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VARIATION IN COLOUR, SPECIFIC GRAVITY AND EQUILIBRIUM MOISTURE CONTENT ALONG THE STEM HEIGHT OF THERMALLY TREATED *BAMBUSA VULGARIS*

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ABSTRACT:

The physical properties of thermal treated wild-grown Bambusa vulgaris were investigated, the test samples were treated with five different treatment regimes; 100, 110,120, 130 and 140°C and with treatment duration 10, 20 and 30 minutes respectively, and sampling heights of Base, middle and top. The colour of the treated samples was observed to change; it changed with increase in temperature and duration, the colour turned to brown at the temperature 120°C/30minutes and turned darker brown at temperature 140°C, the Specific Gravity (SG) and Equilibrium Moisture Content (EMC) of thermal treated Bambusa vulgaris were also examined. The result of analysis of Variance on the S.G as a result of the treatment effect, the sampling height temperature variation (°C) and treatment time (minutes) had significant effect on the specific gravity at 5% level of probability. The highest mean value of S.G (0.61) was found at the base sampling height while the least mean value (0.46). The results of the EMC of thermal-treated bamboo clearly revealed the ability of bamboo to absorb and loss water to atmosphere. The treated bamboo at temperature and time variations; 140°C/30minutes had a lowest (6.06%) EMC value while the control samples and samples at 100°C had the relative highest (10.84%) values.

Thermal treatment, changes the bamboo colour, decreases the Specific gravity and Equilibrium moisture content improved dimensional stability and durability of Bambusa vulgaris.

Key words: *thermal treatment; variation; colour; specific gravity; equilibrium content.*

INTRODUCTION

Bamboo is a lignocellulosic material whose dimensional stability is dependent on its state and the prevalent surrounding environmental conditions, extreme variations in the surrounding conditions e.g., temperature, Relative Humidity (RH), moisture, among others, will always affect unprotected/untreated bamboo material in service, particularly where these variations are detrimental to certain applications. As a lignocellulosic material, it is expected that bamboo will absorb and or release moisture to the surrounding environment at the required temperature and relative humidity, as also influenced by the species' equilibrium moisture content (EMC) and or fibre saturation point (FSP). Fluctuations in moisture absorption/desorption and volumetric/directional shrinkages in lignocellulosic material, particularly those in service, where these are disadvantageous, should be prevented or controlled to avoid situations where failure may occur as a result of these (Erakhrumen and Ogunsanwo 2009). Lee *et al*. (1994) reported results for specific gravity and orthogonal shrinkage of giant timber bamboo (*Phyllostachys bambusoides* Siebold & Zucc.). Specific gravity for this species was, on average, 0.52 (irrespective of layer or height).

The physical characteristics and properties such as the culms, height, and number of internodes, per culms internodes length, internodes diameter, culms, wall thickness girth, moisture content and basic density are considered to be important factors in determining the suitability of bamboo for various application and chemical treatment. Culms of different age groups were studied in order to determine at what age influence for the bamboo treatability (Maya *et al.* 2013). Tewari (1992) explained that bamboo start to shrink both in the wall thickness and diameter as soon as it starts to lose moisture. This behaviour is unlike wood, where most of the

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properties will start to change when it reaches the fibre saturation point. Lee *et al*. (1994) claimed that the average specific gravity of bamboo ranged from 0.3 to 0.8. Chew *et al*. (1992) gave the density of *B. vulgaris* at 630kg/m^3, which is relatively light compared to other bamboo samples. The heat treatment method for modifying wood increases dimensional stability, durability and it is more environmentally friendly than methods that use chemical treatments (Poncsak *et al.* 2006; Kocaefe *et al.* 2008; Gunduz *et al.* 2009; Garcia *et al.* 2012).

The physical and mechanical properties of some important bamboo species have been evaluated. The complexity is due to uneven distribution of vascular bundles, variation in moisture content, differences in the physico – mechanical properties of the node and internode parts, most especially with age. This variation could be 20-25 percent in thick-walled bamboos like *Dendrocalamus strictus* (Sharma and Mehra 1970). In thin- walled bamboos, the differences in density are much less (Sekhar and Bhartari 1960). Moisture also varies from the bottom to the top and from the innermost layers to the periphery. Green bamboo may have up to 150% moisture (oven-dry weight basis) and the variation reported is 155% for the innermost layers to 70% for the peripheral layers (Sharma and Mehra 1970). The variation from the top (82%) to the bottom (110%) is comparatively low. Moisture content decreases with age while the increase in specific gravity is rather limited (Limaye 1952). The fibre saturation point (FSP) of bamboo is around 20-22 percent (Jai Kishen *et al*. 1956; Sharma 1988), while Phyllostachys pubescens has a lower FSP ~13% (Ota 1955). The FSP is influenced by the chemical/anatomical nature of tissues. Parenchyma cells, being more hygroscopic, result in raising FSP. Bamboo shrinks in diameter (10-16%) as well as in wall thickness (15-17%) (Rehman and Ishaq 1947). The Objective of this study is to evaluate the trend of variation of some selected physical properties of thermal treated *Bambusa vulgaris.*

MATERIALS AND METHODS

Thermal Treatment of Bamboo Sample

One thousand and eighty Strips of 30cmx2cmx0.5cm were produced. Strips were air-dried at indoor condition until moisture content value range between 20 to 25%. Thermal treatment was conducted at Biotechnology Department of National Institute of Horticulture, Ibadan inside a Vertical pressure steam sterilizer (Model LS B50L-I and JSA-100). The autoclave is equipped with a close stainless-steel basket (240x190mm in diameters and height respectively) and a microprocessor, which permitted the programming of various times and temperature (from 100 to 140°C). The maximum capacity of the Autoclave is 50L. Strips were subjected to temperature at varying degree of Control (0^0C), 100°C, 110°C, 120°C, 130^0C, 140°C at different time interval; 10, 20 and 30 minutes, and the Culm height are; base, middle and top.

Colour of the untreated and thermal-treated *Bambusa vulgaris*.

This was physically observed both immediately and after thermal treatment at different temperature regime and treatment time, they were matched with standard colour chart and recorded.

Determination of moisture content of bamboo samples

Bamboo specimens of 20mmx20mmx5mm wall thickness were weighed and the weight was recorded as initial weight W_m. The test specimens were oven dried at 103^0C±2^0C using UNISCOPE SM 9053 force air laboratory oven until a constant weight was achieved.

The formula is as shown below:

$$MC = \frac{Wm - Wo}{Wo} X\,100 \qquad (1)$$

where: Mc = Moisture content;
Wm= Weight of specimens before oven-dry (g);
W_o= Weight of specimens after Oven-dry.

Determination of specific gravity

The specimen for specific gravity (SG) was carried out by obtaining a dimension of 20X20Xculm thickness (mm) from each treatment bamboo sample of both thermal-treated and untreated. They were subjected to a gravimetric procedure developed by Smith, (1954) with a little treatment to adopt bamboo due to its nature, in which specimens were completely saturated by soaking in the water. Each treatment was removed from the water, blotted to remove excess water, weighed and oven dried to a constant weight at 103 °C. Specific gravity was determined using the formula:

$$SG = \frac{1}{\frac{Wo - Ws}{Wo} + \frac{1}{1.53}} \qquad (2)$$

where: SG = specific gravity;
W_s = saturated weight of wood;
W_o = oven-dry weight of wood;
1.53 = constant developed by Stamm (1929) as the actual weight of wood substance.

Determination of Equilibrium Moisture Content (EMC)

For the estimation of the equilibrium moisture content, the mass of the oven dried sample (30mmx15mmxthickness) and the mass of the same sample at 20^{o}C and 65% were measured (5 measurements per variant). The treated wood samples were conditioned in a conditioning cabin at 20±2°C temperatures and 70±5% relative humidity to reach EMC throughout 8 weeks (Nguyen *et al.* 2012). At the end of the 8 weeks, the dimensions of bamboo samples and weights. The EMC was determined according to Equation below:

$$EMC = \frac{MF-MO}{MO}\ X\ 100 \qquad (3)$$

where: MF is the mass of the oven were taken;
- dried sample before the thermal treatment, and
MO is the mass of the treated and untreated samples at 20 $^{\circ}$C and 65% relative humidity.

Statistical Analysis

The experiment is a factorial experiment with a completely randomised design, Strips were subjected to temperature at varying degree of Control (untreated), 100, 110, 120, 130 and 140°C each, for 10, 20 and 30 minutes for base, middle and top sampling height, with 3x3x6 experimental design resulting into 54 treatments combination

RESULT AND DISCUSSION

Colour of the untreated and thermal-treated *Bambusa vulgaris*.

Colour of the untreated and the thermal-treated bamboo strips was physically observed both immediately and after thermal treatment at different temperature regime and treatment time, as shown in Fig. 1.

The thermal-treated *Bambusa vulgaris* tended to change in colour as showed in (Fig. 1) the colour changed from yellow to brown and darker brown. The untreated colour of *Bambusa vulgaris* is light yellow as revealed through the comparison with laboratory colour chart. The colour turned to brown at the temperature 120°C/30minutes and turned darker brown at temperature 140°C. This observation is in line with report of Natividad and Jimenez (2015) in their study on thermal treatment of *Bambusa blumena schltes*, the properties of the bamboo were altered with exposure to high temperature and long treatment duration, and the bamboo colour changed from light yellow of untreated samples to brown and latter darker brown at a steady increase in temperature variations (°C) and treatment time (minutes). Some studies have already reported that thermal treatment induced wood darkening and reddening (Johansson and Morén (2006), Lopes (2010), Aksoy *et al.* (2011). Other authors, however, reported reduction of red tonality as a function of heating (Pincelli 1999; De Moura and Brito (2011). In general, heat treated wood is often appreciated for its light-brown to dark-brown appearance (Viitanen *et al.* 1994), the variation in colour changes on heat treated specimens with untreated colour became significantly darker with increasing treatment temperature and time compared with control samples. This may also be due to an increase in lignin content with heat treatment temperature and treatment time (minutes). Coloured by-products formed during the degradation of hemicelluloses might have a contribution to this change in appearance (Kocaefe *et al.* 2008).

Fig. 1.
Colour variations in the thermal treatment of Bambusa vulgaris.

Table 1

Analysis of Variance (ANOVA) of Specific Gravity for untreated and thermal-treated *Bambusa vulgaris*

Source of variation	Df	Sum square	Mean of square	F-cal	P-value
Sampling height	2.00	0.50	0.25	185.98*	0.00
Temperature variation(°C)	5.00	0.17	0.03	25.74*	0.00
Treatment time(minutes)	2.00	0.62	0.31	232.84*	0.00
Sampling height * Temperature variation(°C)	10.00	0.12	0.01	8.60*	0.00
Sampling height * Treatment time(minutes)	4.00	0.04	0.01	6.86*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	0.18	0.02	13.44*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	0.08	0.00	2.94*	0.00
Error	216.00	0.29	0.00		
Total	270.00	83.51			

*= significant at P<0.05
ns = not significant at P>0.05

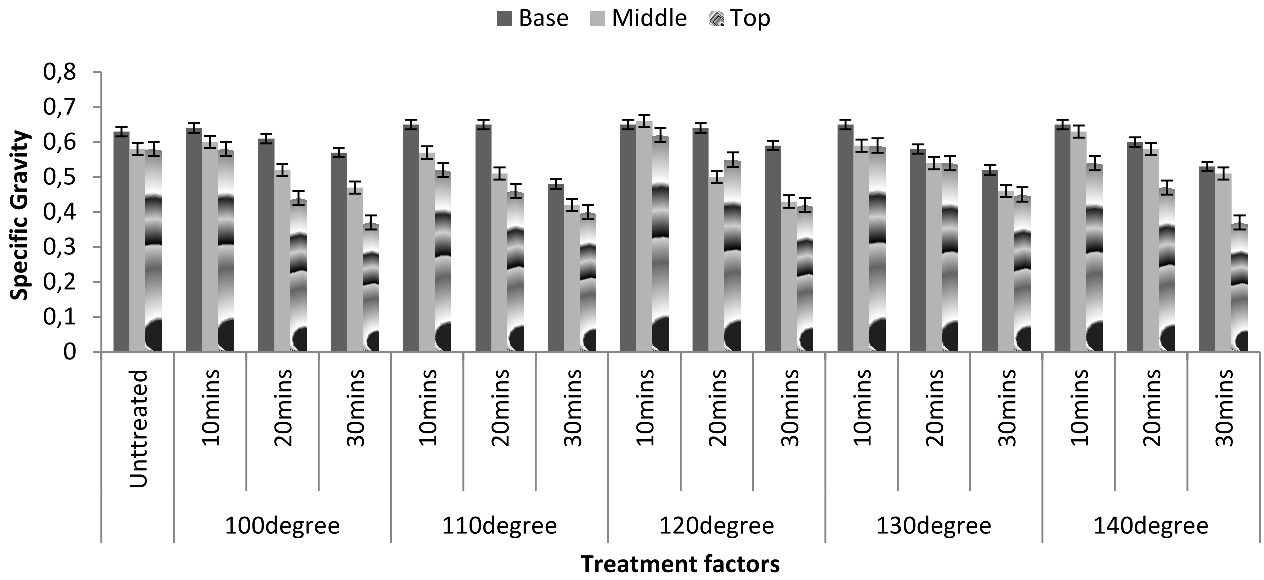

Fig. 2.
Showing Specific gravity (SG) for untreated and thermal-treated Bambusa vulgaris.

Specific gravity (S.G)

There were significant effect in the three effect of interaction among the sampling heights, temperature variation (°C) and treatment time (minutes) as shown in Table 1.The mean variation of the specific gravity of the thermal-treated bamboo is presented in Fig. 2.The result of analysis of variance on the S.G as a result of the treatment effect, the sampling height temperature variation (°C) and treatment time (minutes) had significant effect on the specific gravity at 5% level of probability.

The mean value for thermal-treated bamboo at temperature variations (°C); 100, 110, 120, 130, and 140°C with respective treatment time (minutes); 10, 20 and 30 minutes at base ranged from 0.61 to 0.59, 0.57 to 0.50 at middle and decreased from 0.46 to 0.53 at the top. There is a constant decrease in S.G from base to top, the specific gravity values tended to decrease along the culm from base to top, the effect of the thermal treatment on bamboo samples mean values at temperature at 100 to 140°C decreased also the treatment time from 10 to 30 minutes also decreased. For untreated samples, the value of SG was observed at conditioned moisture content 12%. The S.G of the thermal-treated bamboo at base for temperature 100 were noticed to increase more than untreated samples, this revealed the hygroscopic nature of wood as it readily takes up moisture from atmosphere until it reaches Fibre Saturated Point (FSP).

The treatment effect was not significant at the temperature 100°C, to have reduced its values compared with untreated samples. The result of the thermal-treated bamboo revealed a decreasing trend of S.G from the base to the top, however, density of a wood is directly proportional to its specific gravity, this is in contrary to the report of Razak *et al.* (2010); Kamruzzaman *et al.* (2008), they opined that there was an increasing trend of basic density from the base toward the top of bamboo. In this study, the mean values of S.G of thermal-treated *Bambusa vulgaris* decreases from base top height, the highest value of S.G was observed in the untreated samples, while the least S.G value was recorded in the highest temperature (140°C) adopted. Heating treatment time (minutes) between 10 to 30 minutes also had a significant effect on the S.G values of thermal treatment in such that the SG recorded at 30 minutes of a particular temperature is lesser than of its 10 minutes. Also, the trend of thermal treatment effect on the S.G of *Bambusa vulgaris* is contrary to the report of Brito *et al.* (2006), they studied the specific gravity of *Eucalyptus grandis* wood submitted to thermal treatment ranging from 120, 140, 160, 180 and 200°C. The authors reported that the specific gravity of thermally treated wood was not different from that obtained from natural wood. However, in a previous study by Kortelainen *et al.* (2005), on samples of Scots pine and Norway spruce thermally treated at 130 and 230°C, both weight loss and specific gravity reduction by heat were reported by Santo *et al.* (2014). The follow up test further revealed the interaction effect between temperature variation and time (Table 3).

Table 3

Analysis of Variance (ANOVA) of percentage Equilibrium Moisture Content (EMC) of untreated and thermal-treated *Bambusa vulgaris*

Source of variation	Df	Sum square	Mean square	F-cal	P-value
Sampling height	2.00	40.47	20.24	33.60*	0.00
Temperature variation(°C)	5.00	496.08	99.22	164.76*	0.00
Treatment time(minutes)	2.00	100.09	50.04	83.10*	0.00
Sampling height * Temperatu variation(°C)	10.00	52.43	5.24	8.71*	0.00
Sampling height * Treatm time(minutes)	4.00	9.43	2.36	3.92*	0.00
Temperature variation(°C) Treatment time(minutes)	10.00	57.71	5.77	9.58*	0.00
Sampling height * Temperatu variation(°C) * Treatm time(minutes)	20.00	14.88	0.74	1.24ns	0.23
Error	216.00	130.08	0.60		
Total	270.00	17952.90			

*= significant at P<0.05
ns = not significant at P>0.05

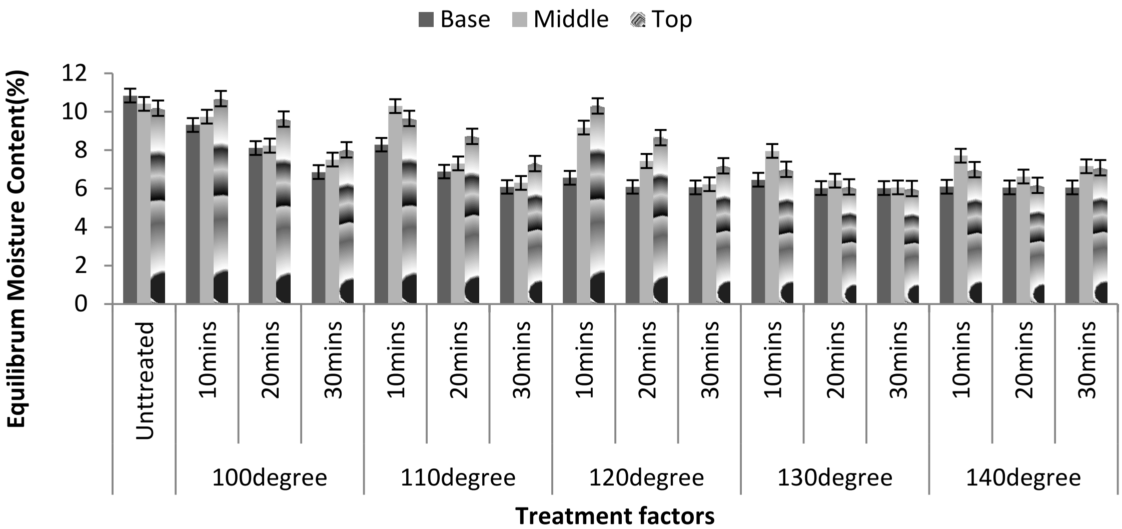

Fig. 3.
Showing Equilibrium Moisture Content (EMC) for untreated and thermal treated Bambusa vulgaris.

Equilibrium Moisture Content (EMC)

The result of analysis of variance on EMC as a result of treatment effect in sampling height, temperature variation (°C) and treatment time (minutes) have significant on EMC at 5%, There were significant effect in the interaction of sampling height, temperature and treatment time (minutes), but there was no significant interaction among the sampling height, temperature and treatment time (minutes) (Table 3).

The average mean value of the EMC for the treated bamboo strips for 100°C at base ranged from 6.07 to 8.10, also ranged from 6.81 to 8.50 at base (sampling height) while from 6.37 to 9.44 the mean values decreased from the temperature variations (°C); 140, 130, 120, 110 and 100°C also from 30 minutes to 10 minutes (Fig. 3).

The results of the EMC of thermal-treated bamboo clearly revealed the hygroscopicity and hydrophobicity tendencies of bamboo while under thermal treatment. The treated bamboo at temperature and time variations; 140°C/30minutes had a lowest percentage (%) EMC value while the control samples and samples at 100°C had the relative highest values. Wood treated at high temperature lacks affinity to absorb water from atmosphere at a corresponding temperature and relative humidity. This finding is in agreement with other researches on bamboo thermal treatment involving hot oil (Salim *et al.* 2010; Nguyen *et al.* 2012), and the report of thermal-treated of *Bambusa blumena* by Natividad and Jimenez (2015), chemical and anatomical properties in the thermal-treated both contributed to the changes in the EMC, most especially the fibre cell wall; The chemical treatment of bamboo cell wall components during heat treatment caused the changes in EMC level. The hemicelluloses were degraded while the amorphous regions of the cellulose were hydrolyzed breaking it to shorter chains with reduced free hydroxyl groups. Treated samples subjected to higher temperatures have lower free hydroxyl groups; thus, less hygroscopic or have lower EMC. According to Nguyen *et al.* (2012) on their study on the thermal treatment of two Vietnamese bamboo species with temperature variations (°C) 130, 180 and 220°C with 30 and 60 minutes treatment time (minutes) respectively, it was noted that the lowest EMC change was observed at 150°C - 30minutes with 1.55% change in EMC and the highest change was observed at 200°C/60minutes with 3.18%, The reduction of EMC (ΔEMC) due to the thermal treatment was very slight at 130°C (0.54 to 0.76%) much stronger at 180°C (3.6 to 4.44%) and 220°C and 5hours it was even higher (5.6 to 5.7%), which is a similar trend with the observation recorded in this work. The Equilibrium Moisture Content (EMC) is a steady-state level achieved when subjected to a particular relative humidity and temperature, relative humidity is strongly dependent on temperature (Wolfram 2006), FSP and EMC values decreased with increasing temperature variations and treatment time. As presumed above, results shown that the EMC of the thermally treated bamboo is lower than the EMC of the KD control sample, as temperature level and treatment duration increased, the degree of change in EMC also increased (Ates *et al.* 2008). The follow up test further revealed the interaction effect between temperature variation and time (Table 4).

Table 4

DMRT Conducted on the Mean Values Obtained for Specific Gravity (SG) and Equilibrium Moisture Content (EMC)

Temperature (°C	Time (minutes)	Specific Gravity (SG)	Equilibrium Moisture Content (EM
untreated	Untreated	0.60d	10.48e
100	10	0.60c	9.91c
100	20	0.52b	8.66b
100	30	0.47a	7.46a
110	10	0.58c	9.42c
110	20	0.54b	7.64b
110	30	0.43a	6.57a
120	10	0.64c	8.69c
120	20	0.56b	7.40b
120	30	0.48a	6.50a
130	10	0.61c	7.14c
130	20	0.55b	6.18b
130	30	0.48a	6.03a
140	10	0.61c	6.94c
140	20	0.55b	6.29b
140	30	0.47a	6.77a

Mean with the same alphabet are not significantly different from one another.

CONCLUSION

Colour of thermal-treated *Bambusa vulgaris* changes from light yellow from untreated (Control) to brown at treatment level (120°C/30minutes) and dark brown at 140°C in respect to increases in treatment time. Specific gravity (SG) of untreated samples decreased significantly from the base to the top samples, while the thermally treated also observed a decreasing trend from the base to top with respect to an increase in temperature and time variations. Equilibrium Moisture Content (EMC) decreased significantly along the bamboo culm from Base to top samples, while the thermal treatment decreased the EMC from middle, top to base samples respectively at treatment temperature and time from 100°C/30minutes to 140°C/30minutes.

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