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Small Scale Sustainable and Eco-Friendly Paper Making Utilizing Groundnut Husks within the Zirobwe-Bukimu Community.

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ABSTRACT

Paper production from agricultural residues offers an environmentally sustainable alternative to conventional wood-based methods. Groundnut shells, rich in cellulose, hemicellulose, and lignin, present a promising resource for paper pulp production due to their physical strength and abundance as agricultural by-products. This project aimed to assess the feasibility of converting groundnut shells into paper pulp and their suitability for papermaking. Two sample groups were established: Group A underwent an extended soaking and retting process at lower temperatures (25°C) for six days, followed by mechanical extraction using a blender. In contrast, Group B experienced a shorter soaking and retting period of four days at warmer temperatures (35°C) before mechanical extraction. Additionally, Group A was treated with a higher quantity of starch (10% by weight) compared to Group B (5% by weight). The study evaluated the quality of paper sheets produced by each group. Group A exhibited higher fiber yields due to prolonged soaking and retting, although resulting in paper with divergent characteristics from standard quality. Notably, paper from Group A displayed increased roughness and reduced tensile strength compared to Group B, which produced fibers closely resembling standard paper characteristics. However, the slightly lower fiber yield in Group B suggests a potential balance between extraction efficiency and paper quality. Additionally, starch played a crucial role in the paper-making process. While higher starch quantities in Group A contributed to increased fiber yield, excessive starch content adversely affected paper quality. Optimal starch levels are essential to achieve the desired balance between extraction efficiency and paper characteristics. These findings emphasize the complex relationship between extraction conditions and paper quality, highlighting the need for thorough optimization of extraction techniques to strike a balance between yield and desired paper properties. In summary, this research contributes to advancing eco-friendly paper production practices and informs sustainable resource utilization in the paper industry. Further research is warranted to refine extraction methods and parameters, facilitating sustainable paper production from agricultural waste.

Keywords: Paper, pulp, groundnut shells, eco-friendly, Starch, Paper quality

INTRODUCTION

Paper, a versatile material composed of cellulose fibers derived from plant sources suspended in an aqueous solution, serves as a cornerstone of modern society [1]. This unique molecular structure, comprising linear polymer chains of hydro-D-glucose units linked by beta-1,4 glycosidic bonds, imbues paper with its characteristic strength, flexibility, and absorbent properties [2,3]. Its applications span from writing and printing to packaging and art, highlighting its essential role in various industries. The paper manufacturing process involves several stages—from debarking and fiber extraction to pulping, bleaching, and paper formation techniques [4]. While chemical pulping methods are conventional for superior pulp quality, this study opts for a mechanical approach using blending due to its cost-effectiveness and environmental advantages [5,6] The pulp and paper industry faces substantial challenges, including the need for cost-effective, high-quality pulp production while minimizing environmental impact. Currently, global pulp fibers primarily originate from wood, driving deforestation rates and contributing significantly to greenhouse gas emissions [7,8]. To mitigate these environmental impacts, alternative pulp sources such as agricultural residues rich in lignocellulose, like groundnut husks, offer a promising solution [8]. The traditional paper-making industry's environmental footprint, characterized by deforestation, chemical pollution, and resource-intensive practices, underscores the urgent need for sustainable alternatives [9]. The rise in global paper consumption, coupled with the depletion of natural resources, emphasizes the critical role of exploring eco-friendly raw materials [10]. Groundnut (Arachis hypogaea), a globally cultivated leguminous crop, is primarily grown for its nutritious seeds and oil [11]. Cultivated extensively across nearly 100 countries, predominantly in developing nations, groundnuts serve as a staple food and vital cash crop, with high edible oil content (40-45%) and protein (25%), enriched with essential vitamins and minerals [12]. While developed nations commonly use groundnuts for peanut butter and confectionery, developing countries focus on oil extraction, utilizing byproducts for both animal feed and human consumption [13,14].

However, a significant byproduct of groundnut processing is its shells, comprising about 20% of the dried peanut pod's weight. Despite being substantial agro-industrial waste, groundnut shells degrade slowly under natural conditions and contain valuable bioactive components such as cellulose, hemicellulose, and lignin, often underutilized in mainstream applications [15,16]. As global groundnut production rises, so does the accumulation of these shells, often discarded through burning or burial, contributing to environmental pollution and posing challenges for sustainable waste management [17,18] Recognizing the potential of groundnut shells as a valuable resource, especially in paper production, presents an opportunity to address both and economic concerns. The high cellulose content (approximately 65.5-79.3%), along with significant hemicellulose and lignin, positions groundnut husks as a promising raw material for sustainable paper making [19]. This potential underscore the need for innovative technologies and a paradigm shift towards achieving zero-waste production systems [20]. By exploring the feasibility of utilizing groundnut shells for paper making, this study aims to bridge the gap between environmental sustainability and economic viability. Converting agricultural waste into eco-friendly paper not only addresses waste management challenges but also reduces reliance on finite natural resources, potentially opening new economic opportunities for farmers and local communities [21]. In conclusion, while the environmental challenges of traditional paper production persist, innovative approaches utilizing agricultural waste, such as groundnut husks, offer promising avenues for sustainable paper production. This study seeks to systematically investigate the feasibility of groundnut husks as a sustainable and cost-effective raw material for paper making.

METHODS

Sample Collection and Preparation

Groundnut husks were collected from various farms in Bukimu-Zirobwe, Luwero district, utilizing a random sampling approach to ensure representativeness. Each site contributed a predetermined quantity of husks (1.2kg), which were labeled with essential details such as date and location. These meticulous procedures enhanced reliability and facilitated subsequent analyses. The collected groundnut husks underwent thorough processing to facilitate subsequent fiber extraction and pulp production. Initially, the husks were thoroughly cleaned to remove impurities and contaminants, ensuring the purity of the extracted fibers. This cleaning process involved rinsing the husks with clean distilled water and air-drying them to achieve an optimal moisture content. Subsequently, the husks were mechanically shredded into smaller fragments to enhance their surface area and facilitate the extraction process. These prepared husks were then ready for the subsequent fiber extraction and pulp production processes, ensuring the integrity and quality of the ensuing experimental procedures.

Paper Production

The experimental procedure for fiber extraction, retting, and pulp production involved a systematic approach aimed at efficiently utilizing groundnut husks as a raw material for paper making. Initially, dry groundnut husks weighing 1.2 kg per group (A and B) were collected and prepared for processing. The husks were then submerged in clean distilled water for a predetermined period to facilitate the softening of the lignocellulosic structure. This soaking process, crucial for loosening the fibers from the husk matrix, typically lasted for several days to ensure optimal fiber extractability. Following soaking, the husks underwent a retting process designed to further degrade the lignin and hemicellulose components, thereby enhancing the separation of fibers. Two sample groups, denoted as Group A and Group B, were established to investigate the effects of different retting conditions.

Group A was subjected to an extended soaking and retting period of six days at a lower temperature (25°C), while Group B underwent a shorter retting duration of four days at a warmer temperature (35°C). After the specified retting period, mechanical extraction techniques were employed to separate the liberated fibers from the residual husk material. In this study, a blender was utilized for mechanical fiber extraction in both Group A and Group B. The softened husks were transferred to the blender, where they were subjected to high-speed agitation to effectively disintegrate the husk matrix and release the fibers. The extracted fibers were then subjected to a series of refining and cleaning processes, including filtration and decanting, to remove any remaining impurities and contaminants. Subsequently, the purified fibers were processed into pulp by beating manually gently to enhance the desired paper characteristics. The pulping process aimed to break down the fibers into a homogeneous slurry suitable for paper making. Throughout the experimental procedure, meticulous attention was paid to maintaining standardized protocols and monitoring key parameters to optimize fiber yield and paper quality. The quantities of groundnut husks used per group (1.2 kg) were carefully measured and recorded to ensure reproducibility and accuracy in the experimental results.

Construction of the Paper Deckle and Mould

In the construction of the paper deckle and mould, meticulous attention was paid to ensuring the precise dimensions and quality of the paper sheets produced. The deckle and mould served as essential tools for shaping and forming the pulp into uniform sheets during the paper-making process. For this study, the dimensions of the paper deckle and mould were standardized to measure 12 inches by 12.5 inches, corresponding to the dimensions of A4 size paper commonly used in paper production. The construction of the paper deckle and mould involved assembling wooden frames with fine wire mesh screens stretched across them. The deckle, which fit snugly over the mould, determined the outer dimensions of the paper sheet, while the mould defined the inner dimensions and thickness of the sheet. Both components were securely fastened together to create a sturdy and stable unit for paper formation. During the paper-making process, the deckle and mould were immersed in a vat containing the pulp suspension. The pulp fibers adhered to the mesh screen of the mould, forming a thin layer that corresponded to the dimensions of the deckle. As the deckle and mold were lifted from the pulp vat, excess water drained through the mesh, leaving behind a wet paper sheet adhered to the surface of the mould. After the initial forming stage, the wet paper sheet was carefully transferred onto a smooth clot to undergo further drying and pressing. The cloth acted as a supportive medium for transporting the wet sheets and facilitated the removal of excess moisture during the drying process. To ensure uniformity and consistency in paper production, the deckle and mould were thoroughly cleaned and maintained between each paper sheet formation. Any residual debris was removed from the mesh screens to prevent contamination and ensure the quality of subsequent paper sheets. The construction and use of the paper deckle and mould were integral steps in the paper-making process, enabling the production of high-quality paper sheets with standardized dimensions and characteristics.

Manual Paper-Making Techniques.

In the manual paper-making techniques employed in this study, careful attention was given to ensuring precision and consistency in the formation of paper sheets from the pulp suspension. This manual approach allowed for greater control over the paper-making process and facilitated the production of customized paper sheets tailored to specific requirements. The process began with the preparation of the pulp suspension, which was thoroughly mixed to achieve a homogeneous mixture of fibers, water, and starch additives. Starch was added in specific quantities, with Group A receiving a higher quantity (10% by weight) compared to Group B (5% by weight), to evaluate its impact on paper quality and characteristics. The prepared pulp, along with the starch additives, was then poured into a vat or container large enough to accommodate the deckle and mould assembly. The depth of the pulp suspension in the vat was carefully regulated to ensure optimal sheet formation and thickness. Once the pulp suspension was prepared, the deckle and mould assembly were immersed into the vat, ensuring that the entire mesh surface was fully submerged. The deckle and mould were then gently agitated or shaken to distribute the pulp evenly across the mesh screen and facilitate uniform sheet formation. With the pulp evenly distributed, the deckle and mould were slowly lifted from the vat, allowing excess water to drain through the mesh screen. As the deckle and mould were raised, the wet paper sheet began to form on the surface of the mould, adhering to the mesh screen in the desired shape and dimensions. Once the sheet formation was complete, the deckle was carefully removed from the mould, leaving behind the newly formed paper sheet on the mesh screen. The wet sheet was then transferred onto a smooth cloth or felt surface for further processing and drying. To ensure uniformity and consistency in paper production, each sheet underwent a pressing and drying process to remove excess moisture and enhance its strength and durability. This involved the use of a sponge and blotting paper to absorb excess water, followed by air drying. Throughout the manual paper-making process, meticulous attention was paid to maintaining cleanliness and hygiene to prevent contamination and ensure the quality of the final paper product. Any debris and impurities present in the pulp suspension or on the deckle and mould surfaces were carefully removed to minimize defects and imperfections in the finished paper sheets.

Drying Process

In the drying process, the freshly formed paper sheets underwent careful handling and treatment to remove excess moisture and achieve the desired level of dryness. This step was crucial for enhancing the strength, durability, and overall quality of the paper product. Initially, the wet paper sheets were gently pressed between layers of absorbent material, called blotting paper, to remove excess water from the surface. This pressing action helped to flatten the paper sheets and facilitated the absorption of moisture by the absorbent material. After the initial pressing, the paper sheets were transferred to a designated drying area where they were arranged in a single layer on a smooth surface. The drying area was well-ventilated and protected from direct sunlight to ensure uniform drying and prevent discoloration of the paper sheets. In some cases, additional drying aids use as sponges and hair dryers were used to improve the drying process, particularly in instances where the environmental conditions were less favorable. However, caution was exercised to prevent excessive heat exposure, which could lead to uneven drying and potential damage to the paper sheets. Throughout the drying process, periodic monitoring of the paper sheets was essential to assess their progress and ensure uniform drying across all sheets. Once the paper sheets reached the desired level of dryness, they were carefully removed from the drying surface and inspected for quality and uniformity. Finally, the dried paper sheets were trimmed to the desired dimensions using scissors. This step helped to ensure uniformity in size and appearance across all paper sheets, readying them for further processing and use in various applications.

The Quality Tests

Conducting the quality tests for assessing the paper sheets produced from groundnut husk fiber involved employing various equipment and methods, each with specific modes of operation to ensure accurate and reliable results. Tensile strength testing was typically performed using a tensile strength tester, which applied a controlled force to the paper sample until it broke. The mode of operation involved securely clamping the paper sample in the testing apparatus and gradually increasing the force until failure occurred. The maximum force applied before rupture was recorded as the tensile strength of the paper. For tear resistance testing, a tear resistance tester was employed, which measured the force required to tear a standardized paper sample. The mode of operation involved subjecting the paper sample to an increasing force perpendicular to the direction of the tear until rupture occurred. The force required to tear the paper was then measured and reported as the tear resistance. Density evaluation was carried out using a density meter or balance, which measured the mass per unit volume of the paper sample. The mode of operation involved weighing the paper sample and determining its volume using precise measurement techniques. The mass was then divided by the volume to obtain the density of the paper. The water absorptivity test, also known as the Cobb test, was a vital procedure for evaluating the ability of paper to absorb water. In this test, standardized paper samples were prepared and conditioned in controlled environmental conditions. Each dry specimen was accurately weighed before being submerged in a container of distilled water for a specified duration, typically around 60 seconds. After immersion, the specimen was removed from the water, excess water was allowed to drain off, and any surface water was removed using absorbent blotting paper. The wet specimen was then weighed accurately, and the water absorptivity was calculated using a standard formula. The thickness evaluation was performed using a micrometer. The procedure involved placing a single paper sheet between the anvils of the micrometer and gently closing the anvils until they made contact with the sheet. The micrometer was then read to determine the thickness of the paper sheet. This process was repeated several times at different points on the paper sheet, and the average thickness was calculated from these measurements. Microscopic analysis was conducted using electron microscopy techniques, of the desired level of magnification and resolution. Electron microscopy offered high magnification and resolution, enabling detailed imaging of individual fibers and surface features. The mode of operation for these tests involved preparing the paper sample according to standardized procedures, mounting it on the appropriate equipment, and following specific testing protocols to ensure consistency and accuracy of results. By employing these methods and equipment, producers systematically evaluated the quality and performance of paper sheets derived from groundnut husk fiber, enabling optimization of the paper-making process to meet industry standards and customer requirements. This was guided by Smith et al. [22].

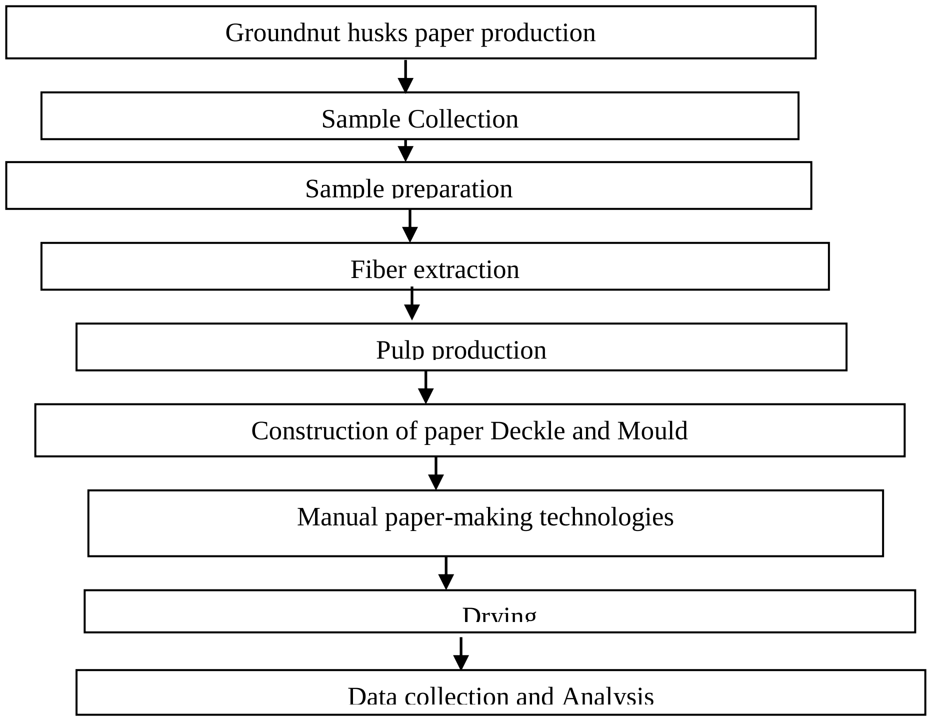

Fig 1: Paper-making Process Flow Chart

RESULTS

Table 1: Mechanical and Physical parameters of paper sheets from Group A

Parameter	Sample 1	Sample 2	Sample 3	Sample 4
Tensile strength (N/mm^2)	16.7	16.9	17.2	16.9
Tear resistance (mN)	117.6	119	120.1	118.9
Density (g/cm^3)	0.89	0.97	0.88	0.89
Basic weight (g)	99	108	101	98
Water absorptivity (%)	47.7	46	47.8	48
Thickness (mm)	0.14	0.15	0.13	0.99

Table 1: Mechanical and Physical parameters of paper sheets from group B

Parameter	Sample 1	Sample 2	Sample 3	Sample 4
Tensile strength (N/mm^2)	19.4	19.8	19.5	19.6
Tear resistance (mN)	132	139	136	134
Density (g/cm^3)	0.73	0.79	0.76	0.74
Basic weight (g)	89	92	90	88
Water absorptivity (%)	40	42	41	40
Thickness (mm)	0.94	0.11	0.99	0.97

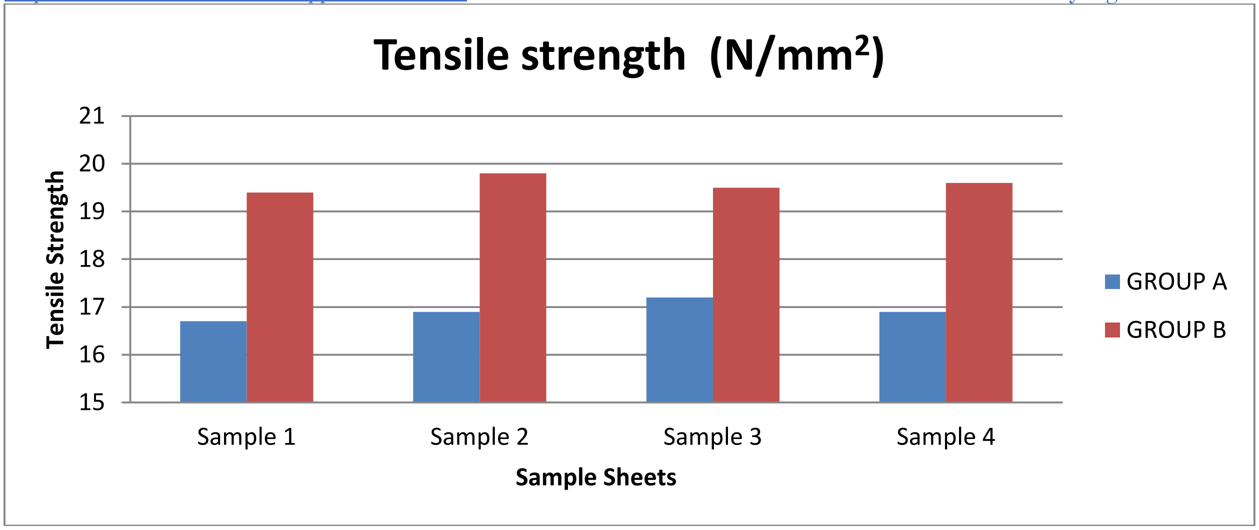

Figure 2: Showing Tensile strength (N/mm²) comparison between Group A and Group B

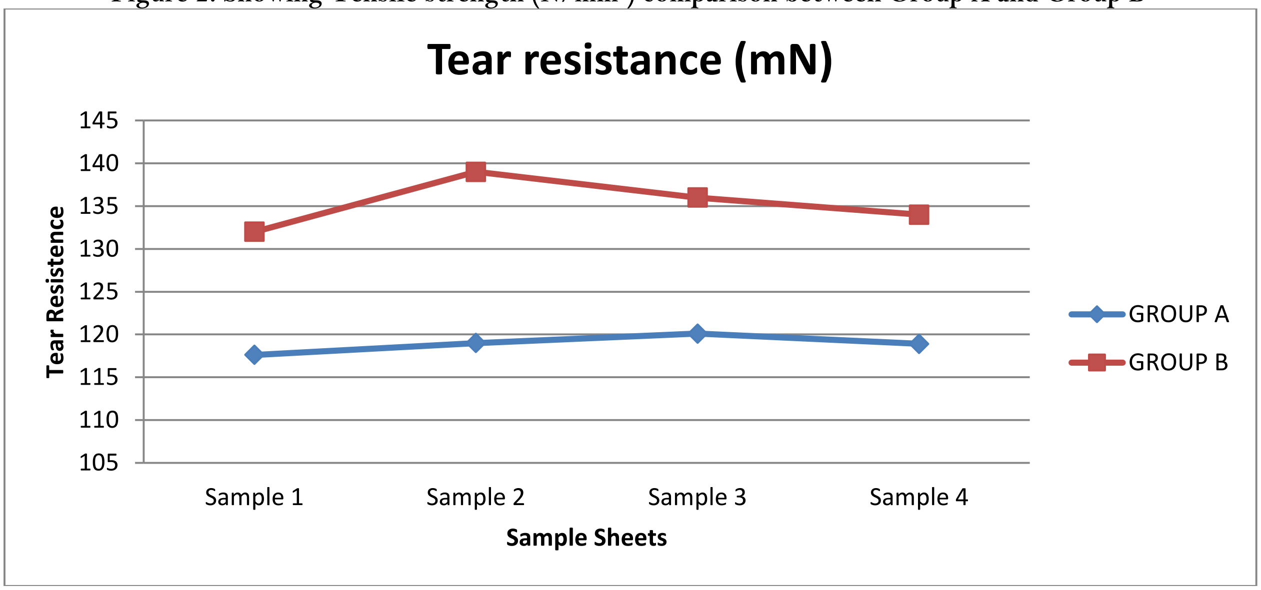

Figure 3: Showing Tear resistance (mN) comparison between Group A and Group B

Table 3: ISO Standards for packaging papers

Parameters	ISO	Units	Reference
Tensile strength	ISO1924-2	N/mm2	30-50
Tear resistance	ISO1974	mN	200-400
Density evaluation	ISO534	g/cm3	0.6-0.8
Basic weight	ISO536	G	70-100
Water absorptivity	ISO535	%	<50%
Surface characteristics	ISO 8791-2	NA	Smooth
Thickness	ISO 534	Mm	0.1-0.2

Under the microscope; it was observed that;
Paper sheets from Group A; Showed the majority of the fibers intact, but some irregularities observed
Paper sheet from Group B; Showed majority of the fibers intact, few irregularities observed.

DISCUSSION

The investigation into small-scale, sustainable paper-making utilizing groundnut husks revealed significant distinctions between Group A and Group B, with Group B demonstrating results more closely aligned with ISO standards. Group A, while achieving satisfactory results across several parameters, fell short of meeting ISO specifications in certain aspects. This can be attributed to the longer soaking and retting durations in Group A, resulting in higher fiber quantity but weaker fibers due to prolonged exposure. Additionally, the use of 10% starch in Group A may have adversely affected the properties of the paper sheets, contributing to deviations from standard quality. In contrast, Group B achieved results that were generally closer to ISO standards, indicating a higher level of consistency and quality. The shorter soaking and retting durations at warmer temperatures in Group B facilitated better fiber quality, as microbial activity is optimal under these conditions. These findings underscore the importance of refining fiber extraction methods, processing techniques, and equipment utilization to enhance paper quality in small-scale paper-making initiatives from groundnut husks. In terms of tensile strength and tear resistance, Group A exhibited satisfactory results but fell short of ISO specifications. Again, the prolonged soaking and retting durations in Group A probably contributed to reduced tensile strength and tear resistance compared to Group B. Conversely, Group B demonstrated improved tensile strength and tear resistance, attributed to the shorter soaking and retting durations at warmer temperatures, which facilitated better fiber quality. Density and basic weight measurements in Group A were within acceptable ranges but did not fully comply with ISO standards. This deviation can be attributed to variations in processing conditions and equipment capabilities. Group B, on the other hand, exhibited density and basic weight values closer to ISO specifications, indicating a higher level of consistency and quality in paper production. Both Group A and Group B showed moderate water absorptivity, with slight differences observed between the two groups. Group A demonstrated slightly higher water absorptivity, potentially due to the longer soaking duration, while Group B exhibited slightly lower water absorptivity, indicative of better fiber quality and denser paper structure. Thickness varied between Group A and Group B, reflecting differences in fiber extraction methods and processing techniques. Group A paper sheets tended to be rougher in texture and slightly thicker compared to Group B, highlighting the influence of processing parameters on paper properties. Despite the progress made, the study encountered challenges and limitations. Variations in raw material quality, processing conditions, and equipment capabilities contributed to discrepancies in results between the two groups. Additionally, the absence of specifications regarding the paper grade produced limited optimization for specific grade requirements, highlighting the need for further research and development in this area. Considering the findings, the quality parameters obtained are more applicable to certain paper grades. The produced paper sheets are most suitable for Packaging paper grade, given their moderate tensile strength and water absorption. Moreover, the observed thicker nature of the paper sheets could be advantageous for packaging applications, providing added durability and protection to the packaged items. Additionally, they may also be suitable for Specialty Papers and Kraft Papers grades, highlighting their potential applications and observed properties.

CONCLUSION

The study on small-scale paper-making utilizing groundnut husks reveals promising prospects for sustainable practices in the paper industry. Through careful analysis, differences between processing methods were identified, with Group B showing closer adherence to quality standards. Despite challenges, the research confirms groundnut husks' potential as a renewable resource. Further refinement of processes can enhance environmental conservation and benefit local communities. In conclusion, while additional research is needed, this study highlights groundnut husks as a viable eco-friendly alternative in paper production.

RECOMMENDATIONS

Drawing from the outcomes of this study, the following recommendations are put forth for future research endeavors and practical implementations. Further refinement of Processing Techniques: by exploring alternative methods for fiber extraction, pulping, and paper making to enhance the consistency and quality of paper sheets derived from groundnut husks. Enhancement and Customization of Equipment: Invest in the upgrade or development of specialized machinery tailored to the unique properties of groundnut husks, enabling more efficient processing and paper production. Standardization of Paper Grades: Define specific grades or applications for the paper sheets produced, facilitating targeted optimization of quality parameters and fostering market acceptance.

Economic Viability Assessment: Undertake comprehensive studies to evaluate the economic feasibility of small-scale paper-making projects utilizing groundnut husks, considering factors such as production costs, market demand, and potential revenue streams. Community Involvement and Skill Development: Engage local communities in paper-making initiatives and provide training programs to equip individuals with the necessary skills and knowledge for sustainable management and utilization of groundnut husks. Environmental Impact Evaluation: Conduct assessments to gauge the environmental sustainability of groundnut husk-based paper-making processes, identifying opportunities for minimizing ecological footprint and enhancing resource efficiency. These recommendations aim to guide future endeavors in leveraging groundnut husks as a renewable resource for eco-friendly paper production, emphasizing the importance of continuous improvement, community involvement, and environmental stewardship.

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