International Journal of Agriculture and Crop Sciences.
Available online at www.ijagcs.com
IJACS/2015/8-1/9-14
ISSN 2227-670X ©2015 IJACS Journal

Extraction & Production of Agro – Sack from Banana (Musa Sapientum) & Plantain (Musa Paradisiaca l) Fibres for Packaging Agricultural Produce

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ABSTRACT: This paper displays the process technology for the production of biodegradable agro- sack from banana and plantain fibres of Nigerian origin for packaging a wide range of industrial and agricultural based produce such as cotton linters, cocoa, onions, potatoes, grains, oil seeds etc. Un-utilized banana/plantain stems were retted and extracted in a controlled system, using natural and microbial retting techniques. A consortium of bacteria species such as; Bacillus cereus, Bacillus licheniformis, Bacillus subtilis and Bacillus polymyxa isolated from soil and retting water of the stems were used, with six to ten (6-10) days of accelerated retting period as against twenty eight to thirty five (28-35) days of natural retting. The Physico-mechanical properties of the fibres were determined according to ASTM standard for textiles –fibres, zippers, yarns and fabrics. Tensile strength: 380-650Mpa & 309.86 – 450.70Mpa, Elongation at break: 1.7-2.7% & 2.5-4.6%, Young's modulus; 24.5-36.0GPa, & 12.99-25.89GPa for natural and microbial retted fibres respectively. The extracted fibres were carded and successfully spun into yarn using a spinning wheel, woven into fabric by interlacing warp and weft yarns in a 0.68m by 0.74m and 1.64m by 1.32m weaving frame respectively. The resultant fibres possess sufficient strength, uniformity, fineness and some level of flexibility which enable it to withstand the strains and stress of spinning and weaving process.
Key words: Banana & Plantain fibres; Retting; Spinning & weaving.

INTRODUCTION

Banana (musa sapientum) & plantain stem (musa paradisiacal) is a tropical humid lowland crop belonging to Musa family of large perennial herb with leaf sheaths that form pseudo stems. Their heights can be 10-40 Feet (3.0-12.2 meters) surrounded with 8-12 large leaves. The leaves are up to 9 feet long and 2 feet wide (2.7 meters and 0.61 meter). The fruits are approximately 4-12 inches (10.2-30.5 centimeters) (PTRI. 2005.). After harvest of fruit, huge quantities of waste biomass (pseudo stem, leaves, etc.) are generated and discarded as waste due to nonindustrial utilization.. There is high demand for fibres generally. For instance, the demand for fibres for clothing alone is expected to rise from the current 60 million tons to 130 million tons per year in the year 2050 (Kozlowski, 1996), A banana or plantain plantation of about 500, 00 acres might yield 100,000-200,000 ton of fibre (Kirby, 1963). And a fresh pseudo-stem yields about 1.5% of fibre.

Banana and plantain occupies a prime place as important house hold fruit crops grown in Nigeria and as a staple in the diet of Nigerian populace, it contributes to national food security, employment, diversified income in rural and urban areas. Banana is the world's second most important fruit crop after oil palm. It is grown in 130 countries worldwide, world production stands at 71 million metric tonnes, while plantain is grown in 52 countries with world production of 33 million metric tonnes (FAO, 2004). However no African country is ranked amongst the top 10 countries for banana production in the world while eight African countries were named among the top ten world producers of plantain with Nigeria ranking as the fifth highest producer of the crop (FAO, 2004). Presently, after harvesting of fruit from the plant, huge qualities of waste biomass (pseudostem, leaves, suckers etc) of over 90% of the plant is generated, which is a worrisome trend this research is set to arrest. We explore the possibility of extracting resources from renewable and waste biomass, for industrial sustainability of textile and agro-sacks industries. The extraction of banana and plantain fibres were centered on more environmental friendly process, easy and efficient method of retting fibres by comparing the extracted fibres from microbial and natural retting process. The consortium of bacteria species such as; Bacillus cereus, Bacillus licheniformis, Bacillus subtilis and Bacillus polymyxa isolated from soil and stems which were used in the fibre extraction show over hundred percent accelerated retting period with similar properties with naturally retted fibre. Controlled system tank retting (CSTR) method was employed which allows greater control of the system, leaching period were observed in the first five to eight hours by discharging water and much of dirt, inorganic and colouring matters to assure clean fibre, environmental dynamism of system was monitored, because the quality of fibres in large extent is determined by the retting conditions and CSTR allows proper management of waste retting water which is channeled to effluent treatment device. The extracted and characterized fibres were with low lignin content, long fibre length, uniformity, quick drying tendency with high tensile strength which is essential for industrial purposes.

World over, jute fibre is among the most versatile fibres gifted to man by nature that are of various uses, especially in agro-sack making. Its demand has been on the high rate to meet the ever-increasing demand of jute bags in the farm-packaging sector and agro-based industries. We foresee emerging opportunities in broadening natural fibres, because of attribute like biodegradability, eco-friendly, sustainability, energy efficiency etc. Having alternative fibres to support jute fibre is our optimal focus, through market oriented research and development with great concern about the environment and shelf-life of agro-produce as farmers have shifted into packaging agro-based products such as cocoa, sugar, coffee, onions etc with hydrocarbon/synthetic (polyethylene/ polyester granules) sack.

MATERIALS & METHODS

Mature Banana & Plantain Stems, soil samples, were used in this investigation & were obtained at different points, from FIIRO experimental garden, of Lagos Nigeria.

Fibres Extraction and processing

An extensive investigation was carried out at Federal Institute of Industrial Research, Department of Chemical, Fibre and Environmental Technology, Polymer and Textiles Research Laboratory. Starter culture for low time retting of fibres was developed by Environmental microbiology division. Isolation of micro-organisms was carried out on the stems and soil of the plant, serial dilution was used to inoculate the micro-organisms into Nutrient agar (NA), Potato Dextrose Ager (PDA) and Agar Bacteriological plates, incubated at 30^0c for 24hours. The colonies of organisms formed after 24hours were characterized and identified using Bergy's manual of determinative study. A consortium of bacteria species such as; Bacillus cereus, Bacillus licheniformis, Bacillus subtilis and Bacillus polymyxa were isolated and used for extraction and processing of fibres from Banana and plantain stems using controlled system tank retting (CSTR) method. The extracted fibres were dried, carded and spurn into yarn, Woven into plain and twill design and sewed/tailored into agro-sacks.

Conditioning

The extracted fibres were conditioned, at 65 $^{+}_{-}$2% relative humidity (RH) and 27$^{+}_{-}$ 2^0C for 2hhrs to ensure environmental equilibrium moisture content, prior to testing. (NIS: 43:1980) and (ASTM: D1776-79).

Burning Test

The effect of flame in contact with fibre samples was carried out using standard method as described in technical manual of the American association of textile chemists and colorists (AATCC-1981/82). Fibre samples were held in tweezers and placed close to the side of small flame. The following observations were made (if fibres melt or shrink from flame, if fibres are self-extinguishing outside flame, if fibres burn in flame, the odour, colour and nature of residue ash).

Moisture Regain

1g of fibre sample was weighted into the tray of the moisture analyzer (m/s-70), closed and monitored to determine the amount of moisture present in a sample. The temperature, time and the %moisture regain was recorded automatically by the machine. The test was carried out in triplicate and average result was taken.

Ash Content

2g of fibre sample were weighed into a porcelain crucible, transferred into the muffle furnace, set at 550^{0c} and left for 4hours. The crucible and its content were cooled at 100^{0c} in air, then at room temperature in desiccators and weighted. The percentage ash content calculated from the formula below:
% Ash content = (weight_of_Ash / original weight of sample) × 100/1

Fibre Density Measurement

Fibres density measurement was carried out using Archimedes method of established protocol for natural fibres density measurement (2008). Fibre density measured in accordance with ASTM standard D3800-99 and D792/D276. The specimens were condition at 60^0c for 72hrs. 1-5g of fibre samples were accurately weighted into a $25cm^3$ measuring cylinder and immersed in $25cm^3$ of fluid for 1min (toluene, acetone & methanol). The specimen was then placed in a vacuum desiccator for 5min to remove trapped air. The reading of displaced fluid was taken. Fibre density was calculated from immersion fluid density and the ratio of recorded masses as follows.
Density (D) = M/V
Where M= mass of fibre in g and
V= volume of fibre in cm^3

Water Absorbency Capacity (ASTM D 2402)

Three test specimens /sample were weighed 1g each, submerged in distilled water at room temperature for 1hour. Then removed and drained for 2-3minutes. The percentage water absorbed calculated from the formula below.
Water absorbed % = ((Y-X)/X) × 100/1
Were X= initial weight of the fibre
Y= final weight of the fibre
The fibres have high water absorbency when compared to the hydrocarbon bags.

Chemical Analysis

Direct method of cellulose, hemicellulose and lignin (Moubasher et al. 1982)
2g of fibre was boiled in ethanol (4 times) for 15 minutes, washed thoroughly with distilled water and kept in oven for dry weight at 40^{O}C overnight, then divided into two parts in which one is considered as A fraction. Second part of residue was treated with 24% KOH for 4 hours at 25^{O}C, washed thoroughly with distilled water, dried at 80^{0}C overnight and the dry weight taken as B fraction. The same samples again treated with 72% H_2SO_4 for 3 hours to hydrolyse the cellulose and then refluxed with 5% H_2SO_4 for 2 hours. H_2SO_4 was removed completely by washing with distilled water, dried at 80^{O}C in an oven overnight and dry weight taken as C fraction
Calculations:
Fibre samples: banana and plantain fibre
Cellulose = B – C
Hemicellulose = A – B
Lignin = C itself

Mechanical Properties

The tensile properties of single fibre in terms of tensile strength (stress @peak), elongation @break, young's modulus, strain, breaking load (force @break), and stress @break were determined using tensile testing machine (Instron machine). Ten (10) single fibres were carefully manually separated from the bundle of fibres. The described preparation procedures according to ASTM 3822-07 Standard were followed. Fibre samples of equal length of 20cm were prepared, a cross sectional head speed of 5mm/min were used. Six (6) fibre samples were tested.

Microscopic analysis of banana & plantain fibre

The experiment was conducted at Forestry Research Institute of Nigeria (FRIN), Ibadan Oyo state. Samples were prepared into slivers of 4mm ×3mm × 3mm and put in test tubes for maceration in equal volumes of glacial acetic acid and hydrogen peroxide (1:1). The solution was put in the oven for 4 hours at a temperature of about 100^{o}C for maceration. Random samples of macerated fibres were mounted on slides and examined under a light microscope. Fibres were viewed and measured using a stage micrometer under × 80 magnification. Twenty (20) fibres were measured from each respective sample. Values that were determined were fibre length, fibre diameter, lumen width etc

Biodegradability Test

Biodegradability test was done based on the soil burial method, to determine the composting period under aerobic condition. Samples of woven matt were prepared, conditioned and constant weight taken as (X2). These samples were then buried in soil for 1 month. The degrading sample was recorded as (X3). % weight loss, (%X) can be calculated from the following equation:

%X = ((X2-X3)/X2) x 100

RESULTS AND DISCUSSION

Table 1. Physico-chemical and mechanical properties of banana & plantain fibres

Parameters	Banana fibre (musa sapientum)		plantain fibre (musa paradisiaca l)	
	Natural retting	Microbial retting	Natural retting	Microbial retting
Moisture content (wt %) @105°C ,3.4-4.5mins	9.01-10.89	9.71-11.50	9.05-10.78	9.73-11.56
Fibre Density(g/cm^3)	0.86-1.12	0.80-1.20	0.86-1.13	0.5-1.25
Ash Content (wt %)	0.8-2.45	0.9-2.67	0.75-2.45	1-2.65
Water absorbency (%)	0.40	0.5	0.4	0.5
Cellulose (wt %)	55.02-63.03	50.05-61.07	54.04-63.7	50.08-60.50
Hemicelluloses (wt %)	12.05-18.00		12.50-18.60	
Lignin (wt %)	8.50-10.07	9.00-12.05	8.60-10.40	9.00-10.45
Tensile Strength(Mpa)	380-650.0	309.86-450.70	385-583.1	309.86-450.70
Elongation @Break (%)	1.8-2.553	2.50-4.58	1.7-2.658	2.50-4.58
Young's Modulus (Gpa)	25-36	12.99-25.89	24.5-34	12.99-25.89
Fibre Length(mm)	1.50-2.87	1.44-2.89	1.86-3.37	1.44-2.89
Fibre Diameter (µm)	15-25	11.25-22.5	13.7-27.5	1.1.25-22.50
Fibre lumen width (mm)	0.0075-0.015	0.0075-0.0136	0.0075-0.0136	0.0075-0.0136
Fibre cell wall (mm)	0.00125-0.00625	0.0025-0.0048	0.002-0.0063	0.0025-0.0048
Runkel ratio (mm)	0.527	0.410	0.826	0.410
Coefficient of flexibility (mm)	82.86	60.44	54.76	60.44
Felting power (mm)	99.47	128.4	123.3	128.4
Wall rigidity (mm)	0.219	0.213	0.547	0.213

Table 2. Burning Test.

Fibre Samples (natural &microbial retted fibres)	Melt Near Flame	Shrink From Flame	Burns In Flame	Continues To Burn outside flame	Appearance Of Ash
Banana Fibre	No	No	Yes	Slightly-Slowly	Light Gray
Plantain Fibre	No	No	Yes	Slightly-Slowly	Light Gray

Retting has been the major and dominant challenge faced during bast fibres processing due to the time required to break non cellulosic materials: pectic material, hemicelluloses and lignin. With the advancement in biotechnology and technical fibre processing, microbial retting of banana and plantain stems with a consortium of bacteria species such as; Bacillus cereus, Bacillus licheniformis, Bacillus subtilis and Bacillus polymyxa isolated from soil and retted water of the stems showed significantly and accelerated shorter retting time with acceptable fibre qualities. The graph in figure two displayed the tensile strength of experimental fibres where the natural retted (NR) banana fibre (B) and plantain fibre (P) is of higher strength than the microbial retted (MR) banana fibre (B) and plantain fibre (P), though both fibres had sufficient strength to withstand the strains and stress of spinning and weaving process. The effectiveness of these biodegradable sacks in packaging of agro-produce was studied and compared with hydrocarbon/synthetic sack. It is of better sack stability, tear resistance, air permeability, thermal shrinkage resistance and also it is stronger than poly-sacks.

Figure1. Extracted Banana and Plantain Fibre

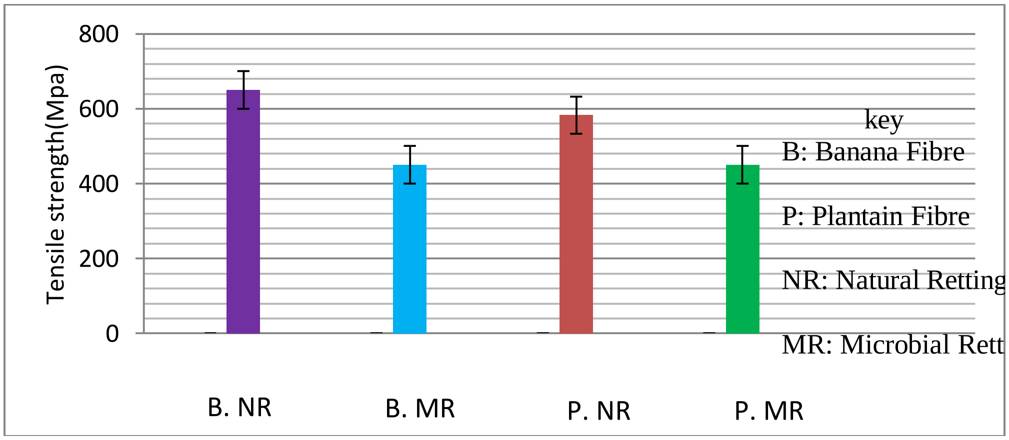

Figure2. Graph of Tensile Test Results of Experimental Fibres

Figure3. Weaving frame, spurn yarn, woven fabric & agro-sack

CONCLUSION

Hydrocarbon free sacks are the safest packaging material for storing edible and agro-based products. It is of pure natural material and do not contain compounds that could produce off-tastes in agro and food materials packed in sacks as it also allows the agro-produce to “breathe” during transportation which reduces internal heat generation and biological attack. It has better stack-stability and porosity, easily repaired and withstands higher temperatures than the synthetic bags manufactured from polyethylene and polyester granules.

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