



PULPING POTENTIAL OF DOUGLAS FIR (*Pseudotsuga menziesii* Mirb. Franco)

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Abstract: Wood is a natural composite of strong cellulose fibres embedded in a lignin matrix that is resistant to compression. It is a complex material, serve as raw material for many chemical products, including pulp and paper. The pulp properties of Douglas fir wood were examined in this study to meet the need of wood for paper production in order to reduce overexploitation of the most used species. Wood samples obtained from a 9-years old tree were chipped for the pulp experiment using the Kraft pulping method. The experiment was subjected to usage of two different alkali charges (NaOH 15% and 17%) and three sulphidity levels (Na₂S 23%, 25% and 27%). Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$. The results show that the highest pulp yield of 51.41% was obtained in this study under active alkali of 15%, sulphidity of 27%, time of 190 minutes and temperature of 170°C. A strong negative correlation coefficient of -0.936 was observed between kappa number and pulp yield. Generally, the pulp properties observed in this study indicated the suitability of Douglas fir for paper production as it has produced high yield and a good pulp quality.

Keywords: Pulp properties, kraft method, pulp, Douglas fir.

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INTRODUCTION

Pulp is a lignocellulosic material created when cellulose fibres from wastepaper, rags, fibre crops and wood are removed or broken down chemically or mechanically. For papermaking, wood has a variety of fibre values and it is the most plentiful source of pulp fibre. Writing, bag packaging, printing, decorating, and other uses for paper make it a vital consumer good for human society in both developing and developed nations. Since it is made from wood, a lignocellulosic material, paper is a necessary item. An estimated 400 million tons of paper are consumed worldwide annually [1], and multiple factors, such as population growth and industrialization in developing nations, are contributing to the continuous rise in the global consumption of paper.

Wood's versatility and affordability compared to alternatives like metals have sustained its demand, especially in sectors like pulp and paper, where it constitutes 90-95% of pulp sources [2]. However, this escalating demand poses challenges in meeting paper production needs. Introducing exotic tree species such as

Pseudotsuga menziesii and lesser-known wood species is increasingly necessary to alleviate pressure on commonly used varieties and ensure sustainable supply for papermaking. According to Anderson and Brown [3], Douglas fir demonstrates rapid growth rates and adapts well to diverse climatic and soil conditions, ensuring a steady and renewable supply of raw material for pulping activities. Besides the fact that Douglas fir is a very fast growing species with a high basic density and a high latewood content [4], the fibre properties of this species are of major importance for its suitability in papermaking. Fibre length, fibre width and cell wall thickness are significantly higher in Douglas fir making it suitable for paper production [5]. Braun and Davis [6] found fibre length of 3.9 mm and fibre widths of 35 µm up to 38 µm. Quick et al., [7] are reporting an average fibre length of 3.9 mm, a fibre widths of 36 µm and a cell wall thickness of 3.2 µm. Therefore, the need to research on its pulping potential to meet the long fibre pulp requirement for paper industry in Nigeria and determine the quality of paper that can be derived from Douglas fir pulp.



MATERIALS AND METHODS

Study Area

The study was conducted at the Department of Forest Production and Products Laboratory, Faculty of Renewable Natural Resources, University of Ibadan, Oyo state. Wood samples of Douglas fir were collected from a 9-years old mother tree from Awotan area of Ido Local government, Oyo state (latitude 7.4431°N and longitude 3.8619°E).

Pulping Procedure

Pulping experiments were determined using Kraft chemical pulping method which is the most used method based on literature which yielded best results. The samples collected for this process were debarked and cut into smaller pieces (chips) for cooking. Oven-dry 400g chips were used for each cooking. The chips were cooked in a 5-litre digester at the departmental laboratory. The cooking liquor contains a solution of NaOH (Sodium Hydroxide) and Na₂S (Sodium Sulphide) in ratio 7:1 for 190 mins. Six batches of cooking were carried out. During this period, the lignin (the reinforcing substances that make tree cells wood hard and 'woody' rather than soft like those of other plants) is removed from the wood. Before the pulp could be released from the digester, a period of 20 minutes was allowed for gas down and the black liquor (chemical mixture that remains after cooking) was ejected.

The cooked chips were then ejected from the digester, washed under running water through a filter until the waste liquid is completely removed. The pulp was screened using sieve to remove knots and uncooked chips from the pulp.

Pulp Properties Determination

Determination of Pulp Moisture Content

About 10g of the pulp was placed inside a petri dish with a cover that had been previously weighed, replicated three times. The dish containing the pulp were placed in the oven and dried at a constant temperature of 103±2°C (TAPPI standard T258 0m-98). The moisture content of pulp was expressed as a percentage of the air-dried weight of pulp. The factor to convert the air-dry weight (A.D) to the oven-dry weight (O.D) equivalent was calculated.

The moisture content was determined using the formula below:

$$\text{Pulp moisture content} = \frac{AD-OD}{AD} \times 100 \dots\dots\dots 1$$

Where;

A.D = Weight (g) of air-dry samples

O.D = Weight (g) of oven-dry samples

Pulp Yield Determination

The pulp was screened using 0.15mm slots mesh to separate pulp from uncooked chips. After screening, the pulp was spin-dried manually. The screened yield and reject were calculated after the moisture content was determined. The screened yield and reject pulp were calculated and expressed below:

$$\% \text{ of screened yield} = \frac{W_2}{W_1} \times \frac{100}{1} \dots\dots\dots 2$$

Where:

W₂ = Weight of oven dried pulp (g), W₁ = Weight of the original chips (g)

The reject pulp was calculated using the formula below:

$$\% \text{ of reject pulp} = \frac{W_2}{W_1} \times \frac{100}{1} \dots\dots\dots 3$$

Where,

W₂ = Weight of oven dried reject pulp (g), W₁ = Weight of original chips (g)

Determination of Kappa Number

Kappa number is used to describe the relative hardness, the degree of delignification obtained in a chemical process, the bleachability or whitening aptitude of pulp. The Kappa number was determined using Tappi standard T 236 cm-85. Disintegration was done using magnetic stirrer. Kappa number calculation is expressed as:

$$\text{Kappa number} = \frac{p \times f}{w} \dots\dots\dots 4$$

$$p = \frac{(b-a)}{0.1} N$$

Where; f = factor for correction to a 50% permanganate consumption dependent on the value of p.

w = weight of moisture free pulp in the specimen, g

p = amount of 0.1 N permanganate actually consumed by the test specimen, ml

b = amount of thiosulfate consumed in the blank determination, ml

a = amount of thiosulfate consumed by the test specimen, ml

N = normality of the thiosulfate solution.

Statistical Analysis

The data obtained from the experiment were analyzed using both descriptive and inferential statistics. Analysis of variance (ANOVA) was used to compare variations pattern in pulp properties of the wood. The data analysis was carried out using 2x3 factorial experiment in completely randomized design. Follow-up test was carried out using Fisher's Least Significance Difference (LSD) to compare the absolute differences between pair of treatment means at 0.05 level of significance. Pearson's correlation coefficient analysis was used to determine the correlation between pulp yield and kappa number of the pulp.

RESULTS AND DISCUSSIONS

Kraft Pulp Yield of Douglas Fir

The highest pulp yield of 51.41% obtained in this study under active alkali of 15%, sulphidity of 27%, time of 190 minutes and temperature of 170°C as presented in Table 1 is higher than 44.6% obtained on thermomechanical pulping of the same species by Quick *et al.* [7], 50.7% obtained for *Acacia melanoxylon* by Santos *et al.* [8], 47% obtained for *Bambusa vulgaris* by Akeem *et al.* [9], 48% obtained on *Leucaena leucocephala* by Oluwadare and Sotannde [10], a bit lower than 54.28% obtained for kraft pulping of Douglas fir with soluble Anthraquinone by Christopher [11], 52% obtained for *Gmelina arborea* by Akeem *et al.* [9], 55.1% obtained for *Eucalyptus spp.* by Gomes and Silva [12]. In the kraft

process, the cooking liquor dissolves approximately 88-92% of the lignin from the pulp and provides a yield of around 45-55%. The average yield of 46.36% obtained in this study falls within this expected range. This means that Douglas fir has a good pulp quality, best at 15%AA and 27%S, serve as a good raw material for paper making. It is acceptable as a good pulpwood. The analysis of variance shown in Table 2 revealed a significant difference in yield based on variations in alkali levels, sulphidity levels, and the interaction between the cooking liquor and other variables. At 15% alkali, the yield was higher than 17% alkali.

Kappa Number of Douglas fir

Kappa number quantifies the amount of lignin in wood pulp. It measures the extent of delignification after pulping [13]. This study observed that both the active alkali and sulphidity percentages significantly impact the kappa number. As the pulp yield increases, the kappa number decreases, indicating a lower lignin content in pulps with higher yield.

The mean kappa number obtained in this study 28.19 shown in Table 1 is slightly higher than the 27.6 obtained by Quick *et al.*, [7] for the same species, 21.6 obtained by Blackman [14] on Douglas fir, higher than 18.2 obtained by Gomes and Silva [12] on *Eucalyptus spp.*, 13.7 by Santos *et al.*, [8] on *Acacia melanoxylon*, 23.6 obtained by Oluwadare and Sotannde [10] on *Leucaena leucocephala*. It can be deduced that high kappa number was obtained at low sulphidity 23% and high alkali 17% which has the lowest yield shown in Table 1.

Effect of Active Alkali (NaOH)

Sodium hydroxide is an effective lignin removal agent, its separate lignin from the wood fibres. An increasing pattern of variation of pulp yield was observed in lower active alkali 15% for Douglas Fir shown in Table 1. The higher the active alkali used during the cooking process, the lower the pulp yield due to the increasing rate of delignification as observed in this study. Excessive active alkali might also cause fibre degradation. According to Ribeiro *et al.*, [15], pulping with low active alkali tend to preserve carbohydrates during cooking with potential yield and pulp viscosity gains. If too low active alkali is used for pulping, it can cause more unexpected

rejects which are the uncooked chips in the cooking process, which means the delignification process is not completed. From this study, increasing alkali charge leads to decreasing pulp yield. Therefore, to get best quality pulp, use of alkali charge needs to be put into consideration.

Effect of Sulphidity (Na₂S)

Sodium sulphide works synergistically with sodium hydroxide to initiate and accelerate the delignification process. Sulphidity level varied in this study are between 23%, 25% and 27% and the best sulphidity which has higher pulp yield in each active alkali was at 23% shown in Table 1. A study reported by Gomes and Silver [12] on variation of sulphidity of kraft pulping of *Eucalyptus spp.* shows that the screened yield at 40 % sulphidity has higher yield than yield at 5% sulphidity. Lower sulphidity percentage has lower rate of delignification, while higher sulphidity percentage led to greater delignification. Due to the high active alkali percentage, pulp yield decreased with increasing sulphidity percentage as observed in this study. Higher sulphidity results in greater delignification while sodium hydroxide will cause carbohydrate depolymerization according to Jia *et al.*, [16].

Correlation between Pulp Yield and Kappa Number

The correlation coefficient of -0.936 indicates a strong negative correlation between kappa number and pulp yield. This means that as the kappa number increases the pulp yield tends to decrease, and as kappa number decreases, the pulp yield increases as observed in Table 1. A study by Johakimu [17] on *Pinus patula* followed same pattern. The t-value associated with the correlation is -8.43056, and the p-value is 0.000007 suggests that the correlation between kappa number and pulp yield is statistically significant at a 95% confidence level.

The strong negative correlation between kappa number and pulp yield in the pulp and paper industry is as expected shown in Table 3. It means that as the lignin content in the pulp (kappa number) increases, the efficiency of fibre extraction (pulp yield) tends to decrease, and conversely [18]. This gives confidence that the observed correlation reflects a genuine association between kappa number and pulp yield.

Table 1: Pulping variables and Pulp Yields of Douglas Fir wood at different Cooking Conditions

Batch no.	Alkali (%)	Sulphidity (%)	Chips to water ratio	Moisture content (%)	Screened yield (%)	Rejects (%)	Total yield (%)	Kappa no.
1	15	23	1:7	64.2	48.55	11.08	59.63	27.41
2	15	25	1:7	65.4	49.44	10.87	60.09	26.54
3	15	27	1:7	57.4	51.41	10.65	62.28	26.12
4	17	23	1:7	57.0	41.33	11.34	52.67	31.22
5	17	25	1:7	58.0	43.25	11.12	54.37	29.63
6	17	27	1:7	61.5	44.21	10.98	55.19	28.24

Temperature (160°C), cooking time (190 min)

Table 2: Significance influence of Pulp Properties Douglas Fir Wood pulping

Pulp properties	Sources of variation	Df	F-cal.	Sig.
Moisture content (%)	Active Alkali (AA)	1	15.12	0.008*
	Sulphidity (S)	2	2.02	0.21ns
	AA* S	2	17.50	0.003*
	Error	6		
	Total	11		
Pulp Yield (%)	Active Alkali (AA)	1	435452	0.000*
	Sulphidity (S)	2	25438	0.000*
	AA* S	2	1078	0.001*
	Error	6		
	Total	11		
Kappa no.	Active Alkali (AA)	1	90400	0.000*
	Sulphidity (S)	2	13365	0.000*
	AA* S	2	4343	0.001*
	Error	6		
	Total	11		

*= Significant (P<0.05), ns= not significant (p>0.05), Df = Degree of freedom

Table 3: Pearson's Correlation Coefficient between kappa Number and Pulp Yield.

	Mean	r(X,Y)	r ²	T	P
Pulp yield (Y)	46.36±1.85				
Kappa no. (X)	28.19±1.85	-0.936299	0.876656	-8.43056	0.000007

CONCLUSION

The pulp properties evaluated in this study indicated that Douglas fir wood possesses a fibrous composition and high pulp yield, which are desirable characteristics for pulping and papermaking processes. These traits suggest that the wood could be efficiently processed from pulp to paper and cellulose-based products. It can be concluded from the results obtained that Douglas fir possesses a good pulp quality, therefore suitable for paper making. To reduce the use of most used species such as *Gmelina arborea*, Douglas fir fit as a good raw material for paper production and would produce high quality writing and printing sheets. Further research is recommended to optimize refining techniques and pulping methods for maximum pulp yield and quality as the initial findings indicate that Douglas fir holds significant potential as raw material for the pulp and paper industry. Materials and necessary resources to enhance production of papers in Nigeria should be made available to reduce unemployment rate and paper importation. Also, there should be Involvement of Public Private partnership in the manufacturing and utilization of Pulp and Paper Products.

Conflicts of Interest

The authors declared that there is no conflict of interest regarding the publication of this paper.

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Declaration

The authors declared that the manuscript titled "Pulping Potential of Douglas Fir (*Pseudotsuga menziesii* Mirb. Franco)" is the original work carried out by Faith Ayodeji Ajidele, Josiah Thomas B. Riki and Abiodun Oluwafemi Oluwadare

Authors Contribution

Professor Abiodun Oluwafemi Oluwadare provided the idea and problem formulation for the study while Mrs Faith Ayodeji Fadiji and Dr. Josiah Thomas B. Riki carried out the research and did the analysis. Both the authors were involved in writing the article.

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