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Imperative Seasoning Characteristics of *Yushania alpina* (Highland Bamboo) Culms Grown in Dire-Inchini, Ethiopia

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ABSTRACT

Bamboo is the world's fastest-growing plant and the finest conceivable substitute for future wood. It has a wide range of applications, from traditional use to industrial manufacture in many countries. Bamboo has been traditionally used in Ethiopia for the construction of huts and fencing, furniture, containers, beehives, and other small-scale objects. Lack of proper processing practices such as seasoning among the reasons for its low use. When bamboo culms are not properly seasoned, they have a high split and shrinkage rate that led to biological and physical degradations. 3–5-year-old samples of *Yushania alpina* culms were gathered from Dire-Inchini (Oromia Region). After harvesting culms, were cut into three portions (bottom, middle and top) to investigate the imperative characteristics of the material during the drying process. Kiln and air-drying procedures were used to dry the culms. Regression analysis was used to describe the functional relationship between moisture loss in the kiln and air drying. They had an average initial MC 103.67%, final MC 12.33%, and basic density 0.69 g/cm³. Bamboo culms dried in the kiln took 7.7 days to attain about 12 % final MC, while air-seasoned culms took 97 days. proper stacking, drying, and handling is critical for improving the quality, productivity, and service life of bamboo culms-based constructions and goods in the future.

INTRODUCTION

Bamboo is the world's fastest-growing plant and the finest conceivable substitute for future wood. Bamboo, like other plants, has high moisture content. On a dry-weight basis, fresh-cut green bamboo may contain 100% moisture (Wakchaure and Kute, 2011). Bamboo culms, unlike timber, require a short rotation (3-5 years) to grow before being harvested and used. According to Zhaohua (2001), there are about 1500 different uses of bamboo in the world. It can be used for a variety of applications, ranging from traditional rural uses to industrial production in developed countries (Omer and Gemechu, 2018). In contrast to other nations, bamboo has long been used in Ethiopia for hut construction, fencing, and to a lesser extent to furniture, containers, baskets, beehives, firewood, fodder, home utensils, numerous artifacts, and

walking sticks (Kassahun, 2004; Getachew and Wubalem, 2014; Getachew, 2015). The usage is mainly limited to local purposes (Yigardu and Mengistie, 2010; Getachew Desalegn, 2015). Despite the numerous uses of bamboo in industry, Ethiopia has not reaped the greatest economic benefit from it to date. One of the reasons for its minimal utilization is the lack of processing technologies such as drying (Getachew, 2015).

Proper bamboo culm drying is not generally practiced by bamboo growers/farmers, traders, and processors. When bamboo products are not properly seasoned to achieve the desired equilibrium moisture content, they have a high split rate, shrinkage rate, and dimensional changes, are susceptible to biological and physical degradations, and their quality and quantity are reduced. When it comes to further processing and manufacturing

finished products, properly seasoned bamboo culms have various advantages over green culms. For example, appropriate moisture reduction and removal limits culm shrinkage and swelling in use to acceptable levels under a variety of processing and usage situations. Many difficulties that occur during the drying of culms and over their service life are caused by bamboo shrinkage and durability (Getachew, 2015; Liese and KöhlKöhl, 2015). When bamboo loses or absorbs moisture, it alters its dimension, just like wood species. Bamboo is a hygroscopic substance, which means its moisture content varies depending on the relative humidity and temperature of its surroundings. Unlike most wood species, bamboo shrinkage manifests itself as a reduction in both cell wall thickness and cell width, which is caused by capillary forces that cause cell collapse as moisture levels fall (Liese and Köhl, 2015). Furthermore, finished bamboo goods made from correctly seasoned culms are not vulnerable to the negative effects of uncontrolled drying, which can cause paint, varnish, and other finishes to perform poorly. Furthermore, well-seasoned culms can be stored for an extended time without deterioration due to moisture/decay, extending the life of the bamboo culm.

Highland bamboo (*Yushania alpina*) culms and splints have recently been utilized in the construction of traditional dwellings, primitive furniture, mats, and household equipment (baskets, winnowing trays) (Getachew Desalegn and Wubalem Tadesse, 2014, 2014; Getachew Desalegn, 2015). Ethiopia is home to the highland or African alpine bamboo (*Yushania alpina*). It's also found in Kenya's, Sudan's, Zaire's, Zambia's, Rwanda's, Burundi's, Tanzania's, and Cameroon's highlands (Kassahun, 2003). It is one of the most widely farmed bamboo, with a wide distribution across the country. This species of bamboo is popular because of its adaptability and ease of processing. It may be used for a variety of products. Bamboo culms are artificially dried in a kiln or air-dried before being used. This research focuses on

the (drying and density) properties of *Yushania alpina* culms growing in Dire-Inchni (Oromia Region, Ethiopia).

METHODS

Sample selection, preparation, and testing

Mature (> 3 years old) highland bamboo (*Y. alpina*) culms were harvested from Dire-Inchni. Dire-Inchine is a district from Ethiopia's Oromia's Region West Shewa Zone. This district is 2485 meters above sea level, with 2800 mm of rain and a temperature of 21 degrees Celsius. Highland bamboo (*Y. alpina*) is available in this district (Figure 1) and culms measuring 8 to 10 cm in diameter and 12 meters in height were chosen. Culms of bamboo were selected and chopped 30 cm above ground level. They were picked in November, right at the start of the dry season. The bamboo culms' tips were cut off, leaving them around 9 meters long. These culms were then cut into three equal lengths, corresponding to the bottom, middle, and top parts of 3 m each, and transported to the Forest Products Innovation Research and Training Center (FPIRTC) while still green for sample processing and testing.

Stacking and drying of bamboo culms

Bamboo culms were stacked with about 3 cm spacing between successive culms to facilitate the circulation of air. Culms were stacked horizontally in vertical alignments separated by well-seasoned, squared, and standard stickers (Figure 1c). The control sample culms were distributed in each stack to represent the bamboo culm in the stack and the drying process at different positions (top-bottom, left-right, and vice-versa). The control sample culms were properly distributed and positioned in the pockets of the different layers of each stack. Bamboo culms for air drying were arranged under air drying yards with dimensions of 1.80 widths, 4 m length, and 45 cm height above the ground on sturdy foundations. Culms were stored under the shed without being exposed to moisture, rain, or sunlight (Figure 1).

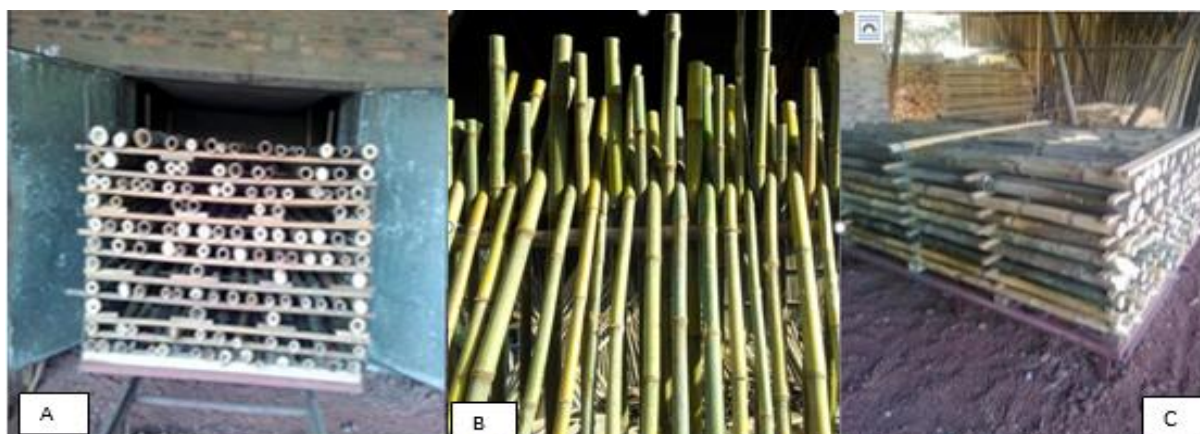


Figure 1. Kiln and air drying of bamboo culms [Photo by Getachew Desalegn and Mahadi Mussa]

Drying in kiln

Culms for kiln drying were stacked out of the kiln on the transfer carriage having a dimension of 2.7 m length and 1.6 m width (Figure 1a). This research used a conventional type of artificial kiln drying machine. The machine has a wood loading chamber with a capacity of 2.5 m³. It contains temperature and relative humidity controls that may be modified with psychrometers (dry-bulb and wet-bulb thermometers), as well as fans to force air

circulation and an air output with a temperature range of 40-70 °C. The kiln drying timetable for wood used to dry bamboo (table 1). Psychrometers were regulated, steaming was done, current weighing of control samples was done, and the direction of the fan was adjusted at 8-hour intervals (three times in 24 hours) to allow uniform air circulation during the kiln drying process. The process was repeated until the required final moisture content of 12% MC was achieved.

Table 1. Kiln Schedule for bamboo culm

Moisture Content (%)	Temperature (0C)		Relative Humidity
	Dry-bulb	Wet-bulb	
100-70	38	35	80
70-60	42	37	70
60-50	44	39	65
50-40	50	40	60
40-30	53	42	55
30-20	55	43	50
20-10	60	45	40

Air Drying

The control sample culms were weighed, placed in the stack, and weighed again after one week. The process was repeated until the stack's average final moisture content (MC) was around 15-12 %, which is the EMC for indoor and outdoor uses.

Determination of initial and final moisture content

For the determination of drying characteristics of *Y. alpinia* bamboo culms, representative samples from three height segments (bottom, middle, and top), two drying methods (kiln and air drying), and five replicates (3*2*5) totaled 30 samples were

used. Two tiny portions of 3 cm in length were cut from both ends of each sample culm to determine the initial moisture content. To control the drying process, the center regions of the test sample with a length of 100 cm were used. The initial weights of the tiny pieces (3 cm sections) and the control samples of bamboo culms were immediately measured and recorded. The control sample culms were placed in the stacks prepared for kiln and air drying. The 3 cm sections were dried in the oven at 103°C for 48 hours until they reached a consistent weight.

Moisture content (MC) of the sections was calculated as follows:

$$MC1 (\%) = \frac{Wg1 - Wod1}{Wod1} \times 100$$

$$MC2 (\%) = \frac{Wg2 - Wod2}{Wod2} \times 100$$

$$AMC = MC1 + MC2$$

Where, MC1: is the initial moisture content of the first piece, MC2: is the initial moisture content of the second piece, Wg: is green weight and Wod: is the oven dry weight of the section, AMC: is the average moisture content of each selected culm.

To determine the moisture level of the bamboo stack in the kiln at various stages and to assess the final moisture content, the oven-dry weight of control samples was computed analytically and then placed into the stack. Using the following formula, the analytical determined oven-dry weight of the control sample (Woc) was calculated:

$$Woc = \frac{Wg}{100 + AMC\%} \times 100$$

Where, Wg: is the green weight of the control sample, AMC: is the average moisture content of the culm.

Control sample culms were reweighted at eight hours interval and the current moisture content of each control sample culms was determined using the following formula:

$$\text{Current MC}\% = \frac{\text{current wt} - Woc}{Woc} \times 100$$

Determination of density and shrinkage

To represent the three height sections, five replicates with a total of 15 samples were used (bottom, middle, and top). Each sample was 30 mm long and made from fresh culms. The green weight and dimensions were measured using a sensitive balance and a digital caliper (resolution of 0.01 gm and 0.01 mm). The volume of each piece of green bamboo was determined using the water displacement method. After that, the sample sections were oven-dried at 103°C until they reached a constant weight with a difference of 0.1-0.2 g between two consecutive weights of each sample. Following that, using ISO Standard 22157-2 as a guide, basic density and shrinkages (tangential and longitudinal) were computed (ISO, 2004). The following formulas were used to compute basic density and shrinkage.

$$\text{Basic density} = \frac{\text{Oven dry weight (gm)}}{\text{Green volume (cm}^3\text{)}}$$

$$\text{Shrinkage (\%)} = \frac{Di - Df}{Di} \times 100$$

Where Di: is the initial dimension before oven-drying (mm) and Df: is the final dimension after oven-drying (mm)

Drying defects

Representatives of culms were selected randomly from each stack of the kiln and air-seasoned experiments and they were visually inspected for defects like collapse, cracking, checks, and splitting that had occurred during drying. They were expressed as the %age of all samples in each kiln and air-drying methods. Regression analysis was used to describe the functional relationship between moisture loss in the kiln and air drying, which yielded high coefficients ($R^2 > 90\%$). The drying method had a significant impact on the drying rate and time of *Y. alpinia* culms, according to the ANOVA table (table 2). The culm part has a considerable impact on the drying duration of bamboo culms, but not on their drying rate.

RESULTS AND DISCUSSION

Drying rate and drying time

The MC of *Y. alpinia* cultivated from Dire-Inchni was reduced from 96.52 to 10.75 % by kiln drying within 7.7 days (table 3). The initial MC of the air-seasoned culm was reduced from 110.81 MC to 13.90 final MC in 97 days. The bottom portion of the culms took longer to dry in the kiln and the air than the middle and top portions (table 3). This could be because the bottom section has the thickest wall culms and the highest initial MC. When compared to the middle and top culms, the bottom culm's drying rate is less noticeable. Air drying of *Y. alpinia* culms took significantly longer than kiln drying (table 3). Because the weather cannot be controlled, air drying offers limited control over the drying process. Air circulation, temperature, and relative humidity are maintained and managed during kiln drying so that it can be dried to the appropriate moisture content in a shorter amount of time during kiln drying.

The results revealed that in comparison to the middle and top culm parts, the bottom portion dries slower. This is owing to the substantial wall thickness of the bottom culm section (Vetter et al., 2015). Bamboo species with a lower specific

gravity/density and shorter internodes dry faster, confirmed the same trend to these authors with the according to Tang et al. (2013) this study also basic density of 0.69 g/cm³ (Figure 2).

Table 2. Summary of ANOVA on drying characteristics of *Yushania alpinia* culms

Mean-square and statistical significances					
Source of variation	DF	Initial MC (%)	Final MC (%)	Drying time (hour)	Drying rate (%)
Portion (P)	2	7904.11**	3.34*	1847970.54**	0.001ns
Drying method	1	967.34**	182.86**	52497088.89**	3.75**
SxP	4	0.92*	1.26ns	24664.65ns	0.0008*

Note: ns-not significant at p>0.05, *-significant at p<0.05, **-highly significant at p<0.05. Where: DF- degree of freedom

In comparison to other commercial timber species of similar density, this bamboo species take a longer time. According to Getachew Desalegn et al. (2012) (2015), kiln and air drying of *Euclyptus saligna* with 0.68 g/cm³ took 4 days and 56 days, respectively. Furthermore, for kiln and air drying, *Fagaropsis angolensis* with 0.70 g/cm³ required 2.3 days and 112 days, respectively. Due to the presence of hygroscopic elements in the parenchyma, bamboo takes longer to dry than wood of comparable density (Vetter et al., 2015).

Initial and final moisture content

The ANOVA table revealed that the initial moisture content of *Y. alpinia* is affected by culm

height and drying methods (Table 2). The interaction impact between the culm section and the initial MC of the *Y. alpinia* culm is strong (Table 3). The drying procedure had a significant impact on the bamboo culms' ultimate MC (Table 2). The initial MC dropped from the bottom to the top of the bamboo culms, according to the findings (Table 3). *Bambusa balcooa*, *Bambusa tulda*, *Bambusa salarkhanii*, and *Melocanna baccifera*, all grown in Bangladesh, showed similar variance to this study (Kamruzzaman et al., 2008; Wahab et al., 2009).

Table 3. The average initial moisture content and the average final moisture content with drying time

Sites	Drying method	Portion	Moisture content (%)		Drying rate/day (Mean)	drying time (hours)
			Initial (Mean)	Final (Mean)		
Dire-Inchni	Kiln	Bottom	109.85 (15.93)	10.63 (0.60)	0.460 (0.037)	216.00 (10.10)
		Middle	94.42 (22.82)	11.10 (0.72)	0.462 (0.021)	180.00 (19.04)
		Top	85.29 (11.14)	10.53 (0.25)	0.468 (0.038)	160.00 (7.70)
		Total	96.52 (18.90)	10.75 (0.57)	0.463 (0.023)	185.33 (26.10)
	Air	Bottom	135.08 (14.18)	14.46 (1.07)	0.041 (0.002)	3004.50 (200.67)
		Middle	107.01 (21.45)	14.24 (1.32)	0.043 (0.001)	2184.00 (237.61)
		Top	90.36 (13.98)	13.00 (0.67)	0.043 (0.002)	1799.00 (76.32)
		Total	110.81 (24.60)	13.90 (1.17)	0.042 (0.002)	2329.17 (551.08)

NB. The number in the bracket () indicates the standard deviation

Shrinkage and Basic density

The basic density and shrinkage % ages are two of the most important criteria that influence bamboo culm's use as a raw material in many

industries. Figure 2 shows the changes in basic density, the tangential, and longitudinal shrinkage % ages in wall thickness along the culm portions.

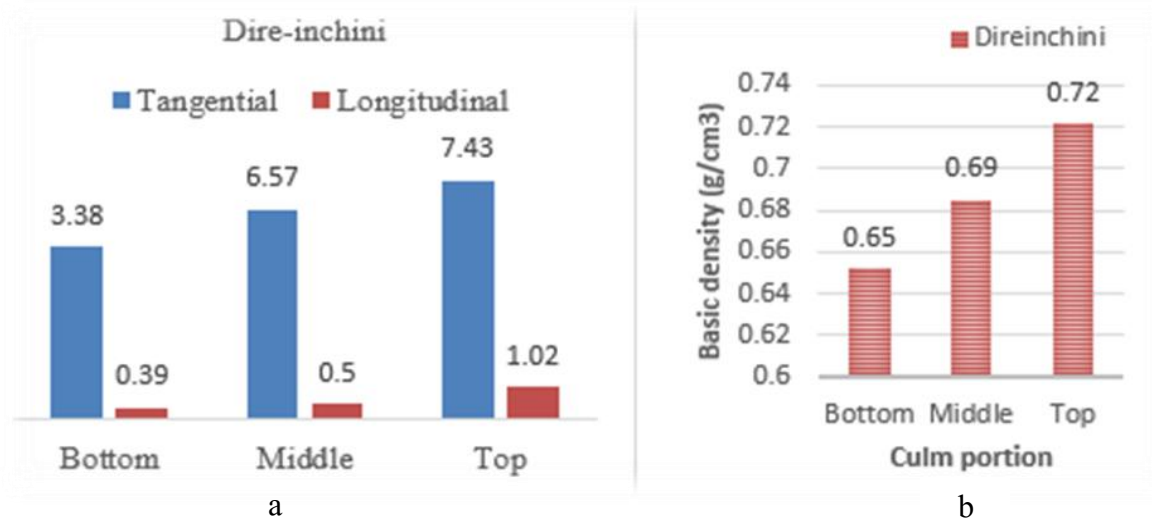


Figure 2. Shrinkage (a) and Basic density (b) along culm portions of *Y. alpinia*

The results revealed that the culm part has a substantial impact on *Y. alpinia's* basic density (Figure 2). Dire-Inchini bamboo had an average basic density of 0.69 g/cm³. The basic density of the culms of *Y. alpinia* rose with rising height levels, according to the findings (Figure 2). This could be attributed to differences in bamboo anatomical structures along the culm parts. Other researchers made similar observations, as well as seeing an increase in basic density as the culm's height levels increased (Wahab et al., 2009). According to Santhoshkumar and Bhat (2015), the increase in basic density from the base to the top height level of the bamboo culm was attributable to the proportion

of fibrous tissue and frequency of vascular bundles increasing from the base to the top sections.

Y. alpinia bamboo culm height showed a significant effect on tangential (circumference) and longitudinal shrinkages (Figure 2). According to the result with rising height levels of the culms of the *Y. alpinia*, the tangential and longitudinal shrinkage in wall thickness increased (Figure 2). *B. blumeana* and *Gigantochloa levis* showed similar variations to this investigation (Kamruzzaman et al., 2008). The presence of several vascular bundles causes the upper section to shrink more (Vetter et al., 2015). The tangential shrinkage was 5.8% on average.

Table 4. Summary of ANOVA on basic density (g/cm³) and shrinkage (%) of *Y. alpinia*

Source of variation	DF	Mean-square and statistical significance		
		Basic density	Tangential	Longitudinal
Site (S)	2	0.013*	0.298ns	0.009ns
Portion (P)	2	0.030**	17.626**	1.940**
SxP	4	0.000ns	0.014ns	0.000*

Note: ns-not significant at p>0.05, *-significant at p<0.05, **-highly significant at p<0.05. Where: DF- degree of freedom

Drying defects

Defects in the bamboo culms occurred during and after drying. Surface checks, collapse, and

cracks were some of the defects detected during the kiln and air-drying procedures.

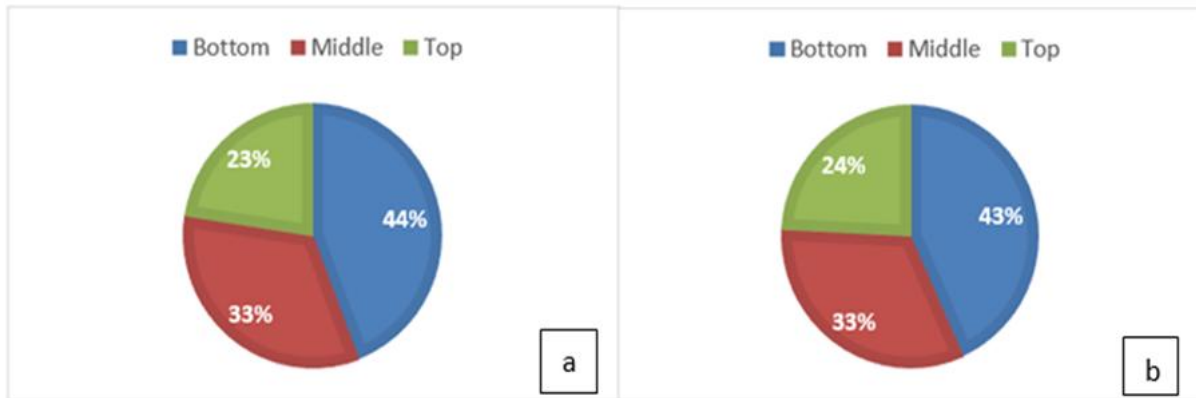


Figure 3. Kiln (a) and Air (b) seasoned defects of *Y. alpinia* culm grown at Dire-Inchni

As illustrated in figure 3 above the bottom portion of the bamboo culms has been impacted by drying defects to a greater extent than the middle and top portions.

CONCLUSION

Not just in the study locations (Dire-Inchni), but also in areas with similar bamboo species and agroecological zones, the findings will be relevant and practical. Because it is possible to construct an air-drying shade for a low cost and a minimal investment, and because some of the approaches are simple to apply with little technical expertise and practical experience, the results can be utilized.

To improve the quality, productivity, and service life of bamboo culms-based structures and products in the future, recommendations include: (i) harvesting mature bamboo culms early in the dry season to reduce starch/sugar content; and (ii) harvested culms should be properly handled and seasoned as soon as possible to the desired moisture content using air drying method. Rather than using a kiln, proper stacking and drying of culms in the air are recommended. Air drying should be done by standing bamboo culms upright in a well-ventilated yard, out of direct sunlight and away from the wind, as rapid drying can lead to various problems.

Because drying is a necessary stage in the processing of bamboo into various products, further research should be done on other prospective bamboo species, such as lowland bamboo (*Oxytenanthera abyssinica*) culms, which are abundant in Ethiopia. The country's various stakeholders must pay close attention to the diverse bamboo resource. The function of research and extension institutions in offering optimal technologies and practices in propagation,

management, product processing, promotion, and rational utilization is critical.

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