Suitability of selected Physical Properties of Acetylated Bamboo (*Bambusa vulgaris* Schrad.) for Structural Uses

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Abstract: This study evaluates some physical properties of bamboo (*Bambusa vulgaris*). Five mature Bamboo (*Bambusa vulgaris*) with equal height and internodes numbers were harvested at a height of 30cm above the ground level from a bamboo grove naturally growing stand at the University of Ibadan, Ibadan, Nigeria. Bamboo culms were marked at each internode using permanent marker from the base to the top to allow for easy identification and re-arrangement of the culm. The bamboo strips obtained were further converted to test samples. From each internode, 5 test samples were obtained, the total number of test samples converted was 625 samples. The test samples with dimensions 20mm (tangentially) x 60mm (longitudinally) x 5mm (radially) were oven dried at 105± 2°C until constant weight is achieved to determine the dry weight before acetylation. The experimental design is a 2 × 25 factorial experiment in a completely randomized design with three samples replication per test. The results shows that mean weight percent gain (WPG) for all the acetylated samples ranged from 11.41% to 16.88% across the culm heights, significant difference was observed in the bulking coefficient with a mean values between 3.21% to 4.75% along the culm height. Also the mean value of moisture content obtained for the acetylated bamboo samples ranged 23.67 to 30.27%. The mean value of specific gravity obtained for the acetylated bamboo samples ranged 1.0475 to 1.1117. Water absorption, swelling coefficient and anti-swelling efficiency were all significant except the dimensional stability efficiency. Based on this study, the dimensional stability and hydrophobicity of bamboo have significantly improved, which increases its suitability for structural use.

Keywords: *Bambusa vulgaris, Physical Properties, culm height, Acetylate*

Introduction

As a natural organic polymeric material, bamboo has more than 10,000 applications (Ramakrishnan *et al.,* 2020; INBAR, 2018). Under the backdrop of the shortage in wood resources today, bamboo has attracted unprecedented attention because of its unique advantages, including its short growth cycle, availability and sustainable harvesting, etc. (Srivaro *et al.,* 2018). The demand for bamboo raw material also has been increasing steadily in recent years (Wang *et al.,* 2019). As an illustration, the number of bamboo exports and imports from China, which has the world's largest bamboo sector, has been rising since 2015 with only a minor reduction in recent years as a result of the COVID-19 epidemic. We will need to take into account the development of bamboo resources to better its usage and satisfy this expanding need because the demand for bamboo materials on a worldwide scale will only continue to grow (Zhang *et al.,* 2022) both for structural uses and paper production (Moradbak *et al*., 2016).

With a wide range of species, bamboo is found across the tropical, subtropical, and mild temperate zones. 1700 bamboo species belonging to 130 genera have been identified globally, according to the World Checklist of Bamboos, which updated the information that was published in 2016 in the World Checklist of Bamboos and Rattans (Vorontsova *et al.,* 2016). However, only a few number of bamboo species have been widely planted and successfully used (Zhang *et al.,* 2022). Bamboo is a homogeneous lignocellulosic material with anisotropic properties (Chaowana, *et al*., 2012). Despite having a tough, highly reflective outer covering, bamboo is largely biodegradable due to its abundance of potential nutrients and lack of chemical resistance. Bamboo's key constituents are lignin, which acts as an incrusting substance, hemicellulose, which serves as a matrix, and cellulose, which forms the skeleton (55%) according to Wijerathne *et al.,* (2022).

Bamboo is also susceptible to degradation by fungus, bamboo borer and certain types of termites. Termites with their cellulose-decomposing bacteria in the gut can easily digest the cellulosic part of bamboo and as a result, the strength of the bamboo reduced drastically which in turn makes it unfit as a construction material (Pournou, 2020). To protect the lignocellulosic material from degradation and enhance its service life for structural uses, various treatment methods have been employed during last few decades such as treating with mineral oil, coal tar; heating in hydrocarbon oil, smoking, treating with various etherifying and esterifying agents, acetals, alkylene oxide and alkoxysilane-coupling agents and have been documented by several researchers (Deka *et al*., 2003).

In Nigeria, timber resources are dwindling and the necessary prerequisites for regeneration are not always readily available (Riki and Sotannde, 2019; Riki *et al.,* 2021). The utilization of alternative raw materials such as bamboo with a great potential to address the problem of wood shortage with minimal negative impact on the environment can form part of the overall plan to secure future sustainable development. Bamboo being a good substitute for wood, could help to bridge the gap of increasing demand for wood and woody products as well as reducing pressure generally on the forest estate and choice tree species thereby giving a time lag for species diversity and maturity of the forest estate. Due to its high cellulose content also contains large amount of starch, sugar, protein and other salt substances, and their structure is different to wood thus, leading to more serious defects in bamboo processing and dimensional stability for structural application and there is need to modify and study its physical properties for structural uues (Deng *et al.,* 2006).

Like other biological materials, bamboo is susceptible to environmental degradation such as moisture, heat, rain, insects etc. as well as dimensional variation when exposed to natural environmental conditions although, with the use of appropriate treatments, the shelf-life of these materials can be prolonged (Runumee *et al*., 2014). By nature, bamboo culm survives less than two years after which it quickly collapses (Liese, 2007). The hydroxyl groups of the culm's polysaccharide derivatives adsorb moisture which hastens bamboo degradation and causes its relatively short lifespan as a building material thus, it becomes necessary to modify the hydrophilic behaviour of the bamboo in order to prolong the natural lifespan by making it more hydrophobic. This paper deals with the chemical modification of the bamboo culm and its physical characterisation in order to improve its stability dimensionally for structural uses.

Materials and Methods

Description of the Study Area

The study area is at University of Ibadan, Ibadan, Oyo State. Nigeria. which is sited 3km to the North of the city of Ibadan. The University of Ibadan is located between latitude 7°23' and 28°19′N, and longitude 3°54' and 59°99'E. The topography of the area is flat and undulating, in terms of climate classifications, the altitude of the area ranges from 150 m to 275 m. The mean total rainfall for Ibadan is 1420.06 mm, falling in approximately 109 days. There are two peaks for rainfall, June and September. The mean maximum temperature is 34.4° C, minimum 18.07° C and the relative humidity is 74.55% (Klimatafel, 2016).

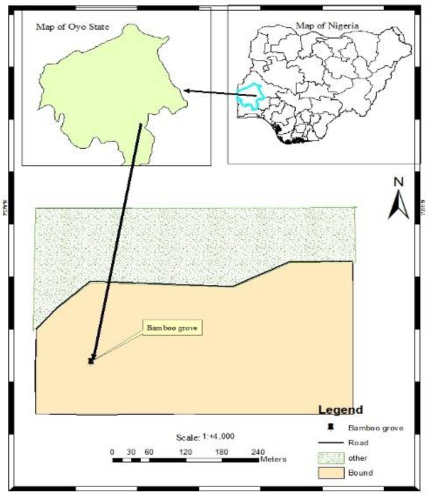

Figure 1: Map of the study area showing points of collection of Bamboo

Collection of Samples

Five mature Bamboo (*Bambusa vulgaris*) with equal height and internodes numbers were harvested at a height of 30cm above the ground level from a bamboo grove naturally growing but managed by the Biodiversity Management Committee, University of Ibadan, Ibadan, Nigeria.

Specimen Preparation

Bamboo culms were marked at each internode using permanent marker from the base to the top to allow for easy identification and re-arrangement of the culm. The culms were thereafter cut across the nodes with the aid of a hacksaw for accessibility and easy transportation. Each internode was then placed in a separate jute bag to avoid contamination from soil. The culms were then transported to and stored for 5 days in the wood workshop of the Department of Forest Production and Products, University of Ibadan, Ibadan, Nigeria for conversion to test specimens.

The culms were carefully sawn with circular sawing machine longitudinally into strips. Each strip was then planed on both the inner and outer surface, using a planning machine, in order to obtain the bamboo timber devoid of the outer protective skin with mean culm thickness of 5±0.5mm for the tests. The bamboo strips obtained were further converted to test samples according to EN 113 (1996) test standard. From each internode, 5 test samples were obtained, the total number of test samples converted was 625 samples. The test samples with dimensions 20mm (tangentially) x 60mm (longitudinally) x 5mm (radially) were oven dried at 105± 2°C until constant weight is achieved to determine the dry weight before acetylation.

Acetylation of Bamboo Samples

The oven dried bamboo specimens were weighed (W_o) and recorded with the use of digital weighing balance of 0.01 precision, the dimensions of the test samples were measured using digital venier calliper and used to estimate the volume of the test samples. Substantial volume of acetic anhydride was poured into the reaction vessel and the oven dried specimens of known weight were subjected to non-pressure hot treatment for 10 hours using a constant heat of 100°C as the only catalyst (the treatment took place in a closed reaction vessel which was tightly wrapped with aluminium foil to prevent evaporation and contamination). After 10 hours, the specimen were brought out of the reaction vessel, rinsed with distilled water to arrest the reaction and dried with the aid of filter paper. The dried modified specimens were then oven dried at 105°C for 24 hours and allowed to cool in a desiccator. The weight of the treated specimens were determined (W_t) using digital weighing balance, the volume was also estimated by measuring the dimensions using digital veneer calliper.

Determination of Modifiability of Bamboo

The weight percent gain (WPG) of the treated bamboo samples was calculated on an oven-dried weight basis by measuring the extractive-free untreated specimens and the treated specimens using the following formula

$$WPG = \left[\frac{W_t - W_o}{W_o}\right] \times 100 \qquad \text{………….…….} (1)$$

Where

WPG is the weight percent gain

W_o is the weight of oven-dried sample before acetylation (g)

W_t is the weight of oven-dried sample after acetylation (g).

Determination of Bulking Coefficient

The bulking coefficient (B) was also determined for all prepared specimens using the following formula.

$$B=\left[\frac{V_t-V_o}{V_o}\right]\times 100 \quad \ldots\ldots\ldots\ldots (2)$$

Where

B is the bulking coefficient

Vt is the volume of oven-dried wood after being acetylated.

V_o is the volume of oven-dried wood before acetylation

Determination of Physical Properties of Acetylated Bamboo

Moisture Content Determination

Test specimens of dimensions 20mm x 60mm x 5mm were used to determine moisture content using oven-drying method in accordance with ASTM D 4442-84, using the equation,

$$MC=\left[\frac{W_w-W_o}{W_o}\right]\times 100 \quad \ldots\ldots\ldots\ldots (3)$$

Where

MC = Moisture content

Ww = Weight of specimens before oven-drying (g)

Wo = Weight of specimens after oven-drying (g).

Determination of Specific Gravity

Specific gravity (SG) of bamboo samples was obtained based on the method described in ASTM D235-69. SG will be estimated using;

$$SG=\left[\frac{1}{\frac{W_s-W_o}{W_o}+\frac{1}{1.53}}\right] \quad \ldots\ldots\ldots\ldots (4)$$

Where

SG = Specific gravity

W_s = Saturated weight of specimen (g)

W_o = Oven dried weight of specimen

1.53 = Constant developed by Stamm (2006) as the actual weight of woody substance.

Determination of Dimensional Changes

To determine the moisture properties of the specimens, the commonly used method given by Rowell and Ellis (1978) was adopted. The oven dried modified and the unmodified bamboo specimens (20mm × 60mm × 5mm) were placed in bowl filled with distilled water for duration of 14 days. The water was replaced with fresh distilled water daily during 14days test period. The weights as well as the volume were determined on 24 hours bases. The moist modified samples were wiped dry with the aid of filter paper after each 24hours before the weight was determined using a digital weighing balance with precision of ±0.01g and the dimensions along the 3-plains also was measured using digital vernier calliper with a precision of ± 0.02mm and recorded on the data sheet. After the fourteen days soaking, the saturated modified sample were then oven-dried at 105°C for 48 hours and the final weight and dimensions were measured and recorded.

Determination of Water Absorption

Water absorption was calculated after each water replacement according to the equations below which is in line with procedure also adopted by Temiz *et al*. (2006).

$$WA=\left[\frac{W_1-W_0}{W_0}\right]\times 100 \quad \ldots\ldots\ldots\ldots (5)$$

Where

WA = water absorption

W_1 = wet weight of the specimen after soaking in water (g)

W_0 = oven-dry weight (g).

Determination of Swelling Coefficient

Swelling coefficient (S) was calculated using equation 7.

$$S(\%)=\left[\frac{V_{wet}-V_{dry}}{V_{dry}}\right]\times 100 \quad \ldots\ldots\ldots\ldots (6)$$

Where

V_{wet} is the water saturated wood volume

V_{dry} is the volume of the same sample after oven drying.

Determination of anti-shrinkage and anti-swelling efficiency (ASE)

Anti-swelling efficiency (ASE) was determined by using equation 8.

$$ASE(\%)=\left[\frac{S_{unmod}-S_{mod}}{S_{unmod}}\right]\times 100 \quad \ldots\ldots\ldots (7)$$

Where

S_{unmod} is the swelling coefficient of the unmodified samples

S_{mod} is the swelling coefficient of the modified wood samples.

Dimensional stabilization efficiency

The dimensional stabilization efficiency (DSE) was calculated with the following equation which is in line with procedure also adopted by Temiz *et al*. (2006).

$$DSE=\left[\frac{ASE-w}{WPG}\right] \quad \ldots\ldots\ldots\ldots (8)$$

Where:

DSE is the dimensional stabilization efficiency

ASE is the Anti-swelling efficiency

WPG is the weight percent gain.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used. Data were subjected to statistical analysis of 2 × 25 factorial experiment in a completely randomized design (CRD) and Mean±SEM. However, a follow-up test was carried out using the least significant difference test (LSD) at 5% level of probability.

Results and Discussions

Weight Percent Gain (WPG)

The WPG values obtained from the bamboo samples are presented in table 4.1. The mean WPG for all the acetylated samples ranged from 11.41% to 16.88% across the culm heights. The highest WPG was recorded in culm 14 which falls in the middle portion of the culm height while the lowest WPG was recorded in internode 25 which falls in the zoning of the top portion of the culm (Table 1). There were significant differences in WPG, among the samples across the culm height at 5% probability level (Table 2).

Weight percent gain (WPG) is used to assess the degree of acetylation of the bamboo samples. Variations in WPG across the treatments could be associated with the intrinsic properties of the internode along the culm. The reaction time and temperature employed would also have affected the overall WPG per culm but not responsible for the variation in WPG along the culm. This result is in line with the report given by Krishna *et al.,* (2009) the average weight percent gain (WPG) increased with increasing reaction time. Furthermore Jian-Zhang (2000) reported a WPG of 8.6% at 8 hour and 20.9% at 24 hour, at a reaction temperature of 125°C and at 140°C the WPG was 21.2% at 2 hour and 34.0% at 24 hour. The decrease in the weight percent gain observed in the 3rd acetylating temperature and time is earth with the report given by Stamm (2006), A more appreciable WPG could be gotten, if the temperature is increased and the reaction time is reduced as woody materials degrade at a temperature above 140°C (Stamm, 2006). Acetylation does not take place at 140°C due to the boiling of acetic anhydride as acetic anhydride boils below 140°C (Jian-Zhang, 2000). The findings in this study are in accordance with the work of Ghorbani (2013), who previously reported that acetylation rate decreased with an increase in reaction time. If the reaction time is long, the temperature required for complete reaction must be low enough. The reaction must also have a relatively fast rate of reaction with the cell wall components. Fast rate of reaction is gotten if the reactions proceed at a high temperature (up to 170˚C) for a very short reaction time (Papadopoulos *et al.,* 2019).

Table 1: Mean Percent Weight Gain for Acetylated Bamboo Samples

Internode Position	Mean	N	Minimum	Maximum	Standard Error
1	13.75 ± 0.70	3	13.04	14.44	0.404
2	13.40 ± 0.70	3	12.69	14.09	0.404
3	14.02 ± 0.70	3	13.31	14.71	0.404
4	13.95 ± 0.70	3	13.24	14.64	0.404
5	14.53 ± 0.07	3	13.82	15.22	0.404
6	15.46 ± 1.37	3	14.08	16.82	0.791
7	15.31 ± 1.37	3	13.93	16.67	0.791
8	15.53 ± 1.37	3	14.15	16.89	0.791
9	14.85 ± 1.37	3	13.47	16.21	0.791
10	15.75 ± 1.37	3	14.37	17.11	0.791
11	16.18 ± 1.37	3	14.80	17.54	0.791
12	16.73 ± 1.37	3	15.35	18.09	0.791
13	16.62 ± 1.37	3	15.24	17.98	0.791
14	16.88 ± 1.37	3	15.50	18.24	0.791
15	16.75 ± 1.37	3	15.37	18.11	0.791
16	15.67 ± 1.37	3	14.29	17.03	0.791
17	15.18 ± 1.37	3	13.80	16.54	0.791
18	14.66 ± 1.37	3	13.28	16.02	0.791
19	14.31 ± 1.37	3	12.93	15.67	0.791
20	13.40 ± 1.37	3	12.02	14.76	0.791
21	12.77 ± 1.37	3	11.39	14.13	0.791
22	12.40 ± 1.37	3	11.02	13.76	0.791
23	11.83 ± 1.37	3	10.45	13.19	0.791
24	11.41 ± 1.37	3	10.03	12.77	0.791
25	11.43 ± 2.44	3	9.38	14.12	1.406
Total	14.51 ± 1.97	75	9.38	18.24	0.227

Table 2: Analysis of Variance for Percent Weight Gain of Acetylated Samples

Properties	Source	SS	Df	MS	F	Sig.
	Culm Position	198.758	24	8.282	4.700	0.000*
WPG (%)	Error	88.100	50	1.762		
	Total	286.858	74			

Moisture Content (MC)

The results of the moisture content of the study samples are presented in figure 3. The mean value obtained of the untreated sampled bamboo for moisture content after immersion in water for 24 hours were ranged 48.49 to 82.91%. Also the mean value of moisture content obtained for the acetylated bamboo samples ranged 23.67 to 30.27%. The highest Moisture content was obtained in the untreated bamboo samples (Figure 3).

The result of the analysis of variance for moisture content presented in Table 4, shows that there were significant differences among the treated and the untreated bamboo samples. There were no significant differences among the culm height at 5% probability level. The interaction between the treatment and the culm height is also significant at 5% probability level (Table 4).

As observed from the study, the moisture content is reduced as the level of acetyl weight gain increases. The reduction in MC is a function of acetyl weight gain. The fluctuations in the MC across the culm height can be attributed to the maturity of the culm as reported by Li *et al.,* (2021) who observed variation in the physical properties of bamboo along the culm height and concluded that there is an un-uniform maturity rate along the culm height as the middle portion of the segment matures first before the top and the base. Furthermore, Zhang *et al.,* (2021) added that the variation in the properties along the culm height could be a factor of the age of the bamboo culm that is a function of the maturity of the culm. Similarly a research conducted by Rowell (2009) confirms that there is a reduction in moisture content (MC) and equilibrium moisture content EMC of acetylated woody samples due to the chemical bonding with the hydroxyl group of the wood which reduce the hydroxyl group available to bond with water molecule thus inferentially lowers the MC of the treated samples. The moisture content varies within one culm and is influenced by its age, the season of felling and the species, In the green stage greater differences exist within one culm as well as in relation to age, season and species (Liese and Tang, 2015).

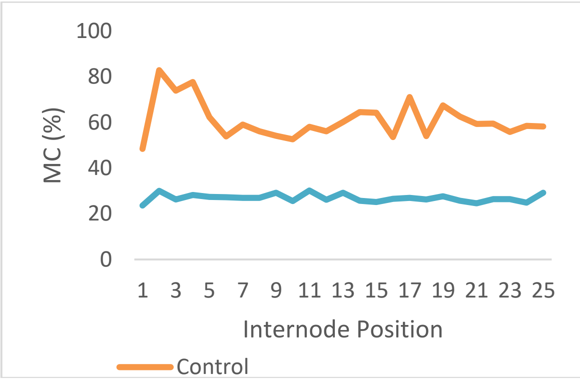

Figure 3. Moisture content showing the interaction between the untreated and treated bamboo samples.

Table 4: Analysis of Variance for Moisture Content (%) of Untreated and Acetylated Bamboo Samples

Source	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	17843.657	1	17843,657	451.738	0.000*
Culm position	2905.446	25	121.060	0.031	0.999ns
Treatment * Culm position	48662.751	49	993.117	21.874	0.000*
Error	197.500	100	39.500		
Total	53202.937	150			

Specific Gravity (SG)

The mean values obtained of the untreated sampled bamboo for specific gravity were ranged 0.7262 to 0.9118. Also the mean value of specific gravity obtained for the acetylated bamboo samples ranged 1.0475 to 1.1117. The highest specific gravity was obtained in the acetylated bamboo samples (Figure 4)

Analysis of variance for specific gravity presented in Table 5 shows that there were positive correlation among the treated and the untreated bamboo samples. There was also a significant difference among the culm height at 5% probability level. The interaction between the treatment and the culm height is also significant at 5% probability level. Generally, there is an increase in the specific gravity of the acetylated bamboo compare to the untreated. There is a rise and fall movement along the culm height from the base to the top in the untreated samples but is relatively stable in the acetylated bamboo samples as seen in figure 4.

Specific gravity of wood/non-wood is defined as the ratio of dry weight of wood substance to the weight of an equal volume of distilled water at 4°C (Ogunjobi, 2022). There was a general increase that was observed across the bamboo culm height. It could be as a result of acetylation impacts on the density of the bamboo samples as observed in the result. The acetylated bamboo samples are denser than the control because there was chemical bulking the cell wall of the treated which makes the samples swell and remain in a permanently swollen state thus a weight gain is than observed and the increase in specific gravity is paramount. This result agrees with studies carried out by Adebawo *et al.*, (2016) who also observed a higher density gain in acetylated tropical hard wood species (*Tryplochyton scleroxylon*). Several authors such as Stamm (2006), Ghorban (2013), Mohebby *et al.*, (2006), also reported a higher density in chemically treated woody samples. As mention above, it is concluded that acetylation has a positive impact on the specific gravity of woody substance.

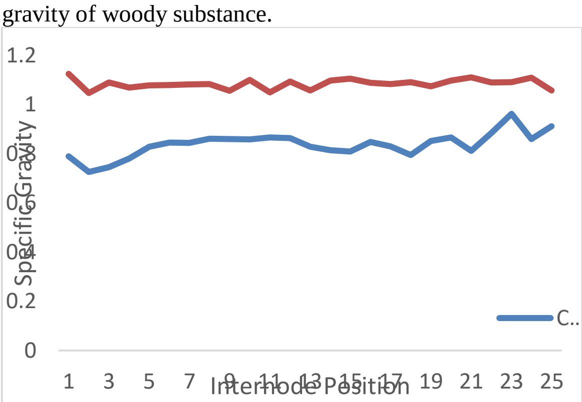

Fig. 4. Graph of mean Specific gravity showing the interaction between the untreated and treated bamboo samples.

Table 5: Analysis of Variance for Specific Gravity of Untreated and Acetylated Bamboo Samples

Source	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	138.658	1	138.658	53414.559	0.000*
Culm Position	2.383	25	0.095	36.715	0.000*
Treatment * Culm Position	2.484	49	0.051	19.529	0.000*
Error	0.260	100	0.003		
Total	141.402	150			

Water Absorption (WA)

Results in figure 5 shows the mean values obtained for sampled treated bamboo for water absorption after immersion in distilled water for fourteen days were ranged 11.416 to 23.87. Similarly, the mean value of water absorption for the untreated bamboo samples ranged from 44.114 to 71.004. The highest water absorption values were observed in the untreated samples while the least water absorption was observed in the treated sample. The results of the analysis of variance for water absorption are presented in Table 6 which reveals that there were significant differences among the treated and the untreated bamboo samples. At 5% probability level, there is a significant difference along the culm height. There is a clear difference in the water absorption of the acetylated bamboo compare to the untreated. There is a fairly rise and fall movement along the culm height from the base to the top in the untreated samples but is relatively stable in the acetylated bamboo samples as seen in figure 6.

Wood can absorb water as a liquid, if in contact with it, or as vapour from the surrounding atmosphere. Although wood can absorb other liquids and gases, water is the most important. Because of its hygroscopicity, wood, either as a part of the living tree or as a material, always contains moisture (Fredriksson, 2019). The base of the acetylated culm had the highest water absorption follow by the middle segment and the top, these trend could be linked with the differential in the culm characteristics and the maturity of the culms. The decrease in water absorption in this study is in consonance with the work of Ramful *et al.*, (2021).

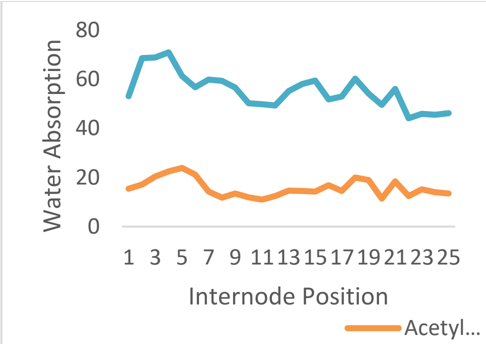

Fig. 5. Graph of mean Water absorption showing the interaction between the Untreated and treated bamboo samples.

Table 6: Analysis of Variance for Water Absorption of Untreated and Acetylated Bamboo Samples

Source	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	253295.642	1	5065.913	120.922	0.000*
Culm Position	60030.776	25	2401.231	57.317	0.000*
Treatment * Culm Position	63614.814	49	1298.262	30.989	0.000*
Error	4189.412	100	41.894		
Total	257485.054	150			

Swelling Efficiency (S)

As shown in figure 6, the mean volumetric swelling efficiency of the study sampled treated bamboo for swelling efficiency after immersion in distilled water for fourteen days were ranged 6.38 to 10.35. Also, the mean value of swelling efficiency for the untreated bamboo samples ranged from 9.185 to 15.26. The highest swelling efficiency values were observed in the untreated samples while the least swelling efficiency was observed in the treated sample.

The analysis of variance for swelling coefficient shows that there were significant differences among the treated and the untreated bamboo samples. At 5% probability level, there is a significant difference along the culm height. The interaction between the treatment given and the culm height is also significant at 5% probability level (Table 7).

Plant normally shrinks as it dries and swells as it absorbs moisture (Momoh *et al.*, 2022). Shrinkage and swelling may occur in any cellulosic material when the moisture content of wood is below the fibre saturation point. Shrinkage occurs as the moisture content reduces, while swelling takes place when water is introduced into the wood (Ayinde *et al.*, 2020). The highest swelling efficiency was observed in the top segment of the culm, these might be due to the immaturity of the top portion of the culm compare with the other part of the culm height as the top portion still continues to grow and maturity is delayed in the top. Stamm (2006) reported that, there is a lag behind in the maturity of the top segment of the culm in reference to the middle and the base, he reported further that the middle segment of the culm matures first followed by the base and then lastly the top segment. These claim was also supported by Krishna *et al.*, (2009) and Jian-Zhang (2000). Contrary, a steady decrease was observed in some selected tree species by Sotannde *et al.*, (2019) and this may be due to the type of material used.

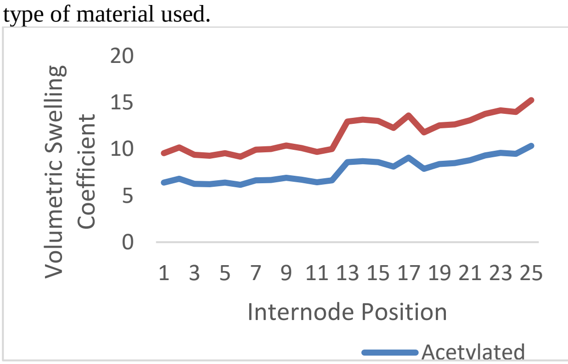

Fig. Figure 6: Graph of mean Volumetric swelling coefficient showing the interaction between the untreated and treated bamboo samples.

Table 7: Analysis of Variance for Volumetric Swelling of Untreated and Acetylated Bamboo

Source	Sum of Squares	Df	Mean Square	F	Sig.
Treatment	14007.523	1	14007.523	17393.529	0.000*
Culm Position	567.229	25	22.689	28.174	0.000*
Treatment * Culm Position	938.070	49	19.144	23.772	0.000*
Error	80.533	100	0.805		
Total	15026.126	150			

Anti-Swelling Efficiency (ASE)

Significant differences were observed among the twenty-five culm heights at 5% probability level (Table 8). Results in figure 7, reveals that the mean values of sampled treated bamboo for anti-swelling efficiency after subjected to moisture property test ranged 47.39 to 51.60. The highest anti-swelling efficiency values was observed in culm fifteen (15) which is a representative of the middle segment along the culm height while the least anti-swelling efficiency was observed at culm twenty-four which is a representative of the top segment along the culm height of the treated sample.

Variations in percentage anti-shrinkage efficiency were observed among the culm height and could be attached to the weight percent gain (WPG) of each samples along the culm height which influences the dimensional stability of bamboo (Rahman, 2015). The variations could also be due to differences in cell wall thickness and also the maturity of each culm height as there is differential properties along the culm height of bamboo as established by Zhang *et al.,* (2021) and Li *et al.,* (2021).

Therefore it could be concluded that a higher anti-swelling efficiency could be gotten if there is an increase in the weight percent gain obtained as there is a direct correlation between the WPG and the ASE of acetylated samples. Krishna *et al.,* (2009), Kumar and Agarwal (1982) and Tarkov *et al*., (1998) reported that an anti-shrink efficiency (ASE) of over 60% is achieved by acetylation of up to 20-25%.

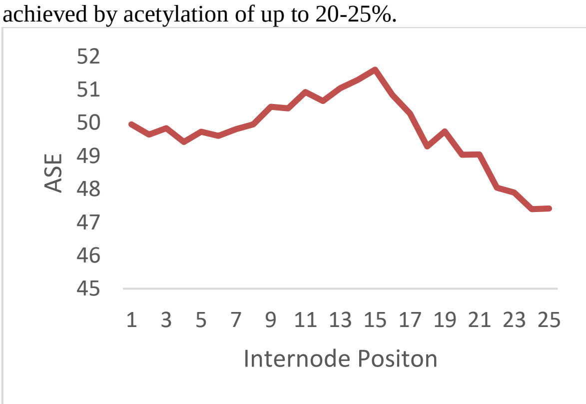

Figure 7. Graph of mean Anti-Swelling Efficiency showing the variation along the culm height

Table 8: Analysis of Variance for Anti-Swelling Coefficient (ASE%) of Acetylated Bamboo Samples

Source	Sum of Squares	Df	Mean Square	F	Sig.
Culm Position	92.801	24	3.867	8.048	0.000*
Error	24.023	50	0.480		
Total	116.824	74			

Dimensional Stability Efficiency (DSE)

Figure 8 shows the mean results of the dimensional stability efficiency of the sampled treated bamboo for dimensional stability efficiency after subjected to moisture property test were ranged 2.620 to 3.389. The highest dimensional stability efficiency values was observed in culm twenty-four which is a representative of the top segment along the culm height while the least dimensional stability efficiency was observed at culm twelve which is a representative of the middle segment along the culm height of the treated sample.

The results of the analysis of variance for dimensional stability efficiency of the acetylated bamboo reveal that there no significant differences among the twenty-five culm heights at 5% probability level (Table 9).

Dimensional stability of wood refers to how much wood will bow, bend or cusp when exposed to moisture. All woods are affected by moisture, which causes it to expand or contract. Depending on the type of wood and how it is cut, the movement is typically across the grain of the wood. The higher the coefficient, the greater the movement that takes place (Garrett, 2021). The trend of variation from base to top along the bamboo culm shows no any positive variation which means any axial part of the plants can be used for structural uses. Ayinde *et al.,* (2020) reported same trend of variation as it equally distributed across particle board produced from *Gmelina arborea*.

The extent of dimensional stability increases with increasing weight percent gain (WPG) and attains an optimum value around 20-30% WPG and then decreases with further modification (Rowel, 2005; Mohebby *et al*., (2006). Bamboo had improved swelling behaviour which is favourable for application to outdoor landscaping, exterior decoration and garden furniture (Yu *et al.,* 2015).

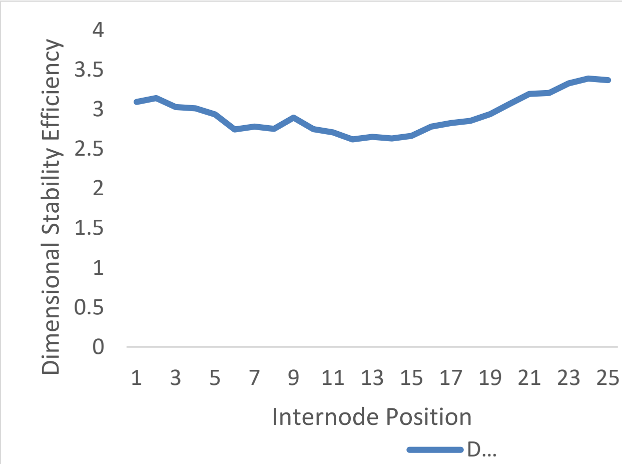

Figure 8. Graph of mean Dimensional Stability Efficiency showing the non-significant variation along the culm height.

Table 9: Analysis of Variance for Dimensional Stability Efficiency (DSE) of Acetylated Samples

Source	Sum of Squares	Df	Mean Square	F	Sig.
Culm Position	4.068	24	0.169	1.726	0.052ns
Error	4.910	50	0.098		
Total	8.978	74			

Conclusion

The findings from the study shows that the extent of hydrophobicity is evaluated as sorption properties which includes swelling coefficient, anti-swelling efficiency, water absorption dimensional stabilization and bulking coefficient all depend on the weight percent gained by each individual bamboo samples during acetylation as there is a direct relationship between weight percent gained and the degree of hydrophobicity, i.e. higher weight percent gain impact a higher degree of hydrophobicity and thus dimensional stability. Acetylation had an effect on the moisture content, equilibrium moisture content and the specific gravity of the treated samples. It should be noted however that acetylation helps to stabilize the variation in the physical properties that was observed along the culm height from the base to the top. Therefore, acetylation could also be used to stabilize the variation in the physical properties along the culm height. The bamboo samples perform optimally when evaluated as to the ones reported in literatures when comparing the weight percent gained obtained and also the trend of variation along the culm height from the base to the top. Therefore, to improve the sorption properties a higher weight percent gain of 20% and above as reported in literatures is essential.

This study therefore establishes the fact that bamboo could be chemically modified using acetic anhydride to improve its physical properties and as a result of the modification in the bamboo, there is a significant improvement in its dimensional stability and hydrophobicity hence, enhances the utilization of bamboo for structural application. Acetylation of bamboo could be done at 100°C or greater for a short reaction time.

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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