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Original Article

Fabrication of a Sustainable Biodegradable Packaging Alternative for the Fashion Industry from Banana Waste

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ABSTRACT

Packaging has both functional and aesthetic purposes. Kenya requires more sustainable biodegradable packaging options after a plastic ban was introduced in 2017 affecting numerous industries such as fashion. Banana stems and peels are part of the waste produced in Kenyan farms, suggested for the construction of biodegradable paper packaging material for the fashion industry. The objectives of this study were: to extract banana stem (BS) fibres using a decorticating machine; pulp the BS fibres using banana peel lye (KOH); and construct samples of paper packaging material from the pulp treated with KOH. The research design for this study was experimental. Kiganda banana stems collected from Kisii County were used in this study. The paper packaging material was constructed by pulping the BS using the KOH as a delignification reagent and then converting the pulp to paper by mounting it on mesh frames to dry. The findings reveal that in BS fibre extraction, decorticating one banana stem takes 10 minutes yielding 105 g of dry BS fibre. It also revealed that the handmade paper-making process takes 8 hours and 12 minutes including drying time to create an A4 size paper with the majority of the time (8 hours) being used for drying. The yield from the KOH pulped BS fibre was determined to be 68%. It was clear from the findings that KOH is comparable to commercial industrial alkalis like Sodium Hydroxide (NaOH) as a delignification reagent for BS fibres as it yields much pulp which produces good packaging material. Part of the recommendations for further research include the exploration of an industrially scaled paper-making process by the paper packaging manufacturing industry using KOH to pulp BS fibres. It is also suggested that research be done on using non-decorticated stems and varied concentrations of KOH to establish the most economical method.

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INTRODUCTION

Packaging is generally used for protection, preservation, containment, communication, promotion, and convenient transportation of products. It has evolved from simple materials such as leaves and tree bark to paper developed by the Chinese and later the innovation of various packaging using metallic tins, glass, corrugated boxes, and plastic bags.

According to Kabaivanova (2018), packaging in fashion marketing is significant, being considered a great aspect of product presentation and brand differentiation. Globally, the fashion industry pays keen attention to packaging as it is a very important aspect of business-consumer relations and, therefore, a great marketing tool. Despite its merits, packaging has also been a major pollutant. It is a major constituent of litter accounting for up to half of the total weight of litter disposed (Pongrácz, 2007). In Europe alone, the total volume of packaging waste was estimated to be about 79.3 million tons in 2019 (Love, 2021). Plastic packaging, for instance, has contributed to a large share of plastic pollution simply due to its short life span. They are non-biodegradable and thus end up in landfills or washed into oceans (Parker, 2018). In the year 2019, 359 million tons of plastic were produced for packaging, but consequently, less than 9% of this was recycled (Vidal, 2020).

Solutions to the plastic bag problem have mainly been aimed at encouraging the manufacture and use of paper bags (which are made from tree pulp) which are favourable due to their biodegradability. However, according to Markarian (2021) increased demand for biodegradable paper bags has encouraged deforestation since they are made of mainly tree pulp. According to Liu et al. (2018), various non-wood sources of fibre have been used to create biodegradable paper due to their high cellulose content. This includes jute, flax, bagasse, corn straw, bamboo, reed, grass, jute, and sisal. Banana stems are part of the non-wood fibres that have great potential as raw material for paper packaging (Subagyo & Chafidz, 2018).

In Kenya, banana pseudo stems are an underutilized source of fibre, given that they are often left to rot after the banana fruits are harvested (Kamau, 2016). Kenya has approximately 80,000 hectares of land for banana cultivation with 1200 banana plants per hectare, which translates to about 96 million banana plants. Post-harvest, these stems have been used for making manure, livestock feed, craft items such as mats, bags, and even potentially; hair extensions (Koigi, 2015). This is encouraging as it presents an opportunity for further examination of the banana pseudo stem and peels to access their potential as a source of raw material for sustainable biodegradable packaging. Product innovations in the fashion industry such as sustainable packaging have a positive and significant influence on the purchasing interests of consumers (Hidayati et al., 2020). Therefore, the introduction of new sustainable packaging options would be beneficial to packaging industries, fashion industries and the environment.

In light of the above background, this study aims to create a solution to the packaging predicament by creating a biodegradable sustainable packaging for the fashion industry by utilizing banana

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pseudo stems and peels, which have been greatly undervalued.

MATERIALS AND METHODS

This study employed an experimental design. The experiments were done in the National Research Fund Labs in KIRDI premises in Nairobi. Kiganda variety banana stems were collected from Kisii County, and the sheaths were taken apart for decortication. The BS fibres were extracted using a decorticating machine. The extracted BS fibres were then pulped in KOH retrieved from banana peels. The pulp retrieved was manually made into paper for packaging. These processes are detailed below.

Banana Stem Fibre Extraction Process

The fibres from the banana stems were extracted using a decorticating machine. 50 stems were decorticated. The decorticated BS fibres were washed and sun-dried. *Figure 1* shows the decorticating process.

Figure 1: The process of decortication and drying of BS fibres

1. Operation of a decorticating machine
2. Decorticated fibres ready for drying
3. Dried decorticated banana stem fibres in a bundle

Pulping Process

The alkaline pulping process was used for pulping the decorticated BS fibres, this is because it was recommended to be most suitable for non-wood fibres such as BS fibres (Subagyo & Chafidz, 2018). In this study the delignification reagent used for pulping was KOH. The standard conditions of 65% ± 2% humidity and temperature of 20 ^{0}C ± 2 ^{0}C were maintained in the pulping process. The time taken, the amount of fibre, and the concentration of the delignification reagents were kept constant. *Table 1* shows the parameters for the set pulping conditions.

Table 1: Parameters for the Set Pulping Conditions

Parameter	Units
Time	120 minutes
Temperature	105 ^{0}C
Alkali solute (KOH) weight for 7% concentration	1440 g
Water for cooking liquor	18 L
Fibre	3000 g

To create the cooking liquor, 18 litres of water was mixed with the 1440 g of KOH alkali. The 3000 g of BS fibres was put in a digester and the cooking liquor was added to the BS fibres leaving it to cook for 120 minutes at 105 ^{0}C. The cooking process is what breaks down the remaining lignin and makes the fibres easier to break during mechanical pulping (Azeez, 2018; Liu et al., 2018). The cooking liquor which is now known as black liquor due to its black appearance after cooking, was then drained and the BS fibres were washed severally to rid the pulp of impurities.

Paper Construction Process

The BS fibres obtained from the chemical pulping were then mechanically pulped using a blender to

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form the pulp paste. In constructing the paper, a handmade craft method was employed. This method was adapted from specifications by Babcock (2020) and Tappi (2002) on the handmade craft method for making paper. The requirements included: a flat firm table, an A4 size mould and deckle, a 2-litre calibrated measuring jug, a sponge, cardboards (3 m by 1 m), cutting tools such as scissors, basins, and 5 cotton cloths (1 m by 1 m).

In constructing the paper, 1000 ml of pulp was measured in the calibrated measuring jug, and 2 litres of water was added to increase the viscosity of the pulp and ensure an even layer when laying out on the mould and deckle. The mould and deckle are hoisted on a sturdy basin where excess water is drained. The pulp-water mixture was then poured onto a mould and deckle. Once most of the water had drained out and the pulp was matted, the mould and deckle were placed carefully onto the tabletop. The pulp on the mould was transferred or couched to an even layered piece of cotton fabric by removing the deckle laying the fabric over the mould and turning it over such that the mould lay on top of the fabric. To remove excess water a sponge is run over the mould gently to suck in water. This is done severally to satisfaction. Similarly, the pulp on the cloth was then transferred in the same way onto the cardboard to dry. More excess water was removed using a sponge. This procedure was repeated for 50 sheets of paper. Pulp preparation, laying of pulp on mould and deckle, and couching took an average of 8 hours and 12 minutes. The pulp sheets were left to air dry on the cardboard for 8 hours, then carefully peeled out when completely dry to get the paper packaging material. The edges were then trimmed using scissors. The paper-making process is presented in *Figure 2*. The packaging prototypes created using the fabricated paper is presented in *Figure 3*.

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Figure 2: The process of paper construction.

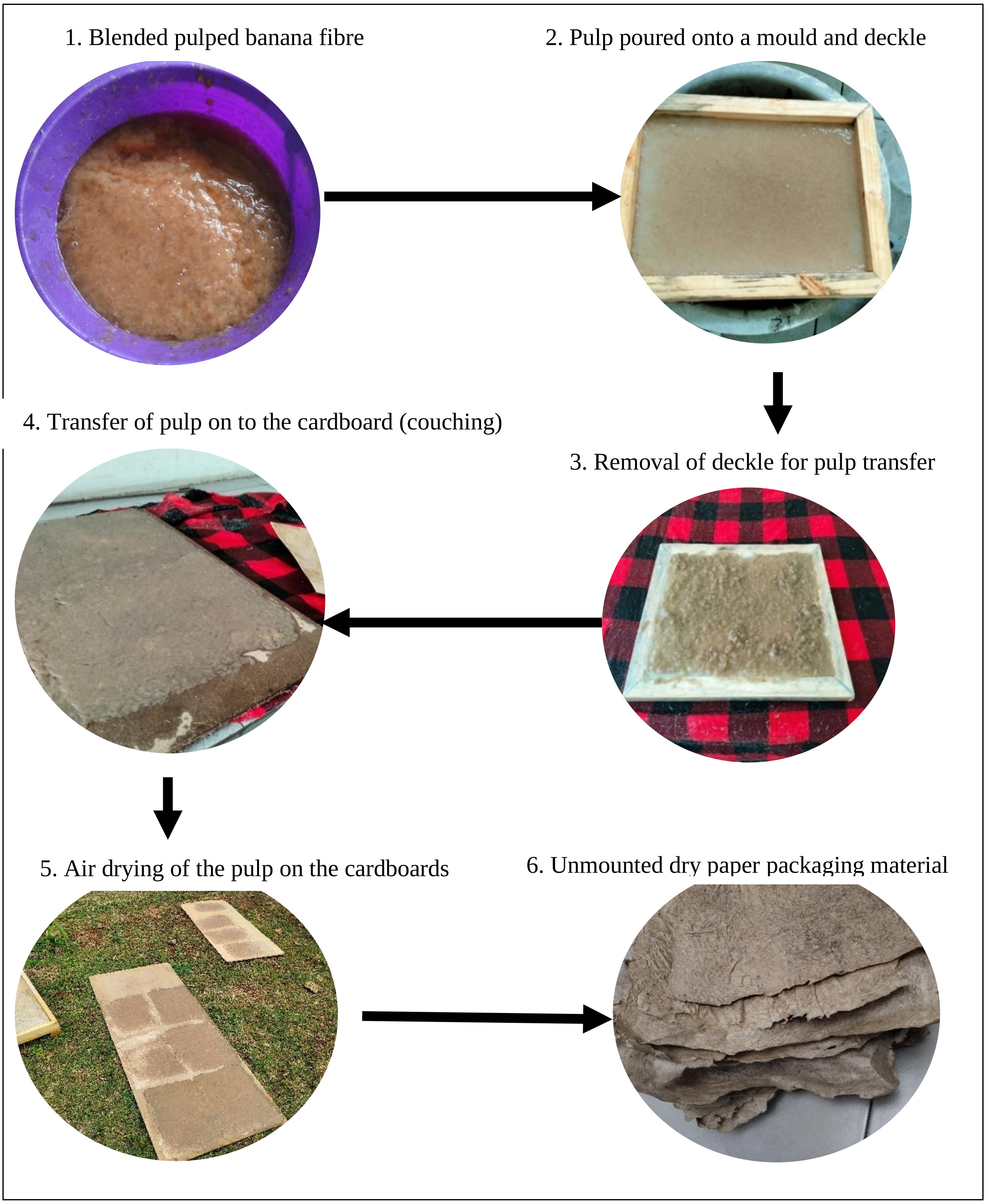

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Figure 3: Packaging prototypes for fashion items.


RESULTS

The results are drawn from all the processes that include the BS fibre extraction through decortication, alkaline pulping process of the BS fibres, and the construction process of the paper packaging material.

Banana Stem Fibre Extraction Process

The BS fibre extraction process was done through decortication. In the decortication process, the following data was recorded: the total number of stems decorticated, the time taken to decorticate one meter of the banana stem and also the average weight of dry fibre retrieved from one meter of the banana stems. The summary of findings from the entire decortication process is presented in *Table 2*.

Table 2: Recorded measurements and observations from the decorticating process

Recorded Measurements and Observations	Results
The number of stems decorticated.	50 stems
Time of decortication for the one-meter stem.	10 minutes
The average weight of dry fibre retrieved from the one-meter stem.	105 grams

Pulping Process

The KOH alkaline pulping process was done under the following constant conditions: alkali; 7%, temperature; 105 ^{0}C, and time was 120 minutes. A total of 3000 g of fibre was pulped. To determine the yield from the 3000 g of fibre pulped, the resultant weight of the dry pulp from the KOH alkaline pulping process was measured and compared to the original dry weight of the fibre before pulping (3000 g) (Briggs, 1994).

The KOH alkaline pulping process had a high yield (by mass) at 68% (2040 g) this is presented in table *(Table 3).*

Table 3: Summary of yield produced by the KOH pulping process.

Pulping process	Original Dry Weight of the Fibre in grams (g) (DW)	Dry Pulp Yield in grams (g) (DP)	% Yield (%Y=DP/DW ×100)
KOH	3000	2040	68%

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The Packaging Construction Process

In constructing the paper packaging material, the time taken by one person for each of the processes was recorded. *Table 4* summarizes the findings of the paper construction process.

Table 4: Summary of findings for time taken for constructing an A4 size paper.

Construction Process	Time in minutes
Pulp preparation	3 minutes
Laying of pulp on mould and deckle	2 minutes
Couching	5 minutes
Air drying	8 minutes
Unmounting	2 minutes

DISCUSSION

This section discusses the findings of the study in relation to the study objectives. The findings are also juxtaposed against known literature that relates to the specific objective being discussed.

Banana Stem Fibre Extraction Process

This study aimed to collect information on the fibre extraction process which was done through decortication. This information would be beneficial in generating information on the making of paper packaging from BS fibres.

The following information was collected:

- The number of stems decorticated.
- The rate of decortication for one-meter stem.
- Average weight of dry fibre retrieved from the one-meter stem.

The average time taken by one person to decorticate one-meter stem was 10 minutes giving a total time of 500 minutes (8 hours 18 minutes) for the 50 one-meter stems. In terms of extraction of fibre for packaging, the rate of decortication in this study indicates that in every hour, 6 (one-meter length) banana stems would be decorticated translating to 48 (one-meter length) stems for a working day of 8 hours if only one person is doing the decortication. The average weight of dry fibre retrieved from the one-meter stem was 105 g. This is consistent with the findings on extracted fibre by Jirukkakul (2019), which revealed that the dry fibre from one stem will range from about 100 g to 200 g per stem. This confirmed why compared to other fibre extraction methods, mechanical decortication is preferred due to its efficiency in time and yield (Badanayak et al., 2023). This information is vital for the introduction of a novel bio-based product derived from waste biomass as the determination of its economic viability and commercialization just as any other product in business, demands accounting for procedural throughput time among other things (Kover et al., 2022).

Pulping Process

In this study, the delignification alkali reagent used was KOH. The KOH was organically derived from the ash component of banana peels. The results revealed that the KOH alkaline pulping process had a high yield (by mass) at 68%. This is in line with a similar study by Goswami et al. (2008), who noted that the unbleached pulp from an alkaline soda process generally has a yield of 50.8%. Similarly, Kalyoncu (2022), determined that the yield of various KOH pulping processes ranged from 47.4% to 53.17%.

Similar studies on the viability of KOH as a replacement alkali, determine that KOH is a suitable replacement for NaOH in the soap-making process (Kalyoncu, 2022; Olabanji et al., 2012; Waithaka & Muriuki, 2019). The results in this study also show that KOH is a viable replacement for alkalis such as NaOH for delignification as it produces a high yield of fibre. When using the KOH pulping process, the BS fibres retain their core strength structure (cellulose) and thus the high yield value. The fibres' lignin is what is mainly detached from the BS fibres making them retain more of their

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hemicellulose and cellulose layers compared to other alkalis such as NaOH that erode more of the cellulosic layers thus contributing to a lower yield (Subagyo & Chafidz, 2018).

Pulping with KOH would be a more economically viable choice compared to pulping using other commercial alkalis as it produces more yield and therefore provides more pulp for papermaking. Additionally, for an eco-friendlier method, pulping with KOH is highly encouraged given that the KOH is obtained from banana peels a byproduct of banana farming which is often discarded as waste. Utilizing it will ensure added value to the banana peels which are considered waste (Kalyoncu, 2022; Kover et al., 2022). Valorisation of agricultural wastes such as banana peels promotes a circular bio-economy and continual exploration of waste biomass for the replacement of industrial chemicals would potentially highlight the need and accelerate the production of waste biomass products on an industrial scale.

The Packaging Construction Process

In this study, hand-made paper sheets were constructed by laying of the pulp on the mould and deckle, couching, air drying, and unmounting the dried paper (Tappi, 2002). For a single person to hand-make an A4-sized paper a total time of 8 hours and 12 minutes is required. 8 hours are for air drying and 12 minutes are for the preparation of the paper before drying. This means that within an hour five papers can be prepared.

Essentially, in fashion marketing handmade products are considered luxurious compared to machine-made alternatives. Handmade products take much more time to produce and because they are dependent on the craftsmanship of the craftsman, variations are much more common. This affects the quality of the product and the quantity produced as well (Denaro & Petrecca, 2020). It is however every business's primary goal to make a profit in the most efficient way possible and this often means curating shorter throughput times during production (Sonegara et al., 2023).

The demand for biodegradable packaging options for industries like the fashion industry which are inclining to sustainable footprints is on the rise and the merger between going green and making a profit is often hard to achieve (Sonegara et al., 2023). In Kenya, the demand for biodegradable packaging options was accelerated by the ban on single-use plastic bags in 2017 (*Kenya Law | Kenya Gazette*, 2017). Furthermore, the increase in e-commerce in businesses has fuelled demand for a range of packaging products, with biodegradable options being at the top of the list (Kisato, 2014; Moretto et al., 2018). To meet such a demand a more mechanized packaging paper-making process would be required. To illustrate this, Beston Company (2019) outlines that one of its lowest output paper-making machines produces up to 40 kgs of paper in an hour (approx. 1000 kgs per day). This is equivalent to 8000 A4 size papers per hour which is 1600 times more than the established rate given by the findings of this study which is 5 A4 sized papers per hour. Therefore, for a more efficient paper-making process, it would be more efficient to mechanize the process by constructing the paper using a paper-making machine.

Summary of Major Findings of the Study

This section outlines the following: the summary of findings in line with the objectives, conclusions from the findings, recommendations and suggestions for further research.

The purpose of this study was to create a sustainable packaging alternative for the fashion industry from banana waste.

The research objectives were:

- Extract banana stem fibres using a decorticating machine.
- Pulp banana stem fibres using KOH.
- Construct samples of paper packaging material from the pulp treated with KOH.

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Banana Stem Fibre Extraction Process

The BS fibres were decorticated using a decorticating machine. Fifty-one-meter banana stems were decorticated using a decorticating machine. The findings revealed that a one-meter stem took an average time of 10 minutes to decorticate. Given that the average height of the Kiganda stem was 2.5 meters then it would take 25 minutes to decorticate one stem, resulting in about 2 and a half stems being decorticated per hour. For a day, one person working 8 hours can decorticate about 20 banana stems.

The Alkaline Pulping Processes

In this study, KOH which is potassium hydroxide was used as a delignification alkali reagent. The KOH was organically derived from the ash component of banana peels. The results revealed that the KOH alkaline pulping process had a high yield (by mass) at 68% (2040 g) of the original dry mass of the fibre (3000 g). This proves that KOH pulping is an efficient alkaline pulping process as it leads to a high yield thus qualifying KOH as a good delignification reagent.

The Paper Packaging Material Construction Process

Preparation of the paper packaging material included pulp preparation, laying of the pulp on the mould and deckle, couching, air drying, and unmounting. The results showed that to hand make an A4-sized paper packaging material a total time of 8 hours and 12 minutes is required of which the 8 hours are allocated for air drying of the paper packaging material. The time taken to prepare the A4-sized sheets was 12 minutes.

CONCLUSION

This study reveals that in the production of sustainable paper packaging from banana waste (peels and stems), decortication is a time-efficient method of extracting the BS fibres, banana waste is a great biomass option whose fibre yield post chemical pulping is very high, and the hand making construction process produces desirable results but is time-consuming. This sheds light on the amount of manpower needed for the decortication of banana stems as well as the average amount of fibre that one can retrieve thus proving valuable to those interested in the waste biomass value-addition business. For pulp and paper packaging industries, additional value can be drawn from the utility of banana peels as sources of a delignification reagent in the pulping process. The emergence of the green economy has pushed businesses to incline to environmentally sustainable production patterns and outputs. Given that consumer purchasing behaviour in industries such as the fashion industry is greatly influenced by product innovations such as sustainable packaging, then packaging companies are highly recommended to explore and adapt the production model in this study.

Additionally, businesses in the production of packaging for such industries would model corporate environmental responsibility by adapting the valorisation of banana waste as raw material for the packaging.

Recommendations

The following recommendations are made based on the conclusions made from this study.

Recommendations for Practice

The paper packaging manufacturing industry should explore making of paper packaging for various industries such as the fashion industry using extracted BS fibres on an industrial scale through mechanization due to their proven viability. The paper packaging-making industry should explore KOH lye (Potassium Hydroxide) as a possible replacement for commercial alkalis such as NaOH (Caustic Soda) in the pulping process of fibres such as banana fibres, for a process with an increased yield and that is less toxic to the environment.

Recommendations for Further Studies

Research could be carried out on pulping the BS fibres using different Lye (KOH) concentrations and other organic delignification reagents. A comparative study where banana stem paper packaging is made from the whole un-

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decorticated stem as opposed to only BS fibres from a decorticated stem should be carried out.

OPERATIONAL DEFINITION OF TERMS

Banana Waste: Banana stems and banana peels which are by-products in the production of banana fruits.

Banana Variety: The species or type of banana plant.

Delignification Alkalis: Potassium Hydroxide Lye

Kiganda: The most popular banana variety prevalent in five counties in Kenya that grow the most bananas regionally. It is a cooking variety characterized by having medium-sized green bananas that are also large.

KOH: Potassium Hydroxide derived from banana peel ash solution.

Packaging Material: The medium used to create different types of wrappings or enclosures specifically for packages.

Stems: The plant axis of banana plants that bear shoots, buds, and leaves, and at its basal end roots.

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