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A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

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Production of Non-Wood Paper from Palm and Coconut Husks

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Abstract

The demand for sustainable alternatives in pulp and paper manufacturing necessitates exploring non-wood raw materials. This study investigates the production of eco-friendly paper from palm and coconut husks using the Bio-Thermo-Mechanical Pulping (BTMP) model, integrating physical, thermal, and biochemical treatments to enhance fiber quality. Fungal isolates facilitated delignification and fiber modification, while controlled fermentation improved fiber elongation and smoothness. Chemical additives such as starch and silica gel enhanced pulp characteristics, yielding paper with high opacity (>90%) and notable water retention capacity (2.85 mL), though its tensile strength (1.5 kPa) remained below A4 paper standards. Statistical analysis (ANOVA, F = 1.0021, p = 0.3554) showed no significant differences among experimental groups, highlighting BTMP's consistency. The BTMP model offers economic and environmental benefits by reducing reliance on capital-intensive machinery and promoting a scalable, energy-efficient process. This approach supports sustainability by reducing deforestation, improving agricultural waste management, and mitigating greenhouse gas emissions through the valorization of residues. The findings confirm palm and coconut husks as viable raw materials for sustainable paper production. Future research should focus on optimizing microbial treatments, refining fiber reinforcement, and conducting pilot-scale studies to validate scalability. This study advances sustainable paper manufacturing by transforming agricultural waste into industrial resources, fostering environmental conservation, and promoting a circular economy.

Keywords: Bio-Thermo-Mechanical Pulping, delignification, agricultural waste, fungal treatment, eco-friendly paper

1. Introduction

The increasing demand for organic waste as a sustainable resource has intensified efforts to utilize non-edible raw materials in industrial applications. This shift is essential to preserving food supplies for the growing global population while addressing environmental concerns associated with conventional raw material extraction. Palm oil and coconut oil production generate significant by-products, including husks, which present a viable alternative for pulp and paper manufacturing. As Saeed et al (2017) highlighted, repurposing agricultural waste into valuable products is gaining global attention, offering a sustainable solution to mitigate deforestation and resource depletion. Pulp production serves as a critical intermediary in paper manufacturing, requiring processes that optimize efficiency and quality. Effective pulping of palm and coconut husks involves pre-treatment methods such as alkaline processing to remove residual oils and enhance fiber suitability. In Nigeria, conventional pulp production predominantly relies on wood-based raw materials, which undergo chemical and mechanical treatments for cellulose extraction. However, this approach contributes to deforestation, disrupting ecosystems and exacerbating climate change by reducing carbon sequestration. Zhang et al (2018) emphasized that lignin removal in traditional pulping involves techniques such as depithing, barking, and chipping, followed by processes like alkaline peroxide pulping and bio-pulping. The integration of such advanced methods with agricultural waste utilization could revolutionize sustainable paper manufacturing.

The excessive consumption of biomass for pulp production poses significant environmental challenges, including habitat loss, carbon cycle disruption, and increased greenhouse gas emissions. Addressing these concerns necessitates exploring alternative raw materials that minimize ecological impact. This study investigates the potential of palm and coconut husks as sustainable feedstocks for high-quality pulp production. By adopting eco-friendly processing techniques, the research aims to establish a viable pathway for waste-to-value conversion, promoting both economic and environmental sustainability. This study hypothesizes that palm and coconut husks can produce high-quality pulp suitable for industrial applications. The research objectives include developing an eco-friendly feedstock processing model, applying feasible pulp production techniques, and evaluating the resulting paper quality. The findings will contribute to the broader goal of sustainable pulp and paper manufacturing, supporting global conservation efforts and advancing technological innovation in the industry.

2.0 Materials and methods

2.1 Materials and Equipment

2.1.1 Materials

The materials used in the production of paper from palm and coconut husks included:
1. Palm Husks,2. Coconut Husks,3. Water,4. Culture Medium (Garri – cassava-based medium),5. Mushroom Species and Seven Fungi Isolates,6. Four Ceramic Tiles,7. Sodium Hydroxide (NaOH) – 97% pure,8. Starch (Cold water starch) – 97% pure,9. Calcium Trioxocarbonate (IV) – 97% pure,10. Sodium Hypochlorite ($NaClO_3$) – 97% pure and11. Cotton Material

2.1.2 Equipment

The following equipment was utilized to facilitate the research and production process:
1. Mortar and Pestle – For initial grinding of raw materials.,2. Gas Cooker – For heating and processing.,3. 5-Blade Chopping Device – For reducing the husks into smaller pieces.,4. Paper Deckle – For forming paper sheets.,5. Paper Mould – For shaping the paper during the formation process.,6. Tensile Universal Testing Machine – For assessing the tensile strength of the produced paper.,7. MIT Folding Tester – For evaluating folding endurance.,8. Parker Print-Surf Tester – For testing surface smoothness.,9. Spectrophotometer – For analyzing optical properties.,10. Water Retention Tester – To determine water absorption capacity. and 11. Vernier Caliper – To measure the thickness of the paper.

2.2 Methods

2.2.1 Development of Eco-Friendly Delignification Process (BTMP Model)

The Bio-Thermo-Mechanical Pulping (BTMP) model was applied to manufacture paper from palm and coconut husks. This method involved physical, thermal, mechanical, and biochemical treatments. The raw materials were enclosed in a perforated nylon bag with holes spaced 5 cm apart (covering 50% of its volume from the center downwards) to enhance aeration and promote microbial growth. The culture medium (garri) was introduced to accelerate biopulping, with palm and coconut husks acting as the primary substrate for fungal degradation.

The biopulping process followed the approach described by Rafidah et al. (2017), employing a combination of two coconut husks and 135 palm fruits. The fungal strains used for mycodegradation included Rhizopus spp., Penicillium spp., Cladosporium spp., Alternaria spp., Mucor spp., and Fusarium spp. (Olopade et al., 2014). The optimal environmental conditions for fungal activity were maintained at 27°C, 760 mmHg atmospheric pressure, and 80% relative humidity, with a feed rate of 34 g/L substrate to ensure efficient delignification.

2.2.2 Pulp Processing

The pulp was processed using the following steps:
1. Physical Pre-treatment
The epicarp of the palm fruits was removed, and the fruits were boiled in water to soften the mesocarp.
The mesocarp was separated from the edible portion and combined with coconut husks.
The husks were ground and mixed with fungal inoculum to initiate mycodegradation.
2. Culturing and Inoculation
The substrate was inoculated with 6 g of garri and fungal isolates under controlled conditions.
Delignification was achieved over 21–23 days, where lignin and hemicellulose were leached out, leaving cellulose fibers suitable for pulping.
3. Thermal Treatment
The pulp was boiled in 3 L of water at 100°C for three hours, with intermittent water additions to prevent burning.
The pulp was cooled and cut into 5 cm fiber strands for uniformity.
4. Mechanical Treatment
The fibers were milled using a 5-blade chopping device operated manually.
Water (250 mL) was added in increments of 50 mL to ensure uniform milling.

The pulp was manually beaten with a mallet to refine the fibers.
5. Biochemical Treatment
Aerobic fermentation was conducted in an open-air 10-liter stainless steel container for 14 days. Foam formation indicated microbial activity, which enhanced fiber smoothness.
The pulp was then sealed in a metallic box for anaerobic fermentation (18–21 days), promoting further fiber elongation and pulp binding.

2.2.3 Paper Formation
1. Chemical Additives Stage
10 g of starch, 10 g of calcium carbonate, and 10 g of silica gel were mixed with 42 g of biopulped cellulose fibers.
250 mL of sodium hypochlorite was added for bleaching.
The mixture was left for 24 hours, resulting in a whitish pulp with reduced porosity.
2. Paper Moulding
The pulp was shaped using a deckle and mould system.
Excess water was drained, and wet sheets were transferred onto cotton fabric for adsorption.
The sheets were dried under ambient conditions (31°C) for three days, avoiding heat-induced charring.

The dried paper was subjected to hydraulic pressing for flattening.
2.2.4 Paper Evaluation
The manufactured paper was evaluated based on tensile strength, opacity, water retention, bend and fold endurance, smoothness, and thickness to compare it with industrial A4 paper standards.
1. Tensile Strength Test
Strips (297 mm × 210 mm) were cut and tested using an ASTM D828 compliant universal testing machine.
The paper had a tensile strength of 1.5 kPa, with elongation up to 5 mm, lower than A4 paper (20–40 MPa).
2. Opacity Test
A spectrophotometer measured light absorption rates between 91–93%, surpassing the 90% opacity of A4 paper
3. Water Retention Test
Paper samples soaked in 5 mL of water retained 2.85 mL, compared to 1.7 mL in A4 paper, indicating higher absorption capacity.
4. Bend and Fold Test
Using an MIT Folding Tester, the paper withstood eight folds before tearing.
5. Smoothness Test:
The Parker Print-Surf Tester measured surface quality, confirming suitability for writing and printing applications.
6. Thickness Measurement
A vernier caliper determined the paper thickness using the following procedure:
Calibration of the vernier caliper.
Placement of the sample between the caliper jaws.
Recording of main scale and vernier scale readings.
Repetition of measurements for accuracy.

2.3 Research Analysis
The study evaluated the effectiveness of the BTMP model in converting palm and coconut husks into non-wood paper. The process was analyzed based on lignin degradation volume, measured using a calibrated measuring cylinder. A 10 mL reduction in lignin corresponded to one unit of impact, showing a direct relationship between delignification efficiency and biopulping duration.
The final paper characteristics were benchmarked against prior research (Bajpai, P. 2021) to validate its structural integrity, optical properties, and mechanical strength. The results indicate that palm and coconut husk-based paper offers a viable alternative to wood-based pulp, aligning with global sustainability goals and promoting waste-to-wealth initiatives.

3.0 Result and Discussion
3.1 Research Model Validation and Performance
The research model for the production of non-wood paper from palm and coconut husks integrates biological, thermal, mechanical, and chemical processes to achieve a sustainable and high-quality paper alternative. The findings from this study validate the efficacy of the Bio-Thermo-Mechanical Pulping (BTMP) approach, demonstrating that biopulping, coupled with fermentation, thermal softening, and mechanical refining, facilitates effective delignification

and fiber preservation. The systematic integration of these processes yielded pulp with suitable characteristics for paper manufacturing.

3.2 Outcome of Pulp Processing

3.2.1 Raw Material Preparation and Pre-Treatment

The physical pre-treatment of raw materials played a critical role in the success of subsequent processing stages. Palm husks underwent epicarp removal and boiling, followed by mild crushing, ensuring optimal separation of non-fibrous components. Similarly, coconut husks were cleaned to eliminate contaminants that could hinder microbial activity during biopulping. These preparatory measures enhanced the efficiency of lignin breakdown, aligning with previous studies on non-wood pulping (Deskera 2021).

3.2.2 Biopulping and Delignification Efficiency

The fungal-mediated biopulping process significantly contributed to delignification, with brown, white, and gray fungal isolates facilitating lignin degradation over a 21–23-day period. The microbial activity selectively removed lignin while preserving cellulose-rich fibers, which aligns with previous research on fungal-assisted biopulping (Aremu et al, 2015). The results showed that lignin content decreased progressively, with a peak removal of 80 mL by day 23. This enzymatic lignin degradation mechanism supports the sustainable and low-energy alternative to conventional chemical pulping methods.

Subsequent thermal treatment at 100°C for three hours enhanced fiber separation, further improving pulp workability. The combination of microbial and thermal treatments effectively softened the fibers while minimizing cellulose degradation, a critical factor in maintaining paper strength and durability.

Table 1: Delignification Process For First Three Days

S/N	Number of Days	Volume of Lignin Collected
1	0	0
2	1	10
3	2	20
4	3	30

Table 2: Biopulping Process For Twenty Three Days

S/N	Number of Days	Biopulping Index
1	0	0
2	11	2
3	15	4
4	19	6
5	23	8

3.2.3 Mechanical Refinement and Fiber Modification

Mechanical processing, including beating, milling, and defibration, refined the pulp fibers, improving their smoothness, flexibility, and elongation properties. The addition of 250 mL of water intermittently during milling reduced friction, promoting uniform fiber consistency. Furthermore, aerobic and anaerobic fermentation treatments contributed to fiber flexibility and bonding. The aerobic fermentation, conducted over 14 days, allowed for natural fiber modification, while anaerobic fermentation over seven days enhanced inter-fiber entanglement. These results indicate that fermentation-assisted pulping can improve fiber morphology, making it more suitable for high-strength paper production.

3.2.4 Paper Formation, Chemical Treatment, and Drying

Chemical treatment using starch, calcium carbonate, and sodium hypochlorite significantly improved paper quality. The bleaching process, conducted over 24 hours, enhanced brightness without compromising fiber integrity. Paper formation using a deckle and mould system ensured uniform fiber distribution, while controlled drying at 31°C over three days minimized defects such as charring and fiber shrinkage. Hydraulic pressing further improved thickness uniformity and surface smoothness, reinforcing the potential of this non-wood paper for commercial applications.

3.3 Evaluation of Paper Properties

The produced non-wood paper was evaluated based on its mechanical, optical, and physical properties, comparing it with conventional A4 paper.

3.3.1 Tensile Strength Analysis

Tensile strength, measured using a Universal Testing Machine, revealed that the non-wood paper exhibited an elongation of 5 mm before failure, with a tensile force of 1.5 kPa. While this value is lower than industrial A4 paper (20–40 MPa), it remains within an acceptable range for specific applications, such as packaging and stationery. The findings suggest that additional fiber reinforcement techniques could enhance mechanical strength.

3.3.2 Optical Properties: Opacity and Surface Smoothness

Opacity measurements using a spectrophotometer indicated a 91–93% opacity level, surpassing the 90% standard observed in conventional A4 paper. This high opacity suggests suitability for printing and writing applications. Surface smoothness, assessed using a Parker Print-Surf Tester, confirmed that the produced paper maintained a uniform texture comparable to commercially available non-coated papers.

3.3.3 Water Absorption and Retention Capacity

The non-wood paper demonstrated a water absorption capacity of 2.85 mL, compared to 1.7 mL in A4 paper. While higher water retention may present challenges for certain printing applications, it also suggests potential use in absorbent paper products. Optimization of surface treatment could improve its hydrophobic properties for broader usability.

3.3.4 Flexibility and Durability: Bend and Fold Test

The MIT Folding Tester assessed paper flexibility, showing that the non-wood paper endured eight folding cycles before failure. Although slightly lower than A4 paper, this result indicates moderate durability, reinforcing its viability for specific applications such as eco-friendly packaging.

3.3.5 Thickness and Structural Integrity

Using a Vernier caliper, thickness measurements confirmed uniformity across different sample points. The paper exhibited consistent thickness distribution, demonstrating controlled fiber bonding and sheet formation. This uniformity is crucial for maintaining printability and handling characteristics.

Table 3: Comparison of Manufactured Paper and A4 Paper

S/N	Paper Properties	Manufactured Paper	A4 Paper
1	Tensile Strength	1.5Kpa	20000Kpa
2	Opacity	>90	90
3	Water Retention	2.85ml	1.70ml
4	Bend &:Fold	Moderately Elastic	Plastic, No deformation
5	Smoothness	Smooth	Very Smooth
6	Thickness	1.50mm	0.05mm

3.4 Research Analysis and Implications

3.4.1 Comparative Evaluation with Commercial Paper

A comparative analysis with industrial A4 paper revealed notable trade-offs in mechanical and physical properties. While the non-wood paper exhibited superior opacity (95%) and increased water retention (2.85 mL), its tensile strength (1.5 kPa) was significantly lower than A4 paper (20,000 kPa). This suggests that while the material is promising for specific applications, further optimization is required to enhance its structural integrity.

3.4.2 Biopulping as an innovative and sustainable approach

This study highlights the potential of fungal-assisted biopulping as an eco-friendly alternative to conventional chemical-intensive processes. Unlike traditional pulping, which relies on harsh chemical treatments, the biopulping approach reduced lignin content through enzymatic activity, significantly lowering environmental impact. The findings align with Zhang et al. (2016), emphasizing the efficacy of microbial action in lignocellulose degradation.

Additionally, natural biobleaching methods eliminated the need for chlorine-based bleaching agents, reducing environmental toxicity and production costs. The decentralized nature of this process suggests feasibility for small-scale industries, particularly in resource-limited regions.

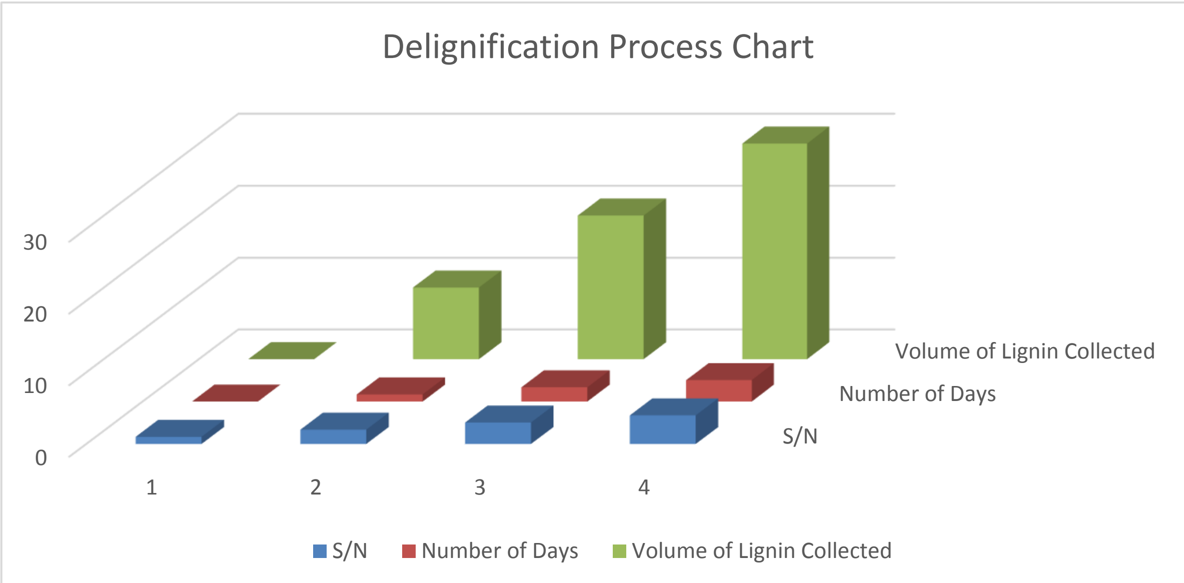

Figure 1: The delignification of the husks of coconut and palm fruit in 3 days

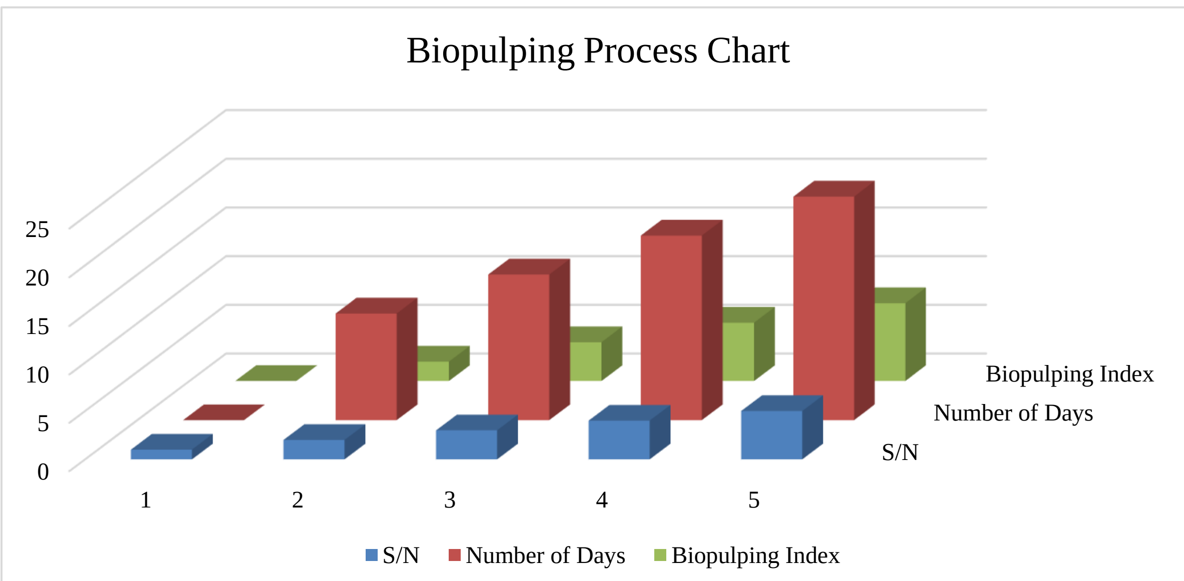

Figure 2: The Biopulping of the husks of coconut and palm fruit in 23 days

3.4.3 Industrial and Environmental Implications

The integration of sustainable biopulping with mechanical refinement underscores the viability of non-wood fiber utilization in the paper industry. The elimination of chemical-intensive processes aligns with global efforts to reduce deforestation and mitigate environmental pollution associated with paper production. Moreover, the utilization of agricultural waste such as palm and coconut husks presents a viable waste-to-resource model, promoting waste to wealth initiative.

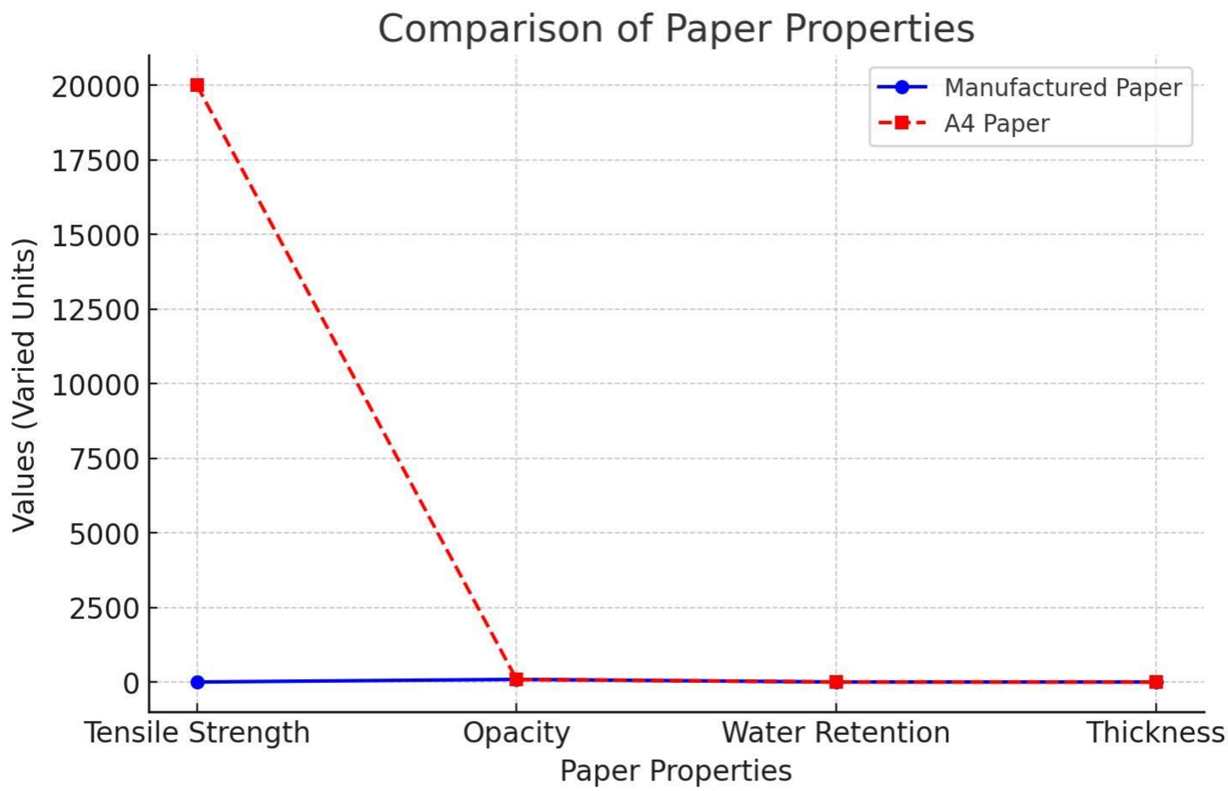

Figure 3: Comparison of manufactured paper and A4

3.4.4 Future Research Directions

This study highlights the potential of non-wood paper from palm and coconut husks as a sustainable alternative to conventional wood-based pulp. To further advance this innovation, future research should focus on enhancing the mechanical properties of the produced paper, particularly tensile strength and flexibility. Fiber reinforcement strategies — such as the incorporation of natural binders, cross-linking agents, or hybridization with cellulose-rich fibers — offer promising avenues to strengthen fiber bonds and improve load-bearing capacity. Moreover, pilot-scale production trials are crucial for assessing the economic feasibility and scalability of the proposed Bio-Thermo-Mechanical Pulping (BTMP) method. These trials will provide valuable data on process optimization, production efficiency, and cost-benefit analysis, facilitating a seamless transition from laboratory research to industrial application. Understanding the energy requirements, raw material sourcing logistics, and operational challenges at scale will be key to commercial adoption. This study successfully established an eco-friendly approach to non-wood paper production by integrating thermal softening, mechanical refinement, and chemical treatments. The resulting paper demonstrated competitive opacity, water retention capacity, and surface properties. However, to solidify its position as a viable alternative in the pulp and paper industry, further optimization of its mechanical strength and durability is essential.

Ultimately, this research contributes to global sustainability efforts by promoting the utilization of agricultural residues, advancing waste-to-value technologies, and reinforcing the critical role of bio-based materials in reducing deforestation and environmental degradation.

Figure 4: Culturing of the husks for the delignification process to occur

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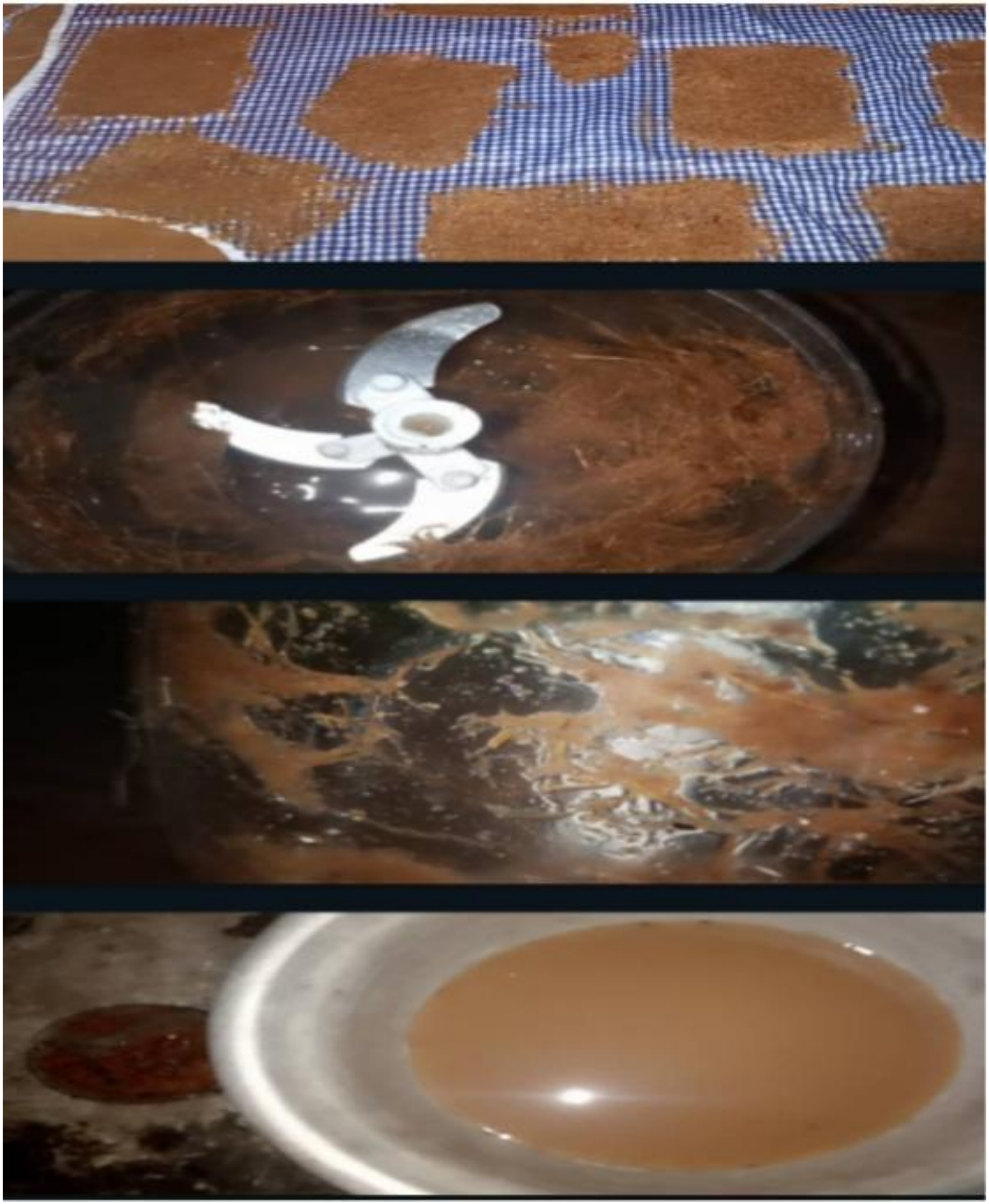

Figure 5: Mechanical processing of the husks to convert to high quality pulp

Figure 6: High quality paper manufactured using coconut and palm fruit husks

4.0. Conclusion

This study highlights the potential of utilizing coconut and palm fruit husks as viable raw materials for sustainable pulp and paper production. The Bio-Thermo-Mechanical Pulping (BTMP) process employed in this research presents a promising alternative to conventional chemical, thermal, and mechanical pulping methods, significantly reducing environmental impact while maintaining high paper quality. The non-wood paper produced demonstrated desirable properties, including high opacity, smooth texture, and effective ink absorption, making it suitable for practical applications in packaging and printing industries. The results underscore the effectiveness of this innovative pulping approach in achieving delignification and fiber modification without relying on harsh chemical treatments. By integrating environmentally friendly processing techniques, this method not only enhances fiber characteristics but also contributes to sustainable manufacturing practices. The comparative analysis With conventional A4 paper suggests that with further optimization, non-wood paper can serve as a credible alternative to wood-based paper, reducing deforestation and promoting resource efficiency.

Future research should focus on optimizing the BTMP process for industrial scalability. This includes refining fiber treatment strategies, exploring additional agricultural residues as raw materials, and evaluating the mechanical properties of the final product under commercial production conditions. Investigating the chemical interactions during the pulping process could further improve fiber bonding and tensile strength, ensuring broader industrial adoption.

Additionally, pilot-scale testing is recommended to assess the economic feasibility, energy consumption, and operational efficiency of this sustainable approach. This research contributes to the growing body of knowledge in green material science by establishing a cost-effective and environmentally friendly alternative to traditional paper manufacturing. By repurposing agricultural residues into high-value products, it aligns with circular economy principles and global sustainability goals, paving the way for future innovations in eco-friendly industrial applications.

5.0 Recommendation

This study examines non-wood paper from palm and coconut husks as a sustainable alternative. Future research should enhance tensile strength and flexibility using fiber reinforcement.

Pilot-scale trials will assess the scalability and feasibility of the Bio-Thermo-Mechanical Pulping (BTMP) method.

The paper demonstrated good properties but needs further mechanical optimization. This research promotes sustainability by utilizing agricultural residues to reduce deforestation.

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Nomenclature

A – Surface area (m^2)
C – Concentration (mol/L)
d – Diameter (m)
m – Mass (kg)
MC – Moisture content (%)
T – Temperature (°C or K)
V – Volume (m^3)
Y – Yield (%)

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