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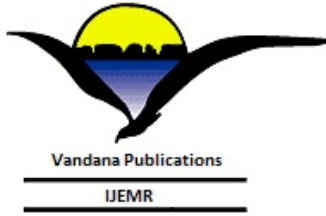
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Effects of Extraction Techniques on the Yield and Mechanical Properties of Empty Plantain Fruit Bunch Fibers

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ABSTRACT

Two major techniques; water retting and dew retting, were used to extract natural fiber from empty plantain fruit bunch. Four different size categories each comprising of a group of six (6) bunches were used for the water retting experiments and two size categories each of six (6) bunch samples were used for the dew retting experiments. Results for the water retting experiment showed that the fiber yield is enhanced by the addition of a load/weights on the retting bunch and the bunch size, while results for the dew retting revealed that fiber yield is dependent on both retting time and bunch size. Results of statistical analysis produced optimum yield value of 85.95% with a maximum added weight of 5kg and bunch diameter size of 4cm for the water retting, and for dew retting, an optimum yield value of 60.38% for the bigger bunch size of 5.5cm when extracted on the same day of harvest. Mechanical tests on fiber from the two techniques showed better mechanical properties for the water retting categories with a maximum tensile strength of 823.295N/mm² and modulus of elasticity (MOE) of 644.318N/mm². The fiber extracted finds use in the manufacture of reinforced composite materials which are fast replacing the use of metallic and plastic materials, due to the quest for materials that are light and cheap, yet strong.

Keywords— Empty plantain fruit bunch fibers, water retting, dew retting, yield, mechanical properties, statistical models.

importance. After harvesting plantain bunches from the trees over a tract of land, a large amount of waste biomass remains, because the plantain plant cannot be used for the next harvest. These bare pseudo-stem and empty fruit bunch are normally felled and usually abandoned in the soil plantation to become organic waste and cause environmental pollution. Therefore, exploitation of the waste plantain pseudo-stems and empty fruit bunches will be significantly beneficial to environment and bring additional profits to farmers [3].

Natural fibers present important advantages such as low density, appropriate stiffness, mechanical properties, high disposability and renewability. Moreover, they are recyclable and biodegradable. And there has been lot of researches on the use of natural fibers in reinforcements. Plantain fiber, a ligno-cellulosic fiber, obtained from the pseudo-stem and empty fruit bunch of plantain plant (*Musa sepientum*), is a bast fiber with relatively good mechanical properties.

Many of our technologies require materials with unusual combination of properties that cannot be met by the conventional metal alloys. This led to the discovery of composite materials with superior corrosion resistance, good temperature resistance and resistance to extreme wears. The facts that composites in general can be custom tailored to suit individual requirements have given them desirable properties in corrosive environments, providing higher strength with a lower weight and their low lifecycle costs has aided in their evolution [4,5,6]. It provides a good combination in mechanical property, thermal and insulating protection. It was observed that these qualities in addition to the ability to monitor the performance of the material in the field via embedded sensors give composites an edge over conventional materials [7]. Plantains (*Musa* spp., AAB genome) are plants producing fruits that remain starchy at maturity [8] and need processing before

I. INTRODUCTION

Plantain pseudo-stem and empty fruit bunch is an abundant natural resource in subtropical and tropical regions and has potential for providing profitable products such as manure [1] and feed [2] which call for practical techniques and processes to exploit this natural resource. In South China, the production has significant economic

consumption. Plantain production in Africa is estimated at more than 50% of worldwide production [9].

Nigeria is one of the largest plantain producing countries in the world [10]. Plantain fiber can be obtained easily from the plants which are left as waste after the fruits have ripened. So plantain fiber can be explored as a potential reinforcement. Many investigations have been made on the potential of the natural fibers as reinforcements for composites and in several cases the result have shown that the natural fiber composites own good in stiffness, but the composites do not reach the same level of strength as the glass fiber composite [10].

Many researchers have given attention in investigating optimal techniques for the extraction of fibers from empty plantain fruit bunch, but no published work have been found to do a comparative study of the several extraction techniques vis-a-vis fiber yield [11, 12, 13, 14]. None has also shown interest in understanding the kinetics of the decay process during water retting or dew retting. This research hopes to bridge the foregoing limitations.

II. METHODOLOGY

Sample/Material Collection and Preparation

Sampling of the materials used for the experiments took place within Eziofodo locality of Owerri West LGA of Imo State, Nigeria. The experimental materials(including the plantain bunches, and other necessities) were gathered to make them readily available for the work. The plantain bunches were assembled from the community central market on a major market day, from the local dealers after large sales were made. Twenty four (24) plastic bowls (for the water retting) were also provided for the experiment, alongside weighing scale, prepared stones(weights/loads) of different sizes, blunt kitchen knife and measuring rule. Sufficient borehole water was also provided for the work.

The empty plantain fruit bunches were assembled, cut into categorized sizes of similar length, diameter and weight(made available for both water retting and dew retting means of extraction). The plastic bowls were arranged on the floor of an empty room (where the retting experiment was carried out), and about three (3) liters of borehole water were poured into each of the 24 bowls for the bunch water retting. Transparent measuring rule, writing pad and pen were provided, both for immediate and periodic recording of experimental results.

Materials used for the fiber Extraction

Water Retting: Plantain Empty Fruit bunch of various sizes(by mass and diameter); Weights(Stones) of different sizes (5kg, 4kg, 3kg, 2kg and 1kg); Borehole water; Wide plastic bowls; Measuring rule (plastic); Weighing scale; Analytical balance.

Dew Retting: Plantain Empty Fruit bunch of two(2) categories (size by mass and diameter); Borehole

water; Blunt kitchen knife; Measuring rule (plastic); Analytical balance.

Experimental Methods

Approach/Procedure for the Water Retting

- Six(6) different group samples, each of four bunch size categories of 5.5cm, 5.0cm, 4.5cm and 4.0cm in diameter respectively were made available in its fresh state at the beginning of the experiment.
- Five(5) hard stones of mass 5kg, 4kg, 3kg, 2kg and 1kg respectively were also made available in quadruplets for the experiment.
- Twenty four(24) new flat and wide plastic bowls were arranged on the floor of an unoccupied room for the work.
- Water was poured into each of the 24 bowls to an extent to accommodate the retting bunch, and the bunches in their order and categories were carefully immersed in water contained in the bowls.
- The various weights/loads were then placed on the immersed bunches in the order of their classification, which are meant to enhance the retting process.
- To each of the four categories of sizes, there was no load placed in one of the bowls, and the fiber obtained there-in served as the Control Samples.
- The retting kinetics was then studied in periods of four days intervals. After every four(4) days, the wetted and retting bunches were removed from the stagnant water in the bowl, and the average diameter of the unretted (unreacted) core region were measured with a transparent measuring rule and recorded. These were done for the entire twenty four bowls at the intervals and the results recorded accordingly.
- At the end of sixteen(16) days, which is the period for the study, the retted bunches were removed and washed. The fiber obtained were weighed, dried and reweighed for the different categories. Also, the loading mass to unretted core ratios and fiber yield were calculated for each of the categories.

Approach/Procedure for the Dew Retting

- Six (6) different group samples each of two bunch size categories of 5.5cm and 4.5cm in diameter respectively were made available at the onset of the study.
- One bunch from each category was taken on the first day, and the bunch mechanically extracted as the fibers are scrapped off the bunch. They are washed, dried and weighed accordingly. The fiber yield was also calculated.
- This was repeated at intervals of three(3) days, until the fifteenth day of study. In each case, after

fiber is obtained from the two(2) categories, they are washed, dried and weighed. Also, the fiber yield were calculated alongside the loss in mass of the bunches, as they are seen/noticed to shrink/reduce in size and mass(due to natural retting) as the days go by.

Mechanical Property Measurements

The standard mechanical properties were determined by the procedures found in ASTM (American Society for Testing and Materials) standards for plastics. The mechanical properties tested for in this work are tensile strength, ultimate tensile strength and modulus of elasticity.



Fig 1: Hounsfield Monsanto Universal Tensometer

IV. RESULT AND DISCUSSION

The experimental results for the water retting of the four bunch categories showed a consistency in all parameters measured. First, for all categories of bunch, it was clear that the added weight had a huge effect on the retting process, as seen in the increased reduction of the bunch radii as the weight increased. This is truly a confirmation to the proposition made by extractors of plantain bunch fibers and some researchers in literature, that loading may improve the retting process and possibly enhance fiber yield.

Result for Water Retted Bunch Categories

Table 1: Result for the water retted bunch **CATEGORY A**

Average Bunch Diameter ($D_A, average$) = 5.50cm, Average Bunch Mass ($M_A, average$) = 341.62g

Sample Code	Bunch Diameter	Bunch Length	Bunch Mass (wet basis)	Weight Added	Bunch diameter After 4days	Bunch diameter After 8days	Bunch diameter After 12days	Bunch diameter After 16days	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
A_i	$D_{A,cm}$	$L_{A,cm}$	$M_{A,g}$	$W_{i,kg}$	d - 4, cm	d - 8, cm	d - 12, cm	d - 16, cm	$m_{A,g}$	$Y, \%$
A_5	5.50	15.0	381.56	5	3.80	3.60	3.30	3.00	251.41	65.89
A_4	5.40	14.0	363.42	4	3.80	3.70	3.50	3.20	183.24	50.42
A_3	5.50	15.6	352.31	3	3.90	3.80	3.60	3.30	150.37	42.68
A_2	5.40	12.8	280.94	2	4.40	4.00	3.70	3.30	129.74	46.18
A_1	5.40	12.9	296.08	1	4.70	4.30	3.80	3.50	137.47	46.43
A-CT	5.50	14.9	375.42	0	4.80	4.50	4.10	3.60	210.84	56.16
Average	5.50	14.2	341.62	2.5	4.23	3.98	3.67	3.32	177.18	51.29

Table 2: Result for the water retted bunch **CATEGORY B**

Average Bunch Diameter ($D_B, average$) = 5.00cm, Average Bunch Mass ($M_B, average$) = 248.80g

Sample Code	Bunch Diameter	Bunch Length	Bunch Mass (wet basis)	Weight Added	Bunch diameter After 4days	Bunch diameter After 8days	Bunch diameter After 12days	Bunch diameter After 16days	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
B_i	$D_{B,cm}$	$L_{B,cm}$	$M_{B,g}$	$W_{i,kg}$	d - 4, cm	d - 8, cm	d - 12, cm	d - 16, cm	$m_{B,g}$	$Y, \%$
B_5	4.90	14.2	240.65	5	3.50	3.20	3.00	2.80	185.01	76.88
B_4	5.00	13.2	244.21	4	3.70	3.40	3.10	3.00	153.00	62.65
B_3	5.00	13.6	249.16	3	3.90	3.70	3.30	3.10	151.74	60.90
B_2	5.10	13.9	247.13	2	4.20	3.90	3.50	3.20	148.03	59.90
B_1	4.90	12.2	221.06	1	4.30	4.10	3.60	3.40	130.78	59.16
B-CT	5.00	14.8	290.58	0	4.30	4.20	3.70	3.50	161.74	55.66
Average	5.00	13.7	248.80	2.5	3.98	3.75	3.37	3.17	155.05	62.53

Table 3: Result for the water retted bunch CATEGORY C
Average Bunch Diameter ($D_{C, average}$) = 4.50cm, Average Bunch Mass ($M_{C, average}$) = 230.05g

Sample Code	Bunch Diameter	Bunch Length	Bunch Mass (wet basis)	Weight Added	Bunch diameter After 4days	Bunch diameter After 8days	Bunch diameter After 12days	Bunch diameter After 16days	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
C_i	$D_{C,cm}$	$L_{C,cm}$	$M_{C,g}$	$W_{i,kg}$	d - 4, cm	d - 8, cm	d - 12, cm	d - 16, cm	$m_{C,g}$	$Y, \%$
C_5	4.50	13.5	210.00	5	3.20	3.10	2.80	2.60	139.94	66.64
C_4	4.50	16.8	237.57	4	3.40	3.30	3.00	2.90	175.52	73.88
C_3	4.50	15.1	258.75	3	3.70	3.50	3.20	3.00	179.55	69.39
C_2	4.50	14.7	237.51	2	3.90	3.70	3.30	3.00	172.50	72.63
C_1	4.40	14.2	204.03	1	4.00	3.80	3.30	3.10	134.44	65.89
C-CT	4.55	13.5	232.41	0	4.10	3.80	3.40	3.20	144.44	62.15
Average	4.50	14.6	230.05	2.5	3.72	3.53	3.17	2.97	157.73	68.43

Table 4: Result for the water retted bunch CATEGORY D
Average Bunch Diameter ($D_{D, average}$) = 4.00cm, Average Bunch Mass ($M_{D, average}$) = 176.20g

Sample Code	Bunch Diameter	Bunch Length	Bunch Mass (wet basis)	Weight Added	Bunch diameter After 4days	Bunch diameter After 8days	Bunch diameter After 12days	Bunch diameter After 16days	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
D_i	$D_{D,cm}$	$L_{D,cm}$	$M_{D,g}$	$W_{i,kg}$	d - 4, cm	d - 8, cm	d - 12, cm	d - 16, cm	$m_{D,g}$	$Y, \%$
D_5	3.95	14.7	186.09	5	3.00	2.50	2.40	2.20	138.88	74.63
D_4	3.90	15.4	178.73	4	3.10	2.70	2.60	2.50	128.92	72.13
D_3	3.80	12.4	162.66	3	3.40	3.00	2.80	2.60	119.36	73.38
D_2	4.10	15.6	200.86	2	3.50	3.20	2.90	2.60	130.86	65.15
D_1	4.00	11.3	148.94	1	3.50	3.30	3.00	2.80	105.21	70.64
D-CT	4.00	15.1	179.94	0	3.60	3.30	3.10	2.90	121.71	67.64
Average	4.00	14.1	176.20	2.5	3.35	3.00	2.80	2.60	124.16	70.60

Table 5: Result for the dew retted bunch CATEGORY A
Average Bunch Diameter ($D_{A, average}$) = 5.50cm, Average Bunch Mass ($M_{A, average}$) = 328.28

Sample Code	Bunch Diameter	Bunch Length	Initial Bunch Mass (wet basis)	Retting Period after Bunch harvest	Bunch Mass after retting period	Loss in Bunch Mass after retting period	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
A_i	$D_{A,cm}$	$L_{A,cm}$	$M_{A,g}$	P_{days}	$M_{Ap,g}$	$M_{AL,g}$	$m_{A,g}$	$Y, \%$
A_0	5.50	13.4	308.46	0	308.46	0.00	179.71	58.26
A_3	5.50	15.4	286.12	3	241.46	44.66	162.57	56.82
A_6	5.50	15.3	472.93	6	414.55	58.38	257.37	54.42
A_9	5.50	14.4	330.31	9	264.86	65.45	152.37	46.13
A_{12}	5.40	12.2	289.62	12	219.49	70.13	113.70	39.26
A_{15}	5.50	15.4	282.22	15	199.80	82.42	107.55	38.11
Average	5.50	14.4	328.28	7.5	274.77	53.51	162.21	48.83

Table 6: Result for the dew retted bunch CATEGORY B
Average Bunch Diameter ($D_B, average$) = 4.50cm, Average Bunch Mass ($M_B, average$) = 217.64g

Sample Code	Bunch Diameter	Bunch Length	Initial Bunch Mass (wet basis)	Retting Period after Bunch harvest	Bunch Mass after retting period	Loss in Bunch Mass after retting period	Mass of Fiber obtained (wet basis)	Fiber yield (wet basis)
B_i	$D_{B,cm}$	$L_{B,cm}$	$M_{B,g}$	P_{days}	$M_{Bp,g}$	$M_{BL,g}$	$m_{B,g}$	$Y_i, \%$
B_0	4.50	14.9	235.86	0	235.86	0.00	131.23	55.64
B_3	4.50	14.7	206.80	3	182.64	24.16	106.36	51.43
B_6	4.50	15.2	208.28	6	175.66	32.62	102.31	49.12
B_9	4.60	14.1	225.12	9	177.93	47.19	96.24	42.75
B_{12}	4.40	13.5	221.64	12	149.66	71.98	90.05	40.63
B_{15}	4.50	14.5	208.16	15	121.14	87.02	73.86	35.48
Average	4.50	14.5	217.64	7.5	173.82	43.83	100.01	45.84

Table 7: Analysis of variance result for water retting – 'yield of fiber' as response

Source	Sum Sq.	d.f	Mean Sq.	F	Prob>F
X_1	344.04	5	68.808	2.28	0.0998
X_2	1345.58	3	448.526	14.83	0.0001
Error	453.65	15	30.244		
Total	2143.27	23			

Table 8: Numerical results for model fit to experimental data for water retting – 'yield of fiber' as response

Variables	Coefficients	Standard error	T-stat	P-val	F-stat
Constant	-80.1711	90.2564	-0.8883	0.3855	Sse = 464.4427
X_1	-1.8135	2.1075	-0.8605	0.4002	Dfe = 19
X_2	73.3713	38.3926	1.9111	0.0712	Dfr = 4
X_1^2	0.7420	0.4046	1.8340	0.0824	Ssr = 1678.8
X_2^2	-9.0667	4.0369	-2.2460	0.0368	F = 17.1699
	$R^2 = 0.7833$	Adj. $R^2 = 0.7377$			Pval = 0.0000041

Table 9: Analysis of variance result for dew retting – 'yield of fiber' as response

Source	Sum Sq.	d.f	Mean Sq.	F	Prob>F
X_1	664.612	5	132.922	43.55	0.0004
X_2	26.85	1	26.85	8.8	0.0313
Error	15.262	5	3.052		
Total	706.725	11			

Table 10: Numerical results for model fit to experimental data for dew retting – 'yield of fiber' as response

Variable	Coefficient	Standard error	T-stat	P-val	F-stat
Constant	35.2288	9.6173	3.6631	0.0064	Sse = 27.9726
X_1	4.5738	1.9139	2.3898	0.0439	Dfe = 8
X_2	-0.3800	1.0588	-0.3588	0.7290	Dfr = 3
X_1X_2	-0.2110	0.2107	-1.0011	0.3461	Ssr = 678.7523
					F = 64.7065
	$R^2 = 0.9604$	Adj. $R^2 = 0.9456$			Pval = 5.9435e-06

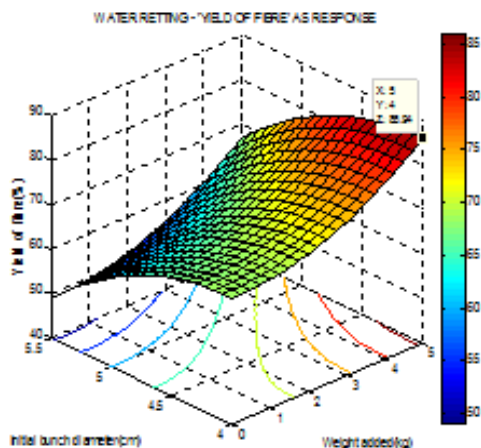


Fig 2: Yield vs Initial Bunch Diameter and Weight (Water Retting)

In the experiment, aside having a consistent decrease in the radius of the bunch (enhanced by the added weight/load), it is seen that the 'weight to un-retted core ratio' was higher for higher weights. Again, fiber yield is found to be positively influenced by the addition of the loads/weights on the retting bunches during the process.

For the dew retted categories, the effect of the ageing period (after harvest) on the fiber yield was monitored, and it was found that the yield values fell continually with time, as the harvested bunches are left to naturally dry up and stick together before manually pulling off the fibers from them. Hence, fiber yield is optimum at the initial days after harvest and decreases thereafter. Again, comparing yield values obtained for the two sizes of bunch used, it was observed that the fiber yield for the bigger sized bunch (5.5cm) was consistently higher, hence suggesting a better yield for larger bunch sizes during dew retting.

From the results of the dew retting, it was obvious that the bunch were losing much weight as they were retting (drying up/shrinking) naturally under atmospheric conditions. This is seen from the increased values of the 'loss in bunch mass' with days, meaning that as the bunch is left to age, after harvest, it loses some of its mass as it shrinks in size (both axially and radially).

In the statistical analysis, for the water retting 'yield of fiber' as response, the ANOVA result (Table 7) shows that the initial bunch diameter is significant at 95% confidence (i.e. ≤ 0.05) while the weight added is adequate only at 90% confidence (i.e. ≤ 0.1), confirming the initial bunch diameter as the more significant of the two variables.

From Table 8, the model is adequate at 95% confidence based on the F-statistics, as P-value is ≤ 0.05 . However, the quadratic term of the initial bunch diameter is the only significant variable with Pval of 0.0368 at 95% confidence. The square of weight added and the linear

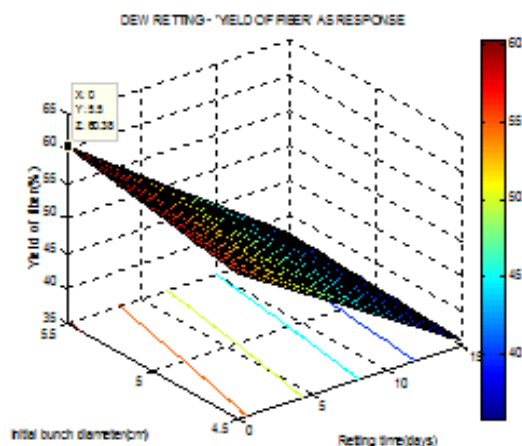


Fig 3: Yield vs Initial Bunch Diameter and Weight (Dew Retting)

term of initial bunch diameter are only significant at 90% confidence level.

Based on the T-statistics values, the significant term is the quadratic term of the initial bunch diameter having T-value of $|2.2460|$.

The model explains 78% of the variability observed in the experimental data.

In Fig 2 (water retting – 'yield of fiber' as response plot), the response have a maximum value of 85.94% when the yield of fiber is plotted against the weight added and initial bunch diameter. The plot also showed no interaction between the two independent variables, as evident from the contour lines of the plot.

The dew retting – 'yield of fiber' as response analysis have shown for the ANOVA (Table 9) that both the retting time and the initial bunch diameter affect the yield of fiber, with F-values of 0.0004 and 0.0313 (both ≤ 0.05 at 95% confidence), although the retting time have proven to be the more significant variable.

From Table 10, the model is very adequate since the Pval satisfies the ≤ 0.05 criterion at 95% confidence ($5.9435e-06$). However, among the terms in the model, only the retting time is very significant, with Pval and T-value of 0.0439 and 2.3898 respectively. The other two terms (the initial bunch diameter and the interaction term) do not sufficiently contribute to the variability of the model.

The model sufficiently explains about 96% of the variability observed in the experimental data.

Fig 3 shows that the dew retting – 'yield of fiber' as response plot, produced optimum values of day 0 and 5.5cm for the retting time and initial bunch diameter respectively, with an optimum response value of 60.38% for the yield of fiber. Hence, the statistical analysis have revealed that dew retting do not necessarily improve fiber yield, as it definitely enhance the ease of extraction.

The mechanical tests on the representative fiber samples from the two techniques have shown better mechanical properties for the water retted fiber categories with a maximum tensile strength of 823.295N/mm² and modulus of elasticity (MOE) of 644.318N/mm².

V. CONCLUSION

This research presents the extraction of empty plantain fruit bunch fibers via two techniques; stagnant water retting and dew retting. As this was done, important experimental parameters such as retting time, bunch size and retting load were measured. The study have shown that fiber obtained by water retting possesses better mechanical properties, exhibits better appearance, alongside having a greater yield.

Results obtained for the water retting categories reveal that there is greater yield of fiber when increased weights are placed on the empty fruit bunch to enhance the retting. Also, the fiber obtained by the increased weights have shown better mechanical properties (tensile strength, ultimate tensile strength, modulus of elasticity), together with having an attractive morphology. While, results for the dew retting means of extraction showed optimum yield of fiber when fiber is obtained on same day of harvest and reduce progressively when left for some days after harvest. The fiber extracted from two different sizes of bunch revealed that the bigger bunch size produced a better fiber yield for dew retting.

The statistical analysis have produced models that predict the yield of fiber production based on the factors measured, together with the optimization, and have proven the water retting to be a better extraction technique viz-a-viz fiber yield.

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