Global Scientific JOURNALS
GSJ: Volume 8, Issue 11, November 2020, Online: ISSN 2320-9186

www.globalscientificjournal.com

SODA PULPING EXPERIMENTS AND YIELD OPTIMIZATION ON BAMBOO FIBER FOR PULP AND PAPER PRODUCTION

Henry Okwudili CHIBUDIKE[1], Nelly Acha NDUKWE[2], Nkemdilim Ifeanyi OBI[3], Olubamike Adetutu ADEYOJU[4], and Eunice Chinedum CHIBUDIKE[5]

[1]Chemical, Fiber and Environmental Technology Department, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O., Lagos-Nigeria
[2]Department of Chemical Sciences, College of Basic & Applied Sciences, Mountain Top University, Magoki, Ogun State, Lagos-Nigeria
[3]National Oil Spill Detection and Response Agency (NOSDRA), Abuja-Nigeria
[4]Production, Analytical and Laboratory Management, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O., Lagos-Nigeria
[5]Planning, Technology Transfer and Information Management, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O., Lagos-Nigeria

Abstract

This paper investigates the physico-chemical characteristics and anatomic properties of African Bamboo, an evergreen perennial flowering plants in the subfamily Bambusoideae of the grass family Poaceae. Assessment of its potentials *to substitute wood for the production of pulp and paper was also investigated. Sample preparation was conducted in accordance with TAPPI Standard T12 – OS – 75, which specifies that samples be grinded to a fine particle size to permeate 0.4mm screen and retained on a 0.6mm screen. The Moisture content, Lignin, Extractives, Alpha cellulose, Ash content and fiber dimensions were investigated. The pulping investigation had three (3) factors at three (3) different levels each: Factor 1, cooking temperature (150, 160 and 170°C); Factor 2, cooking time (60, 90 and 120minutes); Factor 3, liquor concentration (10%, 15% and 20% NaOH charge). Consequently, the experimental design had 27 treatments (3×3×3) and 2 replicates. By using a central composite factorial design, equations relating the dependent variable (pulp yield) to the different independent variables (cooking temperature, cooking time and liquor concentration) were derived; reproducing the experimental result for the dependent variable with errors less than 15%. Pulp Screened Yields was in the range of 32.16 to 47.90% calculated on oven dry (O.D) basis. The resultant pulps obtained from the cooking operation had very good feel, appearance, and consistency and exhibited fairly bright color, with slightly slow tendency to felt, thereby making drainage and consequent paper making time short. It is recommended that the cellulosic pulp obtained from soda pulping of bamboo is appropriate as virgin fiber for strengthening secondary fibers in recycled papers and also for developing certain types of writing, printing and packaging paper materials. Over-all parameter achieved asserts that bamboo fiber have a promising future (when used in blend with certain long fiber plant i.e. kenaf) in substituting wood in the pulp, paper and fiber- board industry.*

Keywords: Bamboo, Anatomy, Lignin, Tappi standards, kappa number, Pulp screened yield, Soda pulping; Oven dried, Optimization

Introduction

The origin of the word "bamboo" is uncertain, but it probably comes from the Dutch or Portuguese language, which originally borrowed it from Malay or Kannada, (**"bamboo", Oxford English Dictionary (3rd edition, September 2005)**). Bamboos include some of the fastest-growing plants in the world, **Farrelly, David (1984)**, due to a unique rhizome-dependent system. Certain species of bamboo can grow 910 mm (36 in) within a 24-hour period, at a rate of almost 40 mm (1 1⁄2 in) an hour (a growth around 1 mm every 90 seconds, or 1 inch every 40 minutes), **("Fastest growing plant". Guinness World Records, September 2014).**

Giant bamboos are the largest members of the grass family. This rapid growth and tolerance for marginal land, make bamboo a good candidate for afforestation, carbon sequestration and climate change mitigation. Bamboos are of notable economic and cultural significance in South Asia, Southeast Asia and East Asia, being used for building materials, as a food source, and as a versatile raw product. Bamboo, like wood, is a natural composite material with a high strength-to-weight ratio useful for structures, **Lakkad; Patel (June 1981).**

Bamboo's strength-to-weight ratio is similar to timber, and its strength is generally similar to a strong softwood or hardwood timber, [**Kaminski, S.; Lawrence, A.; Trujillo, D. (2016) and Kaminski, S.; Lawrence, A.; Trujillo, D.; Feltham, I.; Felipe**

López, L. (2016)]. Cellulose, hemicelluloses and lignin are the three major chemical compositions of bamboo, and they are closely associated in a complex structure. They contribute about 90% of the total bamboo mass. The minor components are pigments, tannins, protein, fat, pectin and ash. **Kitajima, T. (1986).**

The bamboos comprise three clades classified as tribes, and these strongly correspond with geographic divisions representing the New World herbaceous species (Olyreae), tropical woody bamboos (Bambuseae), and temperate woody bamboos (Arundinarieae). The woody bamboos do not form a monophyletic group; instead, the tropical woody and herbaceous bamboos are sister to the temperate woody bamboos. **Kelchner S; Bamboo Phylogeny Working Group (2013) and Grass Phylogeny Working Group II (2012).** Altogether, more than 1,400 species are placed in 115 genera. **Kelchner S; Bamboo Phylogeny Working Group (2013)**

Most bamboo species are native to warm and moist tropical and to warm temperate climates. **Kitsteiner, John (2014)**. However, many species are found in diverse climates, ranging from hot tropical regions to cool mountainous regions and highland cloud forests. Bamboo forestry (also known as bamboo farming, cultivation, agriculture or agroforestry) is a cultivation and raw material industry that provides the raw materials for the broader bamboo industry. Historically, a dominant raw material in South and South East Asia, the global bamboo industry has significantly grown in recent decades in part because of the high sustainability of bamboo as compared to other biomass cultivation strategies, such as traditional timber forestry. For example, as of 2016, the U.S. Fiber corporation Resource Fiber is contracting farmers in the United States for Bamboo cultivation. **Bennet, Chris (2016)**. Or in 2009, United Nations Industrial Development Organization published guidelines for cultivation of bamboo in semi-arid climates in Ethiopia and Kenya. **UNIDO (2009).**

Because bamboo can grow on otherwise marginal land, bamboo can be profitably cultivated in many degraded lands. **Dwivedi, Arun Kumar; Kumar, Anil; Baredar, Prashant; Prakash, (2019).** Moreover, because of the rapid growth bamboo is an effective Climate change mitigation and carbon sequestration crop, absorbing between 100 and 400 tonnes of carbon per hectare. **FAO (2009)**. In 1997, an international intergovernmental organization was established to promote the development of the bamboo cultivation, the International Bamboo and Rattan Organisation. **INBAR (2020).**

Bamboo is harvested from both cultivated and wild stands, and some of the larger bamboos, particularly species in the genus Phyllostachys, are known as "timber bamboos". Bamboo is typically harvested as a source material for construction, food, crafts and other manufactured goods. **Small Farmer's Journal, (2016).**

As the importance of paper extends from the home as toiletries, government and academic institutions as writing, drawing and printing materials, and in the industries as wrapping/packing materials, the demand for paper and paper materials is exponentially rising and this is consequently putting heavy and increasing demand on forest wood resources. Irrespective of these, the world cannot compromise the need to conserve the forest to the detriment of the environment hence the need to engage intensive research to discover more alternative sources of agro-based lignocellulosic fibers suitable for the production of pulp and paper. It is necessary to meet the growing requirement as well as reduce the cost of paper materials in Nigeria, hence, the intensive investigation on bamboo (agro-biomass) to determine its potentials and sustainability in the pulp and paper industry **(Chibudike, 2011)**.

Experimental

Materials

The Bamboo used in this experimental work was obtained during post-harvest treatment in Ikorodu Local Government Area of Lagos State, Nigeria.

Raw material characterization

Prior to chemical characterization and pulping, the raw material was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm and retained on a 0.40mm sieve to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12–oS–75. Particles larger than 0.40 mm are inefficiently attacked by the chemical reagents, whereas those below 0.25 mm can cause filtering problems. The sample was characterized by analyzing its content of moisture, hot water solubility, klason lignin, α-cellulose, 1% NaOH solubility, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in Table 1.

Table 1 Standards used in the Chemical Characterization

Agro-biomass Characterization	**Standards**
Sample preparation	TAPPI Standard Test Method T 12 oS-75
Moisture	TAPPI Standard Test Method T 264 om-88
Hot water solubility	TAPPI Standard Test Method T 207 cm-99
Total Extractives	TAPPI Standard Test Method T 204 cm-97
Acid insoluble (klason) lignin	TAPPI Standard Test Method T 222 om-02
Alpha (α)-cellulose	TAPPI Standard Test Method T 203 os-74
1% NaOH solubility	TAPPI Standard Test Method T4 os-59
Ash	TAPPI Standard Test Method 211 om -02
Holocellulose	TAPPI standard Test method T-249, 2004
Kappa No.	TAPPI Standard Test Method T236 om-06
Viscosity	TAPPI Standard Test Method T230 om-08
Brightness	TAPPI Standard Test Method T452 om-08

Determination of Fiber Morphology

Small slivers were obtained and macerated with 10 ml of 67% HNO_3 and boiled in a water bath (100 ± 2^{o}C) for 10 min **(Ogbonnaya et al., 1997)**. The slivers were then washed, placed in small flasks with 50 ml distilled water and the fiber bundles were separated into individual fibers using a small mixer with a plastic end to avoid fiber breaking. The macerated fibers suspension were finally placed on a slide (standard, 7.5 cm × 2.5 cm) by means of a medicine dropper and stained with1:1 aniline sulfate–glycerin mixture to enhance cell-wall visibility (cell walls retain a characteristic yellowish color) and easier measurement. About twenty (20) fibers were measured per each sample at a magnification of X 101 on a Reichort visopam projection microscope and fiber diameter, lumen diameter, cell wall thickness and cross-sections were obtained. All samples were measured in a swollen condition.

Outline of the Production Process

Figure 1 illustrates the process of making paper from Bamboo. The sample was characterized chemically and morphologically and converted into brown pulp at a delignification degree of 19.4 kappa number by the Soda Process. The resulting pulps was fully bleached by the D1-Ep-D2 sequence and characterized for its beatability, drainability and physical-mechanical properties.

Description of the Pulp and Paper-making Process

The sample was chipped prior to chemical characterization and pulping, a portion of the chipped sample was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm (because samples below 0.25 mm can cause filtering problems) and retained on a 0.40mm sieve (because particles larger than 0.40 mm are inefficiently attacked by the chemical reagents) to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12 – oS – 75. This portion of the sample was characterized by analyzing its content of moisture, hot water solubility, 1% caustic solubility, klason lignin, α-cellulose, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in table 1. The second portion of the shredded sample was subjected to a thorough cleaning process, 2kg of air-dry sample was loaded into a 15 L capacity batch reactor (digester) with eight (8) liter cooking liquor at liquor-sample ratio of 4:1. The digester is furnished with an outer electrical heating jacket. The lid of the digester was firmly bolted to prevent leakage, the digester was switched on and the time of rise of temperature and pressure was noted at intervals of five (5) minutes. The content of the digester was stirred while in operation by rotating the vessel via a motor connected through a rotary axle to a control unit, including measurement and control instruments of pressure and temperature, to facilitate attainment of the working temperature (5ºC/min). At the end of the pulping process, the digester was switched off and allowed to cool below 60^{o}C before the content were blown down. The digester's initial temperature, pressure and starting time were all noted, and the various changes in these parameters were also recorded. The resultant pulp was subjected to thorough washing with plenty of water. When it was observed that subsequent washing resulted in no further change in color, the pulp was transferred into the valley beater for processing into a more refined pulp before the bleaching operation.

GSJ: Volume 8, Issue 11, November 2020
ISSN 2320-9186

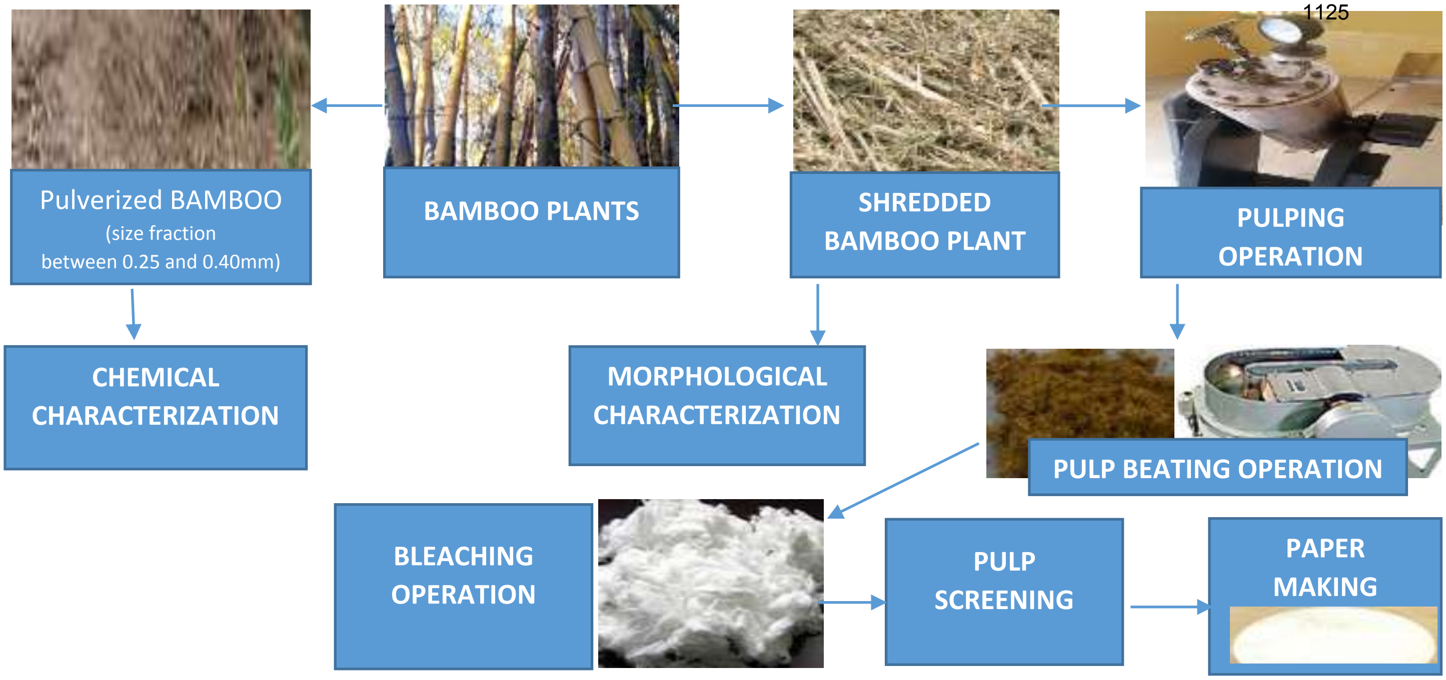


Figure 1: Steps in Bamboo (Agro-biomass) fractionation and conversion to paper

Table 2: Pulping Conditions for Bamboo Investigated

Conditions of Pulping Operation	Parameters
Air dry weight of Bamboo (kg) (A.D)	2
Liquor charge (%)	10, 15 and 20
pH of white liquor	6
pH of black/spent liquor	3
Liquor/biomass ratio	4:1
Maximum cooking temperature (°C)	150, 160 and 170
Time to reach maximum temperature (minutes)	40
Time at maximum temperature (minutes)	20, 50 and 80
Over-all cooking time (minutes)	60, 90, 120
Blow-down temperature (^{o}C)	60

GSJ: Volume 8, Issue 11, November 2020
ISSN 2320-9186

Results and Discussion

Analyses of the Chemical Properties of Bamboo

Chemical analyses of Bamboo was conducted. Table 3 illustrates the results of the characteristics obtained. The moisture content and hot water solubility of Bamboo is quite low, while the extractive content is also low compared to other agricultural residues studied in previous investigation, which means that Bamboo contain less substances like waxes, fats, resins, phytosterols, non-volatile hydrocarbons, low molecular weight carbohydrates, salts and other water-soluble substances.

Table 3: Chemical Characterization of Bamboo

Parameters	Bamboo Fiber (Matured tree)
Source of Bamboo (Geographical Location)	Eastern Nigeria
Age of Maturity (Years)	2
Portion of Plant	Whole
Moisture content (wt%)	3.01±0.17
Alpha cellulose (wt%)	46.80±0.77
Ash (wt%)	4.70±0.42
Lignin (wt%)	19.90±0.21
Extractives (wt%)	3.2±0.33
Holocellulose (%)	69.80±0.12
Pulp yield (wt%)	47.9
Liquor to sample ratio	4:1

A higher content of extractives gets converted into pitch, which often adversely affect the runnability of process equipment and the quality of furnished paper because of shadow marking. Bamboo has low content of extractives hence would not require a high dose of pulping liquor to neutralize acidic extractive, which would have little or no effect on the pulp yield and might create less digester corrosion caused by extractives. The higher the lignin content, the greater the stiffness of fibers. Lignin contents in bamboo is slightly high (19.90%) as observed in Table 3, though almost similar with that of the softwood. In practice, this means that these materials would need mild pulping conditions (lower temperatures and chemical charges) in order to reach a satisfactory kappa number and it would also undergo bleaching more easily and with the utilization of fewer chemicals. The average fiber dimensions of bamboo investigated in this research study is shown in Tables 4. Despite the decrease in the value of lignin, the extractive content, and ash in addition to decrease in chemical consumption and cooking time, pulp yield was unexpectedly high. Papers made from this type of fiber might show reduced water absorbency.

Analyses of the Morphological Properties of Bamboo

The morphological parameters of Bamboo investigated are presented in table 4. The Fiber length of Bamboo is 3.21mm, the Fiber diameter is 15.10µm, fiber lumen width is 2.5µm while the Fiber cell wall thickness is 6.8µm. Softwood fiber is between 3-5 mm long and about 39 to 41 µm wide, meaning that Bamboo fiber length is within the range of the value for softwood but width is about 61.2821% to 63.1707 lower than those of softwood.

Table 4 Morphological properties of Bamboo

Plant Materials	Fibre length, (L), (mm)	Fibre diameter, (D), (µm)	Fibre Lumen, (d), diameter (µm)	Fibre wall/Cell wall thickness, (w), (µm)
Bamboo	3.21±0.28	15.10±0.13	2.5±0.08	6.8±0.65

Figure 2. Bamboo fiber obtained on a visopam microscope

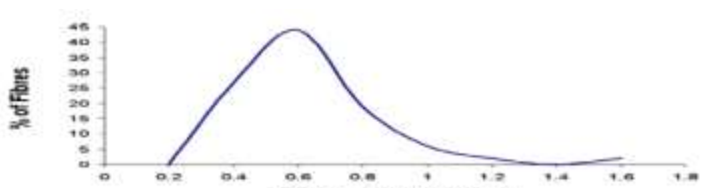


Figure 3. Distribution of Bamboo fibre length

Table 5: Biometry/Morphological Indices of Fiber Dimensions

Plant materials	Derived Values			
	Slenderness ratio, L/D	Flexibility coefficient, (d/D)×100	Runkel ratio, 2w/d	Rigidity Coefficient, 2w/D
Bamboo	229.153	16.94	5.78	0.98

Table 6. Design Layout of Independent Variables (Factors) and the Dependent Variables (Responses) for the Pulping Process

Experiment	Independent Variables			Dependent Variables		
	Cooking Temp. (^oC)	Cooking Time (minutess)	NaOH (%) (D.W.)	TY (%)	SY (%)	Rejects (%)
1	150	60	10	44.51	44.24	0.27
2	150	90	15	49.09	43.23	5.86
3	150	120	20	53.99	37.46	16.53
4	160	60	10	44.31	33.98	10.33
5	**160**	**90**	**15**	**49.60**	**47.90**	**1.70**
6	160	120	20	42.56	32.00	10.56
7	170	60	10	42.08	41.65	0.43
8	170	90	15	46.72	44.48	2.24
9	170	120	20	52.12	40.97	11.15
10	150	60	20	42.49	37.30	5.19
11	150	90	10	47.55	45.52	2.03
12	150	120	15	42.25	36.70	5.55
13	160	60	20	44.33	44.14	0.19
14	160	90	10	47.53	45.74	1.79
15	160	120	15	51.01	46.55	4.46
16	170	60	20	55.04	44.68	10.36
17	170	90	10	47.61	45.89	1.72
18	170	120	15	51.14	44.01	7.13
19	150	60	15	44.40	43.89	0.51
20	150	90	20	47.32	45.59	1.73
21	150	120	10	41.59	32.16	9.43
22	160	60	15	45.01	44.49	0.52
23	160	90	20	46.73	45.27	1.46
24	160	120	10	42.22	38.21	14.01
25	170	60	15	44.56	44.12	0.44
26	170	90	20	47.44	45.94	1.50
27	170	120	10	42.45	33.74	8.71

AQ= anthraquinone charge; TY = total yield; SY: screened yield

Table 8. Sequential Model Sum of Squares [Type 1]

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	39312.73	1	39312.73			
Linear vs Mean	5.96	3	1.99	0.3962	0.7575	
2FI vs Linear	0.9120	3	0.3040	0.0498	0.9846	
Quadratic vs 2FI	34.62	3	11.54	2.58	0.1120	Suggested
Cubic vs Quadratic	26.08	7	3.73	0.5991	0.7407	Aliased
Residual	18.66	3	6.22			
Total	39398.96	20	1969.95			

We then select the highest order polynomial where the additional terms are significant and the model is not aliased

Table 9. Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	2.24	0.0692	-0.1054	-0.5324	132.14	
2FI	2.47	0.0797	-03450	-2.1588	272.38	
Quadratic	1.12	0.4812	0.0142	-1.7050	233.25	Suggested
Cubic	2.49	0.7836	-0.3703	-19.0183	1726.16	Aliased

We now focus on the model maximizing the Adjusted R^2 and the Predicted R^2.

Table 10. ANOVA for Response Surface Quadratic Model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	41.49	9	4.61	1.03	0.4774	not significant
A-Cooking Temp.	0.4308	1	0.4308	0.0963	0.7627	
B-Cooking Time	7.31	1	7.31	1.64	0.2299	
C-NaOH Conc.	1.79	1	1.79	0.4002	0.5412	
AB	0.2548	1	0.2548	0.0569	0.8162	
AC	0.7904	1	0.7904	0.1767	0.6831	
BC	0.4486	1	0.4486	0.1003	0.7580	
A^2	3.66	1	3.66	0.8180	0.3870	
B^2	29.72	1	29.72	6.64	0.0275	
C^2	6.59	1	6.59	1.47	0.2528	
Residual	44.74	10	4.47			
Cor Total	86.23	19				

The Model F-value of 1.03 implies the model is not significant. P-values less than 0.0500 indicate model terms are significant. In this case B^2 is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve this model.

Std. Dev.	2.12	R-Squared	0.4812
Mean	44.34	Adj R-Squared	0.0142
C.V.	4.77	Pred R-Squared	-1.7050
PRESS		Adeq Precision	3.8368

A negative "Pred R-Squared" implies that the overall mean is a better predictor of the response than the current model. In some cases, a higher order model may also predict better.

Final Equation in Terms of Coded Factors: Pulp Screened Yield = $+46.99+0.2311A-1.04B+0.4197C+0.2691AB+0.3499AC+0.3294BC-1.0\ A^2-2.74\ B^2-1.21\ C^2$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors: Pulp Screened Yield = -219.52879+3.11010 Cooking Temp.+0.337170 Cooking

Time+0.216366 NaOH Conc. +0.000897 Cooking Temp. * Cooking Time+0.006998 Cooking Temp. * NaOH Conc. +0.002196 Cooking Time * NaOH Conc. -0.010227 Cooking Temp.^{2} -0.003046 Cooking Time^2-0.048324 NaOH Conc.^{2}

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor.

Table 11: Coefficient table for the quadratic model

p-value shading: **$p<0.05$** $0.05 \le p < 0.1$ $p \ge 0.1$

	Intercept	A	B	C	AB	AC	BC	A^2	B^2	C^2
Pulp Screened Yield	46.99	0.2311	-1.0396	0.4197	0.2691	0.3499	0.3295	-1.0227	-2.7415	-1.2081
p-values		0.7627	0.2299	0.5412	0.8162	0.6831	0.7580	0.3870	0.0275	0.2528

Therefore, the second-order polynomial equation for the Soda pulping process is expressed as follow:

Pulp Screened Yield $=46.99+0.2311A-1.0396B+0.4197C+0.2691AB+0.3499AC+0.3295BC-1.02272^2-2.74145B^2-1.2081C^2$

According to the monomial coefficient value of regression model equation, X_1=A=0.2311 (Cooking Temperature), X_2=B= -1.0396 (Cooking Time), X_3=C=0.4197 (NaOH Concentration) and the order of priority among the main effect of impact factors is NaOH Concentratio (C=X_3)> Cooking Temperature (A=X_1) and then Cooking Time (D=X_3).

Figure 4 describes the interaction of the three (3) factors in relation to pulp screened yield. The graph of interaction of the three factors reveal that at 15% Soda concentration, increase in cooking temperature beyond 160^{o}C and cooking time beyond 90minutes, lead to corresponding decreased pulp screened yield.

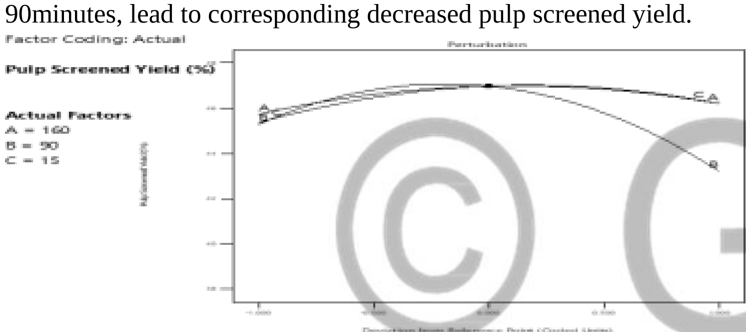


Figure 4: Perturbation plot of deviation from reference point (coded units) vs. Pulp Screened Yield

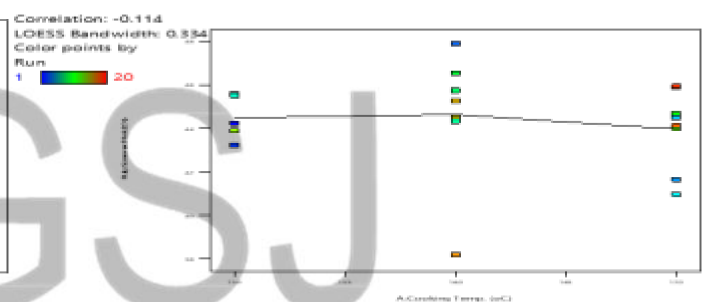


Figure 5: Model Graph of Residual vs Predicted

The actual value is the value that is obtained by observation or by measuring the available data. It is also called the observed value. The predicted value is the value of the variable predicted based on the regression analysis. The difference between the actual value or observed value and the predicted value is called the residual in regression analysis. Each actual value has a predicted value and hence each data point has one residual. However, to evaluate this quadratic model, we regress predicted vs. actual (observed) values or vice versa and compare slope and intercept parameters against the 1:1 line.

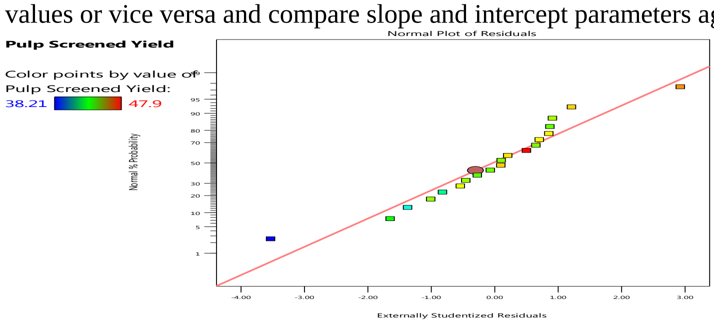


Figure 6: Normal Plot of Residuals to check for normality of residuals

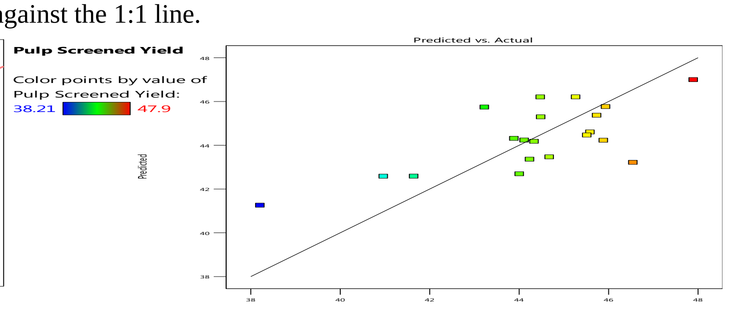


Figure 7: Model Graph of Predicted vs Actual

The Residuals vs. Predicted plot is a plot of the residuals versus the ascending predicted response values. It tests the assumption of constant variance. The plot should be a random scatter (constant range of residuals across the graph). The residuals are represented graphically by means of a residual plot as shown in figure 7. This normal probability plot indicates whether the residuals follow a normal distribution, thus follow the straight line.

GSJ: Volume 8, Issue 11, November 2020
ISSN 2320-9186

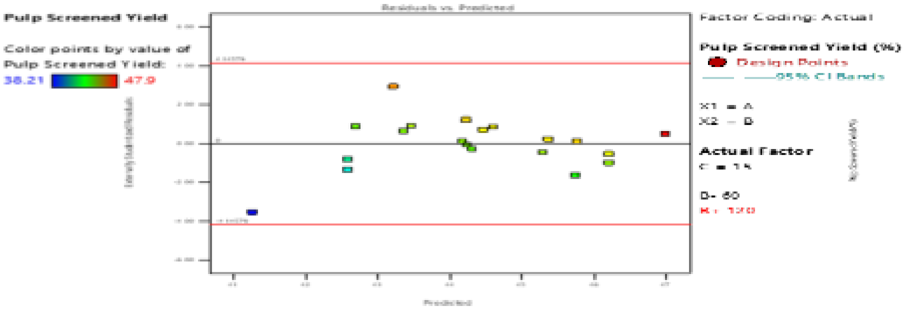


Figure 8: Model Graph of Perturbation Showing Interaction of the three Factors

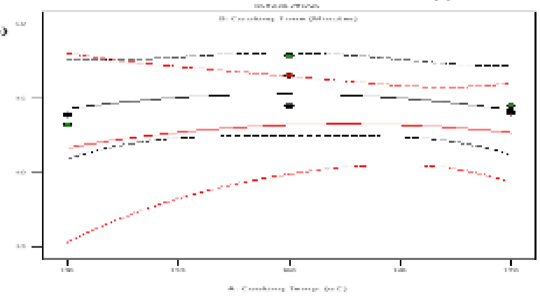
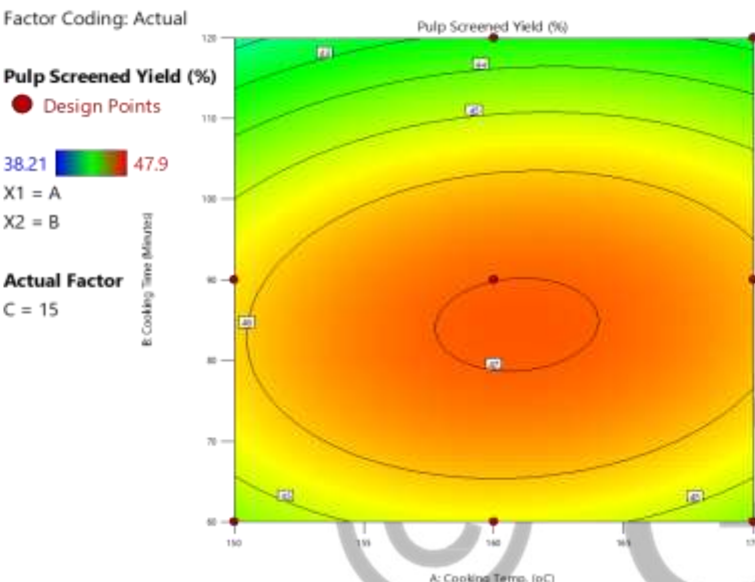


Figure 9: Model Graph of multiple interaction

In figure 6, the scatter had a definite pattern along the straight line which indicates that a transformation of the response may provide a better analysis. Here in figure 8, the residual plots are spread around the horizontal axis, indicating the appropriateness of the linear regression (quadratic) model.



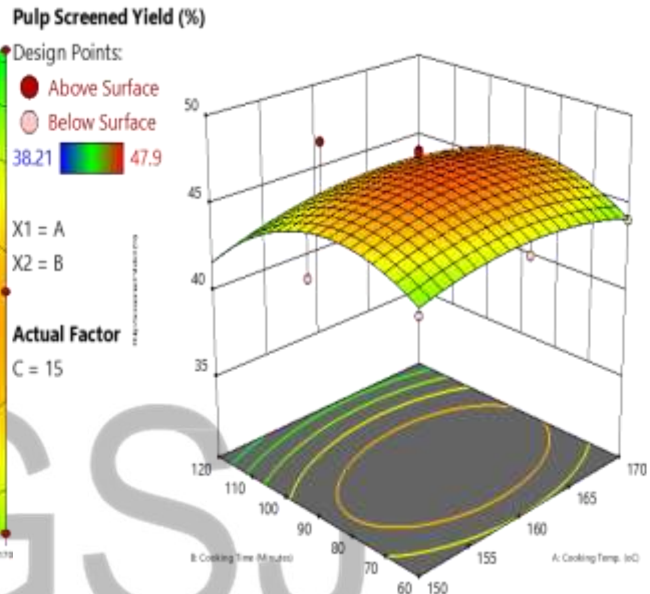


Figure 10: Contour Model Graph showing the Design Points of interaction **Figure 11: Model Graph of multiple in**

The contour model graph, figure 10 presents eight (8) design points. Seven (7) axial design points and one (1) central design point. The central design point is the point of optimum design of best combination of independent variables for the pulping operation and based on the interaction of these independent factors, the central design point indicates 15% soda concentration, 150^{o}C cooking temperature, and 90 minutes cooking time as the point of maximum yield (47.9%) for the pulping operation.

Curve fitting, also known as regression analysis, is used to find the "best fit" line or curve for a series of data points. There are six (6) design points around the 3D surface model graph described by Figure 11 which presents two (2) sets of design points. Two (2) design points above predicted value represented by red dots and four (4) design point below predicted value represented by faint dots. The curve fitting on the 3D surface model graph examined the relationship between three predictors (independent variables i.e. soda concentration, cooking temperature and cooking time) and a response variable (dependent variable i.e. pulp screened yield), with the goal of defining a "best fit" model of the relationship.

The red dotted lines are lines indicating on each factor the points of maximum yield. These are the design points of the optimum parameters of the independent variables furnishing the best pulping conditions as 90minutes cooking time, 15% soda concentration and 150^{o}C cooking temperature. For further confirmation of this, we move on to conduct optimization analysis.

Influence of morphological properties on Biometry (Slenderness, Flexibility, Runkel and Rigidity coefficient) of Bamboo fiber investigated are shown in Tables 4 and 5. The Slenderness ratio of Bamboo is 229.153 while the Flexibility coefficient is 16.94. Generally, there are four different types of fibers which are classified under flexibility ratio **(Bektas et al., 1990)**: (1) High elastic fibers having elasticity coefficient greater than 75; (2) Elastic fibers having elasticity ratio between 50 to75; (3) Rigid fibers having elasticity ratio between30 to 50; (4) High rigid fibers having elasticity ratio less than 30. According to this classification, flexibility coefficient of Bamboo is in uniformity with hardwoods. When Runkel proportion is greater than 1, it indicates that a fiber has thick wall and cellulose obtained from this type of fiber is less suitable for paper production; when it is equal to 1, it specifies that a cell wall has medium thickness and cellulose obtained from this type of fiber is suitable for paper production. When the rate is less than 1, it points out that a cell wall is thin and cellulose obtained from this fiber is the most suitable for production of paper **(Eroglu et al., 1980; Xu et al., 2006)**. Runkel value of Bamboo (5.78) is greater than 1 and according to the Runkel classification, it specifies that the fiber has thick wall and cellulose obtained from this type of fiber is not very suitable for paper production except when used in blend with certain long fiber pulp plants like kenaf to boost its strength potential for producing certain types of paper materials. The high content of lignin in Bamboo (19.90±0.21%) made the fibers appear tougher and stiffer compared to other fibers like pineapple leaves, wheat straws, corn stalk/sheets, coconut fruit bunch, elephant and lemon grass and other fibrous agro-wastes investigated in other studies furnishing rigidity coefficient following the order: (Highest) Bamboo (0.98)>Bagasse (0.59)>Coconut (0.58)>EFB(0.57)> Pineapple leaves(0.56) > Corn(0.50)> Lemon grass (0.44)>kenaf(0.39) >Elephant grass (0.34) > Wheat(0.17)>Rice(0.06)>(lowest) **(Chibudike et al., 2011)**. This is probably because lignin provides compressive strength to plant tissue and individual fibers and stiffens the cell walls, to protect carbohydrates from chemical and physical damages. Detailed research work on these agro-wastes is not included in this report.

At the end of the pulping operation, the pH of the cooking liquor dropped from 6.0 to 3.0. The black liquor obtained after the digestion process was not discarded, but rather employed in further chemical analysis. The black liquor was distinctly alkaline, but not caustic owing to the fact that a large part of the alkali was present in the form of neutral compounds, hence the need for chemical recovery. The Acid-insoluble lignin in the Bamboo was determined to be 19.9%. This necessitated the use of a mild liquor ranging from 10 to 20% for the cooking operation. Ash content of the Bamboo recorded 4.7% which is a measure of inorganic mineral present in the sample. These values afford more effective reuse of spent chemical after the pulping operation. The fibre length of the Bamboo recorded 3.21±0.28mm which does not possess the tendency to contribute to tensile strength of its corresponding furnished paper samples. This is the more reason why it is necessary use Bamboo in blend with long fiber pulp plant in order to achieve better result. Alpha cellulose recorded a value of 46.80±0.77% which indicates the amount of un-degraded higher molecular weight cellulose present. The pulp yield is unexpectedly high (47.99%). This exert a very good beneficial effect. Temperature coefficient of delignification was determined to be approximately 2.0, indicating that an increase in cooking temperature by 5% might result in an increase in the rate of lignin removal.

Conclusion and Recommendation

Bamboo should be considered the most important, fast-growing, strategic intervention for afforestation and deforestation in the mountainous, degraded or tropical regions of the world where they exist. Bamboo appear to be suitable for producing paper products due to lower lignin and extractive components as well as higher in cellulose content, though short in fiber length. Literature studies about softwoods revealed that elasticity coefficient was found within the range 50-70. Examining this information given, and comparing it with data generated in this research study, it seems Bamboo is similar to other softwood fibers. Depending on all the investigation carried out, it is possible to conclude that Bamboo when used in blend with long fiber pulp plants would be suitable for good brightness paper production. Considering the summary of analyses of data generated in this research work in comparison with literature and previous studies on other agro-base fiber residues, Bamboo when used in blend with other long fibrous pulp plants like kenaf can be very suitable for producing good paper based materials like fiber plate, rigid cardboard, cardboard, tissue, corrugating medium, printing and writing paper.

Agricultural wastes, annual plants and non-wood materials have attained such importance in the world cellulose economy, that to ignore their relevance in the pulp and paper industry would result in a complete lack of balance. In a world where virgin pulp sources are scarce, and environmental concerns require reduction in cutting down green forest, agricultural residues could become a good source of fiber in the tropical regions of the world where they are grown. The search for local long fiber pulp material which can be easily propagated remains one of the most important key desirderatum for the eventual resuscitation of the present mom bund paper industries of Nigeria. One important way of stemming the tide of imports is to find a good substitute to fine pulp for the use of the Nigeria paper companies when they eventually start producing. Besides being an innovation and new entry into the pulp map, Oil Palm EFB can become the best gift of FIIRO into the future pulp market of the tropical world.

References

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Sampling and Preparing Wood for analysis (TAPPI Standard Test Method T222 om-02), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Ash in wood, pulp, paper and paperboard: combustion at 525°C (TAPPI Standard Test Method T211 om-02), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: One percent sodium hydroxide solubility of wood and pulp (TAPPI Standard Test Method T212 om-02), Atlanta, USA.

Anonymous, 1999. Technical Association of the Pulp and Paper Industry: Water solubility of wood and pulp (TAPPI Standard Test Method T207 cm-99), Atlanta, USA.

Anonymous, 2007. Technical Association of the Pulp and Paper Industry: Solvent extractives of wood and pulp (TAPPI Standard Test Method T204 cm-97), Atlanta, USA.

Anonymous, 1999. Technical Association of the Pulp and Paper Industry: Alpha-, beta- and gamma-cellulose in pulp (TAPPI Standard Test Method T203 cm-99), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Determination of Acid-insoluble lignin in wood and pulp (TAPPI Standard Test Method T210), Atlanta, USA.

Anonymous, 2004. Technical Association of the Pulp and Paper Industry: Determination of Holocellulose in wood and pulp (TAPPI Standard Test Method T210), Atlanta, USA.

"Bamboo: A Multipurpose Agroforestry Crop". Small Farmer's Journal. 21 July 2016. Retrieved 30 July 2020.

Bamboo Cultivation Manual Guidelines for Cultivating Ethiopian Lowland Bamboo (PDF). UNIDO. 2009.

"Bamboo". Oxford English Dictionary (3rd ed.). Oxford University Press. September 2005. (Subscription or UK public library membership required.)

Bektas, I., Tutus, A. and Eroglu, H. (1990) "A Study of the Suitability of Calabian Pine (Pinus Brutia Ten.) for Pulp and Paper Manufacture. Turkish J. Agric. For., 23: 589-597.

Bennet, Chris (31 October 2016). "Bamboo Set to go Big on U.S. Farmland". Farm Journal.

Casey J.P., (1980) Pulp and Paper: chemistry and chemical technology

Chibudike H.O., "Catalytic Enhancement of Monoethanolamine Pulping Process", PhD Thesis, International University, Bamenda (IUB), Cameroon, 2019 p. 72-92.

Chibudike H.O., Mgbachiuzo E., Adeyoju O.A., Kayode O.F., Arowolo A.B., Orekoya E.O., Tojola O.B. and Ojo B.I. (2011) "Studies of Fiber Characteristics and Paper -making Potentials of Agricultural Wastes", Nigerian Journal of Engineering Management (NJEM) , Vol. 12, No.1, pp 8 -11.

Dwivedi, Arun Kumar; Kumar, Anil; Baredar, Prashant; Prakash, Om (1 May 2019). "Bamboo as a complementary crop to address climate change and livelihoods – Insights from India". Forest Policy and Economics. 102: 66–74. doi:10.1016/j.forpol.2019.02.007. ISSN 1389-9341.

Eroglu H., Andreolety, Silvy J., and Cheradame H., (1980), "The Influence of Poly(styrene sulfonate) addition to Cellulosic Fibers by wet Processing on the Physico- mechanical Properties of Paper", Journal of Applied Polymer Science, Volume 25, Issue 5.

FAO. 2009. Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. Rome, Italy.

FAO, 2009. "THE POOR MAN'S CARBON SINK BAMBOO IN CLIMATE CHANGE AND POVERTY ALLEVIATION" (PDF). FAO Forestry Department.

"Fastest growing plant". Guinness World Records. Archived from the original on 3 September 2014. Retrieved 22 August 2014.

Grass Phylogeny Working Group II (2012). "New grass phylogeny resolves deep evolutionary relationships and discovers C4 origins". New Phytologist. 193 (2): 304–312. doi:10.1111/j.1469-8137.2011.03972.x. hdl:2262/73271. ISSN 0028-646X. PMID 22115274.

INBAR, (2020), "About International Network for Bamboo and Rattan". Retrieved 31 July 2020.

Kaminski, S.; Lawrence, A.; Trujillo, D. (2016). "Structural use of bamboo. Part 1: Introduction to bamboo". The Structural Engineer. 94 (8): 40–43.

Kaminski, S.; Lawrence, A.; Trujillo, D.; Feltham, I.; Felipe López, L. (2016). "Structural use of bamboo. Part 3: Design values". The Structural Engineer. 94 (12): 42–45.

Kelchner S; Bamboo Phylogeny Working Group (2013). "Higher level phylogenetic relationships within the bamboos (Poaceae: Bambusoideae) based on five plastid markers" (PDF). Molecular Phylogenetics and Evolution. 67 (2): 404–413. doi:10.1016/j.ympev.2013.02.005. ISSN 1055-7903. PMID 23454093. Archived from the original (PDF) on 5 June 2015.

Kitajima, T. (1986). "Contact allergy caused by bamboo shoots". Contact Dermatitis. 15 (2): 100–102. doi:10.1111/j.1600-0536.1986.tb01293.x. PMID 3780197. S2CID 36280844.

. Kitsteiner, John (13 January 2014). "Permaculture Plants: Bamboo". tcpermaculture.com. Archived from the original on 31 July 2017. Retrieved 28 July 2017.

Lakkad; Patel (June 1981). "Mechanical properties of bamboo, a natural composite". Fibre Science and Technology. 14 (4): 319–322. doi:10.1016/0015-0568(81)90023-3.

Ogbonnaya C.I., Roy-Macauley H., Nwalozie M.C., and Annerose D.J.M., (1997), “Physical and histochemical properties of kenaf (Hibiscus cannabinus L.) grown under water deficit on a sandy soil” Industrial Crops and Products 7(1): 9-18