bharathi, S. Indran, S. S. Saravanakumar, and Yucheng Liu. "Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree." *International Journal of Biological Macromolecules* 142 (2020): 212-221. https://doi.org/10.1016/j.ijbiomac.2019.09.094

[24] Muhammad, Adamu, Md Rezaur Rahman, Sinin Hamdan, and Khairuddin Sanaullah. "Recent developments in bamboo fiber-based composites: a review." *Polymer Bulletin* 76 (2019): 2655-2682. https://doi.org/10.1007/s00289-018-2493-9

[25] Fitch-Vargas, Perla Rosa, Irma Leticia Camacho-Hernández, Fernando Martínez-Bustos, Alma Rosa Islas-Rubio, Karen Itzel Carrillo-Cañedo, Abraham Calderón-Castro, Noelia Jacobo-Valenzuela, Armando Carrillo-López, Carlos Iván Delgado-Nieblas, and Ernesto Aguilar-Palazuelos. "Mechanical, physical and microstructural properties of acetylated starch-based biocomposites reinforced with acetylated sugarcane fiber." *Carbohydrate Polymers* 219 (2019): 378-386. https://doi.org/10.1016/j.carbpol.2019.05.043

[26] Kumar, P. Sai Shravan, and K. Viswanath Allamraju. "A review of natural fiber composites [Jute, Sisal, Kenaf]." *Materials Today: Proceedings* 18 (2019): 2556-2562. https://doi.org/10.1016/j.matpr.2019.07.113

[27] Travalini, Ana Paula, Buddhi Lamsal, Washington Luiz Esteves Magalhães, and Ivo Mottin Demiate. "Cassava starch films reinforced with lignocellulose nanofibers from cassava bagasse." *International journal of biological Macromolecules* 139 (2019): 1151-1161. https://doi.org/10.1016/j.ijbiomac.2019.08.115

[28] Ilyas, Rushdan Ahmad, Salit Mohd Sapuan, Rushdan Ibrahim, Hairul Abral, M. R. Ishak, E. S. Zainudin, Mochamad Asrofi et al. "Sugar palm (Arenga pinnata (Wurmb.) Merr) cellulosic fibre hierarchy: A comprehensive approach from macro to nano scale." *Journal of Materials Research and Technology* 8, no. 3 (2019): 2753-2766. https://doi.org/10.1016/j.jmrt.2019.04.011

[29] Sheltami, Rasha M., Ibrahim Abdullah, Ishak Ahmad, Alain Dufresne, and Hanieh Kargarzadeh. "Extraction of cellulose nanocrystals from mengkuang leaves (Pandanus tectorius)." *Carbohydrate Polymers* 88, no. 2 (2012): 772-779. https://doi.org/10.1016/j.carbpol.2012.01.062

[30] Wan Ishak, Wan Hafizi, Noor Afizah Rosli, and Ishak Ahmad. "Influence of amorphous cellulose on mechanical, thermal, and hydrolytic degradation of poly (lactic acid) biocomposites." *Scientific Reports* 10, no. 1 (2020): 11342. https://doi.org/10.1038/s41598-020-68274-x

[31] Subash, Mira chares, and Perumalsamy Muthiah. "Eco-friendly degumming of natural fibers for textile applications: A comprehensive review." *Cleaner Engineering and Technology* 5 (2021): 100304. https://doi.org/10.1016/j.clet.2021.100304

[32] Diyana, Z. N., R. Jumaidin, M. Z. Selamat, and M. S. M. Suan. "Thermoplastic starch/beeswax blend: Characterization on thermal mechanical and moisture absorption properties." *International Journal of Biological Macromolecules* 190 (2021): 224-232. https://doi.org/10.1016/j.ijbiomac.2021.08.201

[33] Yang, Haiping, Rong Yan, Hanping Chen, Dong Ho Lee, and Chuguang Zheng. "Characteristics of hemicellulose, cellulose and lignin pyrolysis." *Fuel* 86, no. 12-13 (2007): 1781-1788. https://doi.org/10.1016/j.fuel.2006.12.013

[34] Pattnaik, Falguni, Sonil Nanda, Vivek Kumar, Satyanarayan Naik, and Ajay K. Dalai. "Isolation of cellulose fibers from wetland reed grass through an integrated subcritical water hydrolysis-pulping-bleaching process." *Fuel* 311 (2022):

122618. https://doi.org/10.1016/j.fuel.2021.122618

[35] Razali, Nadlene, S. M. Sapuan, Mohammad Jawaid, Mohamad Ridzwan Ishak, and Yusriah Lazim. "Mechanical and thermal properties of Roselle fibre reinforced vinyl ester composites." *BioResources* 11, no. 4 (2016): 9325-9339. https://doi.org/10.15376/biores.11.4.9325-9339

[36] De Rosa, Igor Maria, Josè Maria Kenny, Debora Puglia, Carlo Santulli, and Fabrizio Sarasini. "Morphological, thermal and mechanical characterization of okra (Abelmoschus esculentus) fibres as potential reinforcement in polymer composites." *Composites Science and Technology* 70, no. 1 (2010): 116-122. https://doi.org/10.1016/j.compscitech.2009.09.013

[37] Vijay, R., D. Lenin Singaravelu, A. Vinod, M. R. Sanjay, Suchart Siengchin, Mohammad Jawaid, Anish Khan, and Jyotishkumar Parameswaranpillai. "Characterization of raw and alkali treated new natural cellulosic fibers from Tridax procumbens." *International Journal of Biological Macromolecules* 125 (2019): 99-108. https://doi.org/10.1016/j.ijbiomac.2018.12.056

[38] Moshi, A. Arul Marcel, D. Ravindran, S. R. Sundara Bharathi, S. Indran, S. S. Saravanakumar, and Yucheng Liu. "Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree." *International Journal of Biological Macromolecules* 142 (2020): 212-221. https://doi.org/10.1016/j.ijbiomac.2019.09.094

[39] Abera, Getnet, Belay Woldeyes, Hundessa Dessalegn Demash, and Garret Miyake. "The effect of plasticizers on thermoplastic starch films developed from the indigenous Ethiopian tuber crop Anchote (Coccinia abyssinica) starch." *International Journal of Biological Macromolecules* 155 (2020): 581-587. https://doi.org/10.1016/j.ijbiomac.2020.03.218

[40] Indran, S., R. Edwin Raj, and V. S. Sreenivasan. "Characterization of new natural cellulosic fiber from Cissus quadrangularis root." *Carbohydrate Polymers* 110 (2014): 423-429. https://doi.org/10.1016/j.carbpol.2014.04.051

[41] Dawit, Jonathan B., Yohannes Regassa, and Hirpa G. Lemu. "Property characterization of acacia tortilis for natural fiber reinforced polymer composite." *Results in Materials* 5 (2020): 100054. https://doi.org/10.1016/j.rinma.2019.100054

[42] Kamaruddin, Zatil Hafila, Ridhwan Jumaidin, Mohd Zulkefli Selamat, and R. A. Ilyas. "Characteristics and properties of lemongrass (Cymbopogan citratus): a comprehensive review." *Journal of Natural Fibers* 19, no. 14 (2022): 8101-8118. https://doi.org/10.1080/15440478.2021.1958439