BirEx JOURNAL
Budapest International Research in Exact Sciences
Medical, Biological, Argiculture, Engineering Science and other related areas
e-ISSN : 2655-7827
p-ISSN : 2655-7835
http://www.bircu-journal.com/index.php/birex

Preliminary study on Gongronema latifolium stem fibers as a renewable engineering material for reinforcing polymer composites

Christian Emeka Okafor[1], Peter Chukwuemeka Ugwu[1,2], Godspower Onyekachukwu Ekwueme[3], Nürettin Akçakale[4], Emmanuel Ekene Ifedigbo[1], Augustine Uzodinma Madumere[1]

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Nigeria.
[2]Department of Power Engineering Technology, Nova Scotia Community College, Akeyley Campus, Dartmouth, Canada.
[3]Department of Industrial and Production Engineering, Faculty of Engineering, Nnamdi Azikiwe University Awka, Awka, Nigeria
[4]Textile, Clothing, Footwear and Leather Department, Gerede Vocational School of Higher Education, Abant İzzet Baysal University, Bolu 14900, Turkey
Email: ce.okafor@unizik.edu.ng, og.ekwueme@unizik.edu.ng

Abstract: *The ultimate analysis of Gongronema latifolium plant stem fibers was conducted to evaluate their potential as a renewable engineering material. The study utilized Gongronema latifolium plant fibers sourced from a local farm in Anambra State. Lignin determination was done by using 0.3 g samples prepared alongside 0.3 g for cellulose and crude fiber analyses. Key chemicals used included 72% sulfuric acid for lignin extraction and petroleum ether for defatting. Standard laboratory glassware and equipment, including a muffle furnace for ash content determination and an electric oven for drying, were employed. Ash content was determined from the incineration of 2 g of fibers at 800 °C and the bulk density was determined using a pycnometer. Moisture content was determined through oven drying while crude fibre was carried out using Association of Official Analytical Chemists (AOAC) procedure where sample was treated with refluxing acid and alkali solutions of sulfuric acid and sodium hydroxide respectively. Cellulose content was determined via the Crampton and Mayrand method, involving centrifugation and acid digestion. Samples for lignin content determination were subjected to 72% sulfuric acid hydrolysis and weights obtained were used for calculation of lignin. The percentages of cellulose content were 12.862%, lignin 10.301%, and hemicellulose 6.005%. The moisture content of stem fibers was determined to be 1.711% from a sample weight of 1.344 g. The ash content was calculated at 10.095% from a sample of 1.466 g. additionally, the fiber content was found to be 4.249% from a sample weight of 1.624 g, while the bulk density was measured at 0.417 g/ml. These findings indicate a favorable composition for reinforcing materials in composites and other engineering applications. As the findings have revealed, fibers obtained from Gongronema latifolium have notable potential in being used as the substitutes to the conventional engineering materials that would pave way for the creation of environmentally friendly products in the field of material engineering. Further studies are recommended to explore the processing techniques and performance characteristics of these fibers in reinforced composite applications.*

Keywords: *Gongronema latifolium, plant fibers, cellulose, lignin, renewable materials.*

I. Introduction

Natural fibers have received much interest as environmentally friendly engineering material because of their good mechanical properties, bio-degradability as well as least effects on the environment. These fibers are processes from different plant sources which makes them to have different chemical contents and their chemical contents determine their usage in specific areas (Okafor et al, 2022). The final characterization of natural fibers generally discusses the elemental composition of the fibers, particularly with regard to carbon, hydrogen, nitrogen, sulfur and oxygen. This analysis helps to understand the mechanical characteristics of fibers and their potential functional utility (Sadrmanesh & Chen, 2019). Cellulose, which provides most natural fibers with tensile strength and flexibility, is a polysaccharide. This feature makes the fibers usable in the composite materials, which are in high demand for use in construction, automotive, and aerospace industries (Szymańska-Chargot et al, 2017).

Besides cellulose, natural fibers have lignin and hemicellulose as the secondary constituents. Hemicellulose and lignin contributs to rigidity and resistance to decay in any environment (Wang et al, 2019). Hemicellulose, being comparatively less crystalline and hence less rigid that cellulose, plays a role in moisture absorption and heat resistant characteristics of the fibers. Altogether, these parts allow natural fibers to act as appropriate reinforcements in composite materials, enhancing mechanical properties and being environmentally friendly. Nitrogen content analysis is another important factor that forms part of the ultimate analysis (Okafor, 2021). Most of the natural fibers tend to have low nitrogen content and therefore they are not prone to microbial attack and decay. This property is useful for systems where durability and resistance to degradation is important.

Another important characteristic of natural fibers is ash content, which refers to inorganic matter remaining after combustion of the sample, as well as the purity level of the sought fibers. Less ash content often means that more of the organic material is of a higher purity and is beneficial for manufacturing processes to include fewer impurities in the end product (Okafor et al, 2022). Thermal characteristics of natural fibers are noteworthy for high temperature usage. Some research indicates that most natural fibers have high thermal stability, and, therefore, applicable to the creation of heat-resistant composites (Okafor et al, 2022). This characteristic coupled with the facts that natural fibers are biodegradable, therefore natural fibers can provide substitution to synthetic fiber products that poses environmental hazard.

Natural fibers also come with some great physical properties that can add aesthetic and sensory values to the products in consumer goods sector. Due to their renewability as well as low processing demands, these materials are associated with low carbon footprints than conventional materials (Okafor & Ihueze, 2020). Due to the use of synthetic materials in engineering applications, there is continued pollutions of the environment and depletion of resources. However, the study of new and unconventional materials regarding sustainability is, nevertheless, still limited. Gongronema latifolium plant stem fibers present a promising yet under-researched option for reinforcing polymer composites.

Current literature lacks comprehensive data on the ultimate analysis of these fibers, particularly their chemical composition, mechanical properties, and potential applications in engineering. Knowledge of these aspects is important for making the most of these materials as sustainable resources. However, even though numerous studies focus on the advantages of natural fiber, there is limited detailed information on Gongronema latifolium thus contributing to research lacunae which has an impact on its use in industries. It is important to fill this gap since sustainable development and the use of renewable resources such as Gongronema latifolium can have a major positive effect on the environment. The purpose of this research is to carry out a comprehensive ultima analysis of Gongronema latifolium fibers in order to determine their aptitude for usage as environmentally friendly engineering materials to enhance sustainability in the future of material science.

II. Research Methods

2.1 Material

The study utilized *Gongronema latifolium* plant fibers, which were collected from a local farm in Anambra state. A 0.3 g sample of the fibers was used for lignin determination, while 0.3 g samples were also prepared for cellulose and crude fiber analyses. Chemicals included 72% sulfuric acid for lignin extraction and petroleum ether for defatting. Glassware such as 16 x 100 mm test tubes, a desiccator, and a Gooch crucible were employed for the procedures. Additionally, a water bath was used for hydrolysis, and an electric oven was utilized for drying samples. All measurements adhered to standard laboratory practices.

2.2 Method

Determination of ash content: Ash content of the fibers was established from the residual weight after burning of the sample for *Gongronema latifolium*. This residue which was referred to as ash majorly contained inorganic matters. In the procedure a 2g sample was taken in this crucible (W_1) and spread evenly in the crucible using brush. The crucible was then taken and placed in a muffle furnace on which the heat was gradually turned up to 800 ^oC. When the temperature was raised to 800°C it was further retained for one hour to ensure that the sample was duly incinerated. The crucible was left to cool after the burning and later the crucible was placed in a desiccator. After it had cooled down the crucible was weighed again with the weight recording as W2. It is calculated as follows; weight of crucible after completion of combustion – weight of crucible taken before starting the combustion + weight of ash collected in the crucible. The ash content was then determined as the percentage of ash to the initial weight of the sample using the formula.

$$\text{Ash content} = \frac{W_2 - W_1}{\text{Weight of sample}} \times 100$$

Determination of Bulk Density: The bulk density of the fibers of the plant *Gongronema latifolium* was determined according to AOAC guidelines (1994). Firstly, a 50 ml capacity of a pycnometer bottle was washed with a detergent, followed by with water and Petroleum ether to clear any contamination. To make sure there was no liquid present in the bottle before the sample was added, the bottle was similarly weighed and spinning to get rid of moist before filling and weighing the bottle with the sample. The sample was also measured in a measuring cylinder and the volume was recorded next. The bulk density was calculated using the formula:

$$Bulk\ density = \frac{weight\ of\ Xml\ sample}{\text{Volume of sample}}$$

Determination of Moisture Content: Determination of moisture content of *Gongronema latifolium* fibers was done according to the following procedure outlined by AOAC (1994). This consisted in rinsing a petri dish and followed it by drying the same in an oven. One to two milligrams of the sample were taken out and placed into the petri dish. The weight of the empty petri dish and of the substance taken for drying was also noted before placing the samples for drying. The sample in the petri dish was then taken and placed in the oven at the temperature 105°C for two hours. The weight was recorded, then heating was done for further one hr. until constant weight was achieved. This drying process continued until a constant weight was achieved. The percentage of moisture content was calculated using the formula:

$$\% \; moisture \; content \; = \frac{w_1 - w_2}{\text{Weight of sample}} \times 100$$

Where w1 = weight of petridish and sample before drying, W2 weigh of petridish and sample after drying.

Determination of Crude Fibre: The crude fiber content of *Gongronema latifolium* fibers was analyzed using the AOAC (1994) method. Firstly, if the fat content in the material was more than 10%, 2 g of the material was defatted by petroleum ether. It was then boiled under reflux for 30 mins using 100ml of 1.25gm sulphuric acid in water. The solution was then filtered and the residue washed on the linen with hot water; the washings were titrated for acidity. The residue was then transferred to a beaker and the mixture boiled for a further half an hour with 1.25 g of carbonate-free sodium hydroxide per 100 ml of solution. Following this, the final residue was filtered through a thin but close pad of washed and ignited asbestos in a Gooch crucible. The residue was dried in an electric oven and weighed. After drying, it was incinerated, cooled, and weighed again. The loss in weight after incineration was calculated, and the percentage of crude fiber was determined using the formula:

$$\% \; crude \; fibre \; = \frac{weight \; of \; fibre}{\text{Weight of sample}} x \; 100$$

Determination of Cellulose Content of *Gongronema latifolium* fibers: Cellulose content was measured according to Crampton and Mayrand method of 1978. 3g of sample was measured ready and weighed into 50ml glass centrifuge tubes, 50ml of water was added and mixed, the contents were then centrifuged at 1500 revolutions per minute for ten minutes after which the supernatant drip was decanted. The sample was further mixed with 12.5ml of glacial acetic and 2.5ml of concentrated nitric acid and the precipitate was digested using boiling water bath for 20min and the resultant supernatant obtained. The supernatant was transferred to a Gooch crucible (w1), washed successfully with hot alcohol, 10ml of 90% benzene, and 60% of ether, dried and weighed, (w3) finally ashed (w2) and reweighed.

$$Cellulose \; content \; = \frac{w_3 - w_2}{w_1} x \;\; 100$$

W_3 = weight of dried sample, W_2 = weight of ash content, W_1 = weight of sample

Determination of Lignin content: The lignin content of the fibers of *Gongronema latifolium* was determined from the analized value with the aid of official method of AOAC (1994). To begin with, about 0.3 ± 0.01g of the calcium carbonate sample was taken and weighed accurately and placed in a 16×100 thin-walled test tube and named W1. To minimize variation, the analysis of each sample was performed in duplicate. Concurrently, samples for total solids determination were weighed to avoid moisture gain or loss that could affect the results; the average total solids value was recorded as Tfinal. Subsequently, 3.00 ± 0.01 mL of 72% sulfuric acid was then deployed and the test tube vortexed for one minute to ensure the sample is moistened thoroughly. The test tube was then placed in a water bath for a time of two hours at a temperature of 30 + /- 10°C for hydrolysis. The sample was then cooled in desiccator and the weight was noted as W2 which will be the weight of crucible with the amount of acid insoluble lignin and the amount of ash which remained insoluble to the acid. The weight of the crucible and acid-insoluble ash was also noted down as W3. The percentage of acid-insoluble residue on an extractive-free basis was calculated using the formula:

$$\%\ acid - insoluble\ residue = \frac{W_2 - W_3}{W_1 \text{ x } \frac{\%\text{ T final}}{100\%}} \times 100\%$$

Where W_1 = initial weight of extracted sample, W_2 = weight of crucible, acid-insoluble residue, acid – insoluble ash, W_3 = weight of crucible and acid- insoluble ash, % Tfinal = % total solids of the extracted sample determined at 105^0c as described by the standard method for the determination of total solids in biomass.

III. Results and Discussion

3.1 Cellulose content

Cellulose content = $\frac{(W_3 - W_2)}{W_1} * 100$

$$W_3 = weight\ of\ dried\ sample = 0.102$$

W_2 = weight of ash content = 0.062

W_1 = weight of sample = 0.311

$$Cellulose\ content\ \% = \frac{(0.102 - 0.062)}{0.311} * 100 = 12.862\%$$

3.2 Lignin Content

$$\%\ Lignin\ content = \frac{(\text{W2} - \text{W3}) * 100}{\text{W1} * \frac{[\%\ \text{Tfinal}]}{100\%}}$$

Where W_1 = initial weight of extracted sample = 0.302, W_2 = weight of crucible, acid-insoluble residue, acid and insoluble ash = 42.673, W_3 = weight of crucible and acid-insoluble ash = 42.645, % Tfinal = % total solids of the extracted sample determined at 105^0c as described by the standard method for the determination of total solids in biomass. Total solid = 100 – (moisture content). Moisture content = 9.740, % total solid = 100 – 9.740 = 90.260.

$$\%\ lignin = \frac{(42.673 - 42.645)}{0.302 * \frac{[90.260]}{100}} * 100 = 10.301\%$$

3.3 Hemicellulose

$$\%\ Hemicellulose = \frac{(\text{W}_2 - \text{W}_3) * 100}{\text{W}_1 - \frac{[\%\ \text{moisture content}]}{100\%}}$$

Where W_2 = 47.433, W_3 = 47.419, W_1 = 0.311, Moisture content = 6.785.

$$Hemicellulose\ \% = \frac{(47.433 - 47.419) * 100}{0.302 - \frac{[6.785]}{100}} == 6.005\%$$

Chemical composition of *Gongronema latifolium* Plant Stem Fibers includes carbohydrates such as cellulose, lignin, and hemicellulose. The cellulose content was estimated to be was 12.862% and is in accordance with previous works where cellulose levels in different plant materials (Szymańska-Chargot et al, 2017). On the other hand, the yield of lignin was identified to be 10.301%, which finds correlation with the existing studies that found that lignin was in a range of 0.60% to 45.00% in similar samples (Chokshi et al, 2022). This finding is supported by a related study that highlighted the crucial role of lignin in biomass recalcitrance, affecting degradation processes (Ren et al, 2024). Furthermore, hemicellulose content was calculated at 6.005%. This is slightly lower than previous reports where hemicellulose ranges from 6.8% thus showing that the percentage will depend on the specific biomass that has been weighed (Wang et al, 2019). Altogether, these results show that the density of cellulose, lignin, and hemicellulose determines biomass suitability for conversion into bioenergy. The variations observed emphasize the need for targeted studies to optimize biomass utilization strategies.

Table 1. Moisture Content of Gongronema latifolium Plant Stem Fibers

Samples	Weight of samples	Wt of crucible	Wt of sample+ crucible bf dry	Wt of sample + crucible after dry	% moisture content
Stem fibre	1.344	71.798	73.142	73.119	1.711

Table 1 illustrates the moisture content of Gongronema latifolium plant stem fibers. The initial weight of the sample was 1.344 g, and the crucible weighed 71.798 g. Cobmination of the two weight before drying was 73.142 g, but after drying the waight reduced slightly to 73.119 g. This results in a moisture content of 1.711%, indicating a low level of moisture retained in the stem fibers post-drying. Figure 1 indicates a low moisture content of 1.711%. This finding aligns with a related study by Célino et al, (2014), which reported similar moisture levels in plant fibers, suggesting effective drying processes that preserve fiber integrity. In contrast, higher moisture contents in other fiber studies can lead to degradation and affect usability (Asim et al, 2020).

Table 2. Ash content of Gongronema latifolium Plant Stem Fibers

Sample	Wt of sample	Wt of crucible	Wt of sample + ash	% ash content
Stem fibre	1.466	38.562	38.710	10.095

Table 2 presents the ash content of Gongronema latifolium plant stem fibers. The sample weight was 1.466 g, while the crucible weighed 38.562 g. The combined weight after adding ash was 38.710 g, resulting in an ash content of 10.095%. This indicates a significant mineral presence in the stem fibers, which may influence their functional properties. Figure 2 shows that the ash content is 10.095%, indicating a significant mineral presence in the fibers. This result is consistent with findings by Vassilev et al, (2013), which emphasized the importance of ash content for potential applications. The mineral composition of fibers plays a critical role in their functional properties, supporting their use in various industrial applications.

Table 3. Fibre matter of Gongronema latifolium Plant Stem Fibers

Sample	Wt of sample	Wt of crucible	Wt of sample + fibre	% fibre content
Stem fibre	1.624	25.833	25.902	4.249

Table 3 displays the fibre matter content of Gongronema latifolium plant stem fibers. The initial sample weight was 1.624 g, with the crucible weighing 25.833 g. After adding the fiber, the total weight was 25.902 g, yielding a fibre content of 4.249%. This indicates a relatively low proportion of fibrous material in the stem, which may affect its utility in various applications. As depicted in Figure 3, the fiber content is relatively low at 4.249%. This aligns with the observations of Fattahi et al, (2023), who noted that lower fiber content could limit the mechanical strength and durability of plant materials. Such findings highlight the necessity of evaluating fiber content in developing composites or biodegradable materials.

Table 4. Bulk Density of Gongronema latifolium Plant Stem Fibers

Samples	**Wt of empty bottle**	**Wt of sample + bottle**	**Volume of sample**	**Density g/ml**
Stem fibre	76.034	81.039	12	0.417

Table 4 illustrates the bulk density of Gongronema latifolium plant stem fibers. The weight of the empty bottle was 76.034 g, but the combined weight with the sample was 81.039 g. comparing the volume of the sample was 12 ml with the mass gave a density of 0.417 g/ml. This low bulk density suggests that the stem fibers have a lightweight structure, which may influence their handling and application in various products. Figure 4 reveals a bulk density of 0.417 g/ml, indicating lightweight characteristics. This finding agrees with research by Sadrmanesh and Chen (2019), which noted that low-density fibers facilitate easier handling and transport, making them suitable for various applications, including insulation and biodegradable packaging materials.

3.4 Implication for reinforced polymer composite materials tailored for light weight applications

The results of this study show that the stem fibers of Gongronema latifolium can be a valuable source of reinforcing material for lightweight polymer composite products which can be useful in manufacturing industries such as automobiles, aerospace, and packaging. It has to do with the fact that most of them contain cellulose 12.862% which gives fibers most of their strength as well as stiffness while at the same time reducing their density. This makes them ideal for use where weight reduction is required such as in cars with improved fuel efficiency. The fibers also include lignin at 10.301% and this play a vital role of increasing the durability and toughness of the mechanical properties of the developed composite material (Chokshi et al, 2022). This property of lignin makes the composites more resistant to wear and tear and effects of the environment when stressed. Furthermore, the inherent flame resistance of lignin can provide extra value to polymer composites intended for use in applications exposed to high temperatures. The particularly low value of moisture absorption of 1.711% for Gongronema latifolium fibers also helps to improve the stability and dimensional stability of the composite and prevents changes in its dimensions due to fluctuating humidity levels. This stability is vital in ensuring the performance of lightweight composites under varying conditions.

Hemicellulose (6.005%) provides flexibility and enhances the bonding between the fibers and polymer matrix, allowing for better moldability and formability, crucial for manufacturing lightweight parts with complex shapes. Furthermore, the fibers' low bulk density (0.417 g/ml) supports the creation of composites that are both lightweight and structurally sound. It also brings ash content (10.095%) which helps in improving thermal stability of the composite in the high temperature applications. Gongronema latifolium fibers appear to have the potential of acting as a reinforcing material in the fabrication of light weighted polymer composites due to their characteristics such as high strength, flexibility, durability and reclamation from natural resources in various industries.

IV. Conclusions

Conclusively, the characterization of engineering properties of fibers obtained from Gongronema latifolium plant stem proves its potential for application in engineering and constructions. They pointed out that there are essential components in the fibers, which are cellulose, lignin, and hemicellulose that explain the fibers' structural and functional properties. The moderate cellulose value indicates the likelihood of its use in biocomposites and in the paper industry, as well as the occurrence of lignin for strength. Additionally, the low moisture content indicates effective processing and durability, making these fibers suitable for various engineering applications. The significant mineral presence, as indicated by the ash content, further underscores their potential in enhancing nutritional and functional attributes, particularly in health-related industries. However, the relatively low fiber content may limit their mechanical strength, necessitating further optimization for specific applications. Overall, Gongronema latifolium stems present an environmentally friendly alternative to conventional materials, aligning with sustainable practices in material engineering. Future research should focus on exploring innovative processing techniques and applications, enhancing the usability of these fibers in diverse engineering fields.

References

AOAC (1994) Commonly Used method for soil analysis. 16th , Edition, United States of America, Baltimore, Maryland. Analyst 98,213.

Asim, M., Paridah, M. T., Chandrasekar, M., Shahroze, R. M., Jawaid, M., Nasir, M., & Siakeng, R. (2020). Thermal stability of natural fibers and their polymer composites. Iranian Polymer Journal, 29, 625-648.

Célino, A., Fréour, S., Jacquemin, F., & Casari, P. (2014). The hygroscopic behavior of plant fibers: a review. Frontiers in chemistry, 1, 43.

Chokshi, S., Parmar, V., Gohil, P., & Chaudhary, V. (2022). Chemical composition and mechanical properties of natural fibers. Journal of Natural Fibers, 19(10), 3942-3953.

Crampton, F. E., & Mayrand, U. C. (1978). Determination of cellulose content. Hamilton: CABI Publishing, 34-48.

Fattahi, M., Taban, E., Soltani, P., Berardi, U., Khavanin, A., & Zaroushani, V. (2023). Waste corn husk fibers for sound absorption and thermal insulation applications: a step towards sustainable buildings. Journal of Building Engineering, 77, 107468.

Mutiso, S., & Gatari, C. (2023). Influence of Inventory Returns Management on Performance of Food and Beverage Manufacturing Firms in Kenya. Britain International of Humanities and Social Sciences (BIoHS) Journal, 5(1), 12-22.

Okafor, C. E. (2021). Review of natural fiber composite design for sustainable infrastructural development. University-Led Knowledge and Innovation for Sustainable Development, 64.

Okafor, C. E., & Ihueze, C. C. (2020). Strength analysis and variation of elastic properties in plantain fiber/polyester composites for structural applications. Composite and Nanocomposite Materials-From Knowledge to Industrial Applications, 1-23.

Okafor, C. E., Kebodi, L. C., Ihueze, C. C., Rangappa, S. M., Siengchin, S., & Okonkwo, U. C. (2022). Development of Dioscorea alata stem fibers as eco-friendly reinforcement for composite materials. Journal of King Saud University-Engineering Sciences.

Okafor, C. E., Kebodi, L. C., Kandasamy, J., May, M., & Ekengwu, I. E. (2022). Properties and performance index of natural fiber reinforced cross-ply composites made from Dioscorea alata stem fibers. Composites Part C: Open Access, 7, 100213.

Okafor, C. E., Onovo, A. C., Ani, O. I., Obele, C. M., Dziki, D., Ihueze, C. C., & Okonkwo, U. C. (2022). Mathematical study of bio-fibre comminution process as first step towards valorization of post-harvest waste materials. Cleaner Materials, 4, 100067.

Orji, M. G. (2024). Assessing the Sustainable Development Goals and Its Application in Nigeria. Britain International of Humanities and Social Sciences (BIoHS) Journal, 6(2), 70-88.

Ren, W., Zhang, D., Zhou, Y., Wang, H., Xia, L., Tan, C., Guo, F., Zhang, X., Yang, R. and Yu, Y., 2024. Lignin's complex role in lignocellulosic biomass Recalcitrance: A case study on bamboo. Chemical Engineering Journal, 490, p.151422.

Romanus, N., Orji, M. G., & Chris, O. (2024). Assessing the Effectiveness of Green Business Practices on Nigerian Economic Sustainability: A Study of Dawaki Groups, Kano, Nigeria. Economit Journal: Scientific Journal of Accountancy, Management and Finance, 4(2), 116-130.

Sadrmanesh, V., & Chen, Y. (2019). Bast fibres: structure, processing, properties, and applications. International Materials Reviews, 64(7), 381-406.

Szymańska-Chargot, M., Chylińska, M., Gdula, K., Kozioł, A., & Zdunek, A. (2017). Isolation and characterization of cellulose from different fruit and vegetable pomaces. Polymers, 9(10), 495.

Vassilev, S. V., Baxter, D., Andersen, L. K., & Vassileva, C. G. (2013). An overview of the composition and application of biomass ash. Part 1. Phase–mineral and chemical composition and classification. Fuel, 105, 40-76.

Wang, Q., Xiao, S., & Shi, S. Q. (2019). The effect of hemicellulose content on mechanical strength, thermal stability, and water resistance of cellulose-rich fiber material from poplar. BioResources, 14(3), 5288-5300.