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THE EFFECTS OF SELECTED ANATOMICAL CHARACTERISTICS ON PHYSICAL PROPERTIES OF ETHIOPIAN HIGHLAND BAMBOO *ARUNDINARIA ALPINA* K. SCHUM. (POACEAE)

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ABSTRACT: A study was conducted to evaluate the effects of vascular bundles concentration and fiber sheath percentages of *Arundinaria alpina* culms on basic density and moisture content. All variables were evaluated along the culms height and among different age-groups in light of this bamboo's suitability for industrial applications. The results indicated a great heterogeneity and significant difference in vascular bundles concentration and fiber sheath percentages along culm portions. However, both variables didn't show a significant difference among culms of different age-groups. On the other hand, basic density and moisture content of *A. alpina* culms were significantly different along culm portions and among different age groups. The results indicated that *A.alpina* culms need about 3 years for complete maturation of tissues. Culms that complete their growth and rotation at the end of this period or stage may be considered satisfactory for industrial applications. In early maturing bamboo, fibers are relatively small in wall thickness. The results of statistical analyses revealed that bamboo portion has significant effects on all variables. Lower portion of culms from all age groups showed low-density, high moisture content, few vascular bundles and fiber sheath concentration. Upper portion of the culms showed high basic density, low moisture content, high vascular bundles and fiber sheath concentrations. The results also revealed that vascular bundles concentration and fiber sheath percentage were positively correlated with density and negatively correlated with moisture content.

Key words/phrases: *Arundinaria alpina,* Fiber sheath, Mean density, Moisture content, Vascular bundles

INTRODUCTION

In Africa, there are about 43 species of bamboo under 11 genera, covering an area of over 1.5 million hectares. Ethiopia has two indigenous bamboo species: the highland bamboo *Arundinaria alpina* K.Schum. (synonym: *Yushania alpina* (K.Scum) W.C.Lin (Phillips, 1995), and the monotypic genus lowland bamboo *Oxytenanthera abyssinica.* (A. Rich.) Munro. These two bamboo species are widespread in Ethiopia covering approximately one million hectares of land. The Ethiopian natural bamboo forest is about 7%

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of the world total and 67% of the African bamboo forest area (Kassahun Embaye, 2000).

In Ethiopia, the economic potential of bamboo has not yet been explored and the role of bamboo resources in the national economy is negligible. Bamboo resources have not been used for bamboo-based panel boards and pulp and paper production, or in any other large-scale bamboo industry. On the other hand, the country's natural forests are declining at an alarming rate, estimated at 150,000 to 200,000 hectares per year (EFAP, 1994). Despite the decline, the country is still highly dependent on wood as a raw material for building construction, wood–based panel industries and furniture. Recently, the use of bamboo in many Asian countries has expanded into manufacturing various commercial structural composite panels such as oriented strand board (OSB), particleboard, fibreboard and laminated bamboo composite (Lee *et al.,* 1996; Naresworo and Naoto, 2000; Jamaludin *et al.,* 2001; Lee and Liu, 2003).

The abundant resources of bamboo in Ethiopia can be used as an alternative raw material for wood–based panel boards and paper industries. However, due to lack of scientific knowledge on inherent natural properties of bamboo such as anatomical, physical and chemical properties, these resources have not been used for industrial applications to the level they should be utilized. Especially, there is lack of information on how the natural properties of bamboo affect technological properties and processing methods that influence bamboo's end uses for industrial application.

Detail investigation of anatomical characteristics and physical properties of bamboo will help to determine the suitability of bamboo species for industrial uses. As stated by Espiloy (1992), anatomical, chemical and physical properties are the major species variables that determine the suitability of bamboo species for industrial applications.

Many researchers have proved that the anatomical structure of bamboo culm is the basis for understanding the physical and mechanical properties and ultimately reflects its usability. For example, mechanical properties of the culm, important in building materials, wettability, gluing and finishing properties, are determined by its basic density and anatomical properties (Liese, 1998). The length of the fibers is also an important feature for paper industry (Latif and Liese, 2001).

Research conducted by Grosser and Liese (1971) on 53 species of Asian bamboos from 14 genera showed that the anatomy of bamboo culms showed differences in the structure of the vascular bundles between genera and between species and thus has considerable value for bamboo utilization and processing. The shape, size, arrangements and number of vascular bundles determine the gross anatomical structure of a transverse section of any culm internode. At the peripheral zone of the culm, the vascular bundles are smaller and more numerous and in the inner parts larger and fewer within the culm wall (Liese, 1985). In all Asian bamboo species investigated, the size of vascular bundles decreases steadily from the base to the top (Grosser and Liese, 1971). Within the culm wall, the total number of vascular bundles decreases from bottom towards the top, while their density increases at the same time (Liese, 1987). The culm tissue is mostly parenchyma and vascular bundles, which are composed of vessels, sieve tubes with companion cells and fiber (Grosser and Liese, 1971). The total culm comprises about 50% parenchyma, 40% fiber and 10% conducting tissues (vessels and sieve tubes) with some variation according to the species (Liese, 1987).

Arundinaria alpina is an African bamboo species with hollow culms. Its culm has an average of 8 cm diameter and 17 m height (Anonymous, 1997). About 15% or more than 100,000 ha of the bamboo forests in Ethiopia is covered by this species. The anatomical characteristic of this bamboo species has not been studied and there is a lack of information on its basic properties that may have implication on its industrial uses. In this study, the effects of *A. alpina* vascular bundles concentration and fiber sheaths percentage on basic density and moisture content were investigated, to determine the suitability of this bamboo for industrial applications.

MATERIALS AND METHODS

Sample collection

Arundinaria alpina culms used in this study were harvested from Bore, one of the major bamboo growing areas in Ethiopia. Bore is located 395 km southeast of Addis Ababa, Ethiopia, at 6^0 36’N and 38^0 45‘E. The bamboo culms were randomly selected from three age-groups (1, 2 and 3 year-old). The procedure outlined in Liese (1985) was used for determination of bamboo ages. Bamboo culms were identified based on the colour of the sheath. The young culms were usually dull in colour, having hair around the nodes with a few branches. Two-year-old culms seldom retain the bracts; the internodes appear greenish and side branches were formed at the nodes. In three-year-old, the culm often turns yellowish with dry appearance.

One, two and three-year-old selected culms were cut at 30 cm height above ground level using sharp machete and axe. After felling, all branches were removed and the length of the culms was measured from the base to tip and coded. Naturally, bamboo culms taper from the basal portion towards the tip. Based on the minimum solid culm wall thickness at the top of the bamboo stem, the merchantable length of culm was fixed at 6 m length. After coding, the stem of each culm was marked and cut at about 2 m into three equal portions, namely the bottom (B), middle (M), and top (T) portions.

Determination of vascular bundles concentration and fiber sheath percentages

The procedures outlined in Grosser and Liese (1971) and Abd. Latif (1996) were used for the determination of vascular bundles concentration and fiber sheath percentages. Nine specimens of bamboo splits of 2 cm length were selected from each age group and each culm portions (basal, middle and top) to evaluate the characteristics of vascular bundles concentration and fiber sheath percentage. The samples were boiled for four days and then cut into 25-30 µm thick section by a microtome with 15-degree knife angle.

Each section was washed with 30%, 50%, 70% and 95% alcohol within an interval of 2 minutes. The above procedure was repeated to ensure the complete removal of moisture. Then all sections were dipped in safranin solution for 24 hours. The stained sections were washed again with 70% and 95% alcohol for 2 minutes each. Prior to mounting the sections on the slides, the glass slides were warmed over a flame to remove air bubbles. The sections were mounted on glass slides with resin and covered with a cover slip. Before taking the measurements, the slides were dried for one week on electrical hot plate.

LEICA Qwin image processing and analysis system (Anonymous, 1996) was used to measure vascular bundles concentration and fiber sheath percentages. The system has a camera, which can convert the image of the specimen from the microscope into video signal and displays the image on a separate monitor. A microscopic magnification of x25 was used for the determination of vascular bundles concentration with an area of 256 µm x 1927 µm. The number of vascular bundles were counted from each field and translated into an area of one square centimeter.

A microscope magnification of x400 was used to determine the percentage of fiber sheath. The image gave an area of 302,107.4 µm^2 for each field. Five fields were observed in each section to measure the concentration of vascular bundles and fiber sheath along the culm height (bottom, middle and top portions).

Determination of moisture content

Replicates of green samples with dimension of 3 cm length were taken from the middle parts of the first internodes of each portion to investigate the moisture variations within and between culms. The method used for the determination of moisture content was based on TAPPI Standard method (Anonymous, 1994). The green weights of all samples from each age group and culm portion were recorded immediately after harvesting and the samples were then transported to the laboratory. Samples were dried at a temperature of 103 ± 2^{o} C in an oven until constant weight was obtained. After cooling for 30 minutes in desiccators, the initial moisture content of the sample was calculated as follows:

$$\text{Moisture content} = \frac{Wg - Wo}{Wo} \times 100\% \qquad \text{Equation 1}$$

Where,

W_g = the green weight of the sample (g)

W_o = the oven dry weight of the sample (g)

Determination of basic density

The basic density of bamboo was measured from fresh samples based on the most commonly used wood basic density measure, which is defined as the weight of any given volume of a substance divided by the weight of an equal volume of water. Using water displacement method, the volume of bamboo samples was obtained by immersing in water (Panshin and de Zeus, 1980). Replicated samples of 3 cm length were cut from the middle part of the second internode in each portion (second internode from basal side of each portion). The volume of each piece was determined by water displacement method where the weight of water displaced from the beaker by the submerged sample was recorded. The samples were then dried at 103 ± 2^{o}C until constant weight. The basic dry density of the samples was calculated as follows:

$$\text{Basic density} = \frac{oven\ dry\ weight\ of\ sample\ (g)}{weight\ of\ displaced\ water\ (cm^3)} \qquad \text{Equation 2}$$

Experimental design and analyses

Completely randomised design (CRD) was used in this experiment from 3 age-groups and 3 portions of *A. alpina* culms. Analysis of variance (ANOVA) was used to analyse the effects of vascular bundles concentrations and fiber sheath percentage on moisture content and basic density. Further analysis of the means were carried out by mean separation using least significant differences (LSD) method at $p<0.05$.

RESULTS AND DISCUSSION

Vascular bundles

The anatomy of *A.alpina* culm is mainly composed of collateral vascular bundles embedded in parenchyma tissue. The concentration and numbers of vascular bundles of *A.alpina* culms vary from the base towards its apex and from periphery towards the inner section. Close to the periphery, the vascular bundles were small, numerous and concentrated (Fig.1), while in the middle section of the culm, they were larger and more widely spaced.

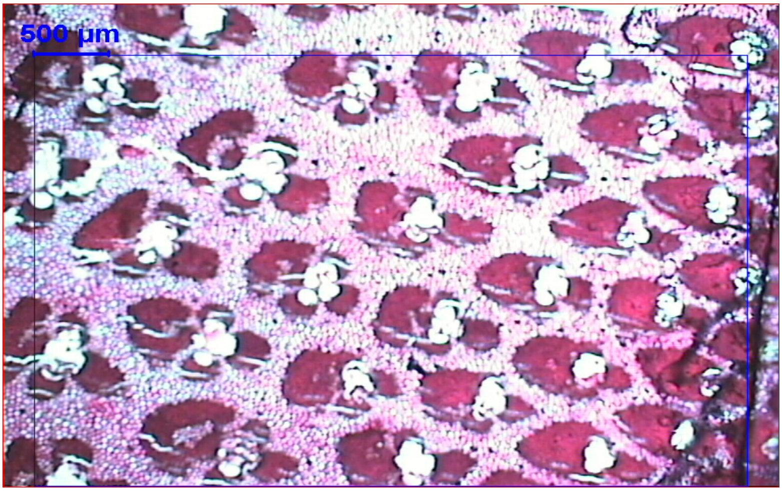

Fig.1. Basal portion of vascular bundles concentration across the culm wall (magnification x25)

Based on the culm wall pictures taken from image analyzer, the amount and concentration of *A. alpina* vascular bundles across culm walls decreased gradually from the periphery towards the inner part of the culm (Fig.1). On the contrary, the number and the size of vascular bundles were smaller near the periphery compared to the inner part of the culm.

The concentration of vascular bundles or number of vascular bundles occurring in one square centimetre along the culm height showed increasing trends from basal towards the top portion (Fig. 2). The concentration of vascular bundles at basal portion of the culm was significantly lower (165 bundles/cm^2) compared to the middle and the top portions of the culm that had 222 bundles/cm^2 and 243 bundles/cm^2, respectively. This may be due to high amount of parenchyma cells that form the ground tissue, in which fewer and larger vascular bundles are embedded. According to Taihui and Wenwei (1985), the parenchyma in vascular bundles serves as a buffer zone contributing to the elasticity of the culms, without which the culm would be inflexible and brittle.

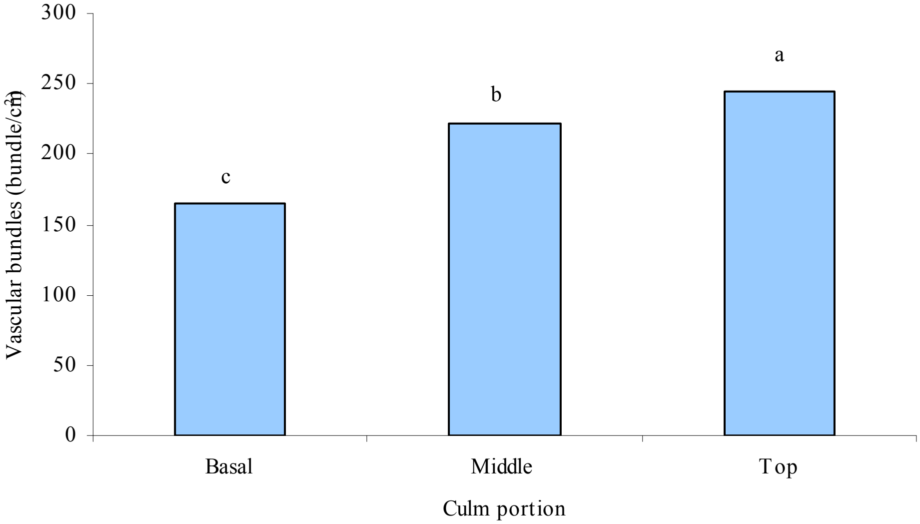

Fig. 2. The concentration of vascular bundles along *A.alpina* culms height

Note: Each value is the average of 27 specimens (9 specimens from each culm portions)

Means having the same letter were not significantly different at $P<0.05$

Parenchyma cells contribute to the stabilility and flexibility of the bamboo culm. They are vital for the storage and mobilization of the culm's energy. In comparison to vascular bundles, parenchyma cells contain more nutrients and starch that could attract beetles, insects, microbes and blue-stain fungi. The upper parts of the culm consist mainly of many smaller vascular bundles with a high portion of fibers. The number of vascular bundles per cm^2 is closely related to basic density, modulus elasticity, splitting and shrinkage. Grosser and Liese, (1971) also reported that the size of most of Asian bamboos vascular bundles decreased noticeably from the base towards the apex with a corresponding increase in their density and number. The upper part of the culm with more vascular bundles and less parenchyma has higher basic density and therefore bending and compression strength increase with height. In contrast to the above established fact, the culms from different age–groups showed insignificant differences in vascular bundles concentrations, varying from 194 bundles/cm^2 in one-year old culm to 220 bundles/cm^2 and 217 bundles/cm^2 in two-year old and three-year old, respectively.

In comparison to other bamboo species *A. alpina* showed fewer amounts of vascular bundles concentration (Table 1).

Table 1 Comparisons of *Arundinaria alpina* vascular bundles concentration with some bamboo species

Bamboo species	Vascular bundles concentration (cm^2)			
	Age (yrs)			
	1	2	3	
Bambusa blumeana [1]	255	362	356	
Gigantochloa sortenchinii[2]	222	275	291	
Bambusa vulgaris[2]	312	276	279	
Guadua angustifolia[3]	346	388	408	
Phylostachys kwangsiensis[4]	-	-	-	441 (5-year-old)
Phylostachys heteroclada [4]	-	-	-	449 (5-year-old)
Phylostachys bambusoides[4]	-	-	-	442 (5-year-old)
Arundinaria alpina	194	220	217	

Source : [1]Abd. Latif and Amin, 1992; [2]Abd. Latif, M., 1996; [3]Londono *et al*., 2002; [4]Huang, L. *et al.*., 1992.

As depicted in Table 1, the extent of *A. alpina* vascular bundle concentration is lower compared to Asian and Latin America bamboo species. From this comparison, it is possible to estimate that *A. alpina* may have high amount of parenchyma cells that form the ground tissue, in which fewer, large vascular bundles are embedded. This indicated that *A. alpina* has lower basic density than the compared bamboo species. Due to its low density, this bamboo species may process easily and is not difficult for cutting tools and consumes less adhesives for various products applications. Based on the above mentioned properties, it is possible to conclude that *A. alpina* culms are suitable for industrial application such as for furniture and bamboo-based panel boards' manufacture.

Fiber sheaths

Fibers are mechanical tissues and their principal function is essentially to impart strength to the culm. According to Liese (1998), an average culm consists of about 52% parenchyma, 40% fibers and 8% conducting tissue. The region with more density in the vascular bundles is called fiber sheath and contains cellulose micro-fibers, which are responsible for the bamboo strength. The fiber sheath in the internode surrounding the conducting elements is depicted in Fig. 3.

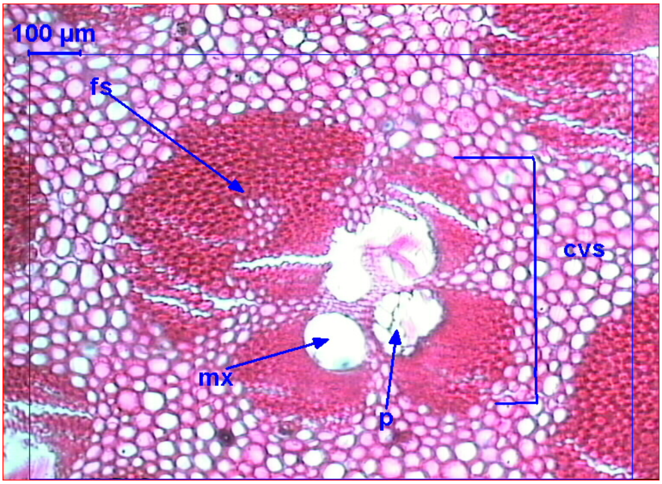

Fig. 3. Cross section of *A. alpina* culm fiber sheath from basal portion (magnification x400). Note::Cvs.;central vascular strand , Fs:fiber strand, MX: metaxylem , P:phloem

The relative area of *A. alpina* fiber sheaths in a vascular bundle varied depending on its position along the culms height and across the culm's wall. An increasing trend in fiber sheath coverage was observed from the basal towards the top portion (Fig. 4).

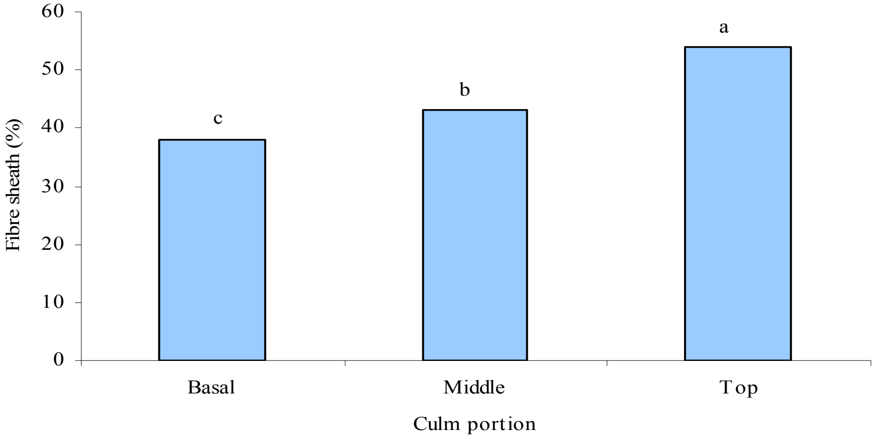

Fig. 4. The concentration of fiber sheath percentage along *A.alpina* culms height

Note: Each value is the average of 27 specimens (9 specimens from each culm portions)

Means having the same letter were not significantly different at $P<0.05$

Fiber sheath coverage at the top portion of the culm was higher (54%) than those in the basal and the middle portions (38% and 43%, respectively). Relatively greater concentration of vascular bundles in culm top portion could probably be attributed to an increase in fiber sheath percentage along the culm height. These basic differences in the fiber sheath percentage may affect a number of properties like density, strength, bending behaviour, splitting and shrinkage (Espiloy, 1985). Insignificant differences of fiber sheath percentage were observed among culms of different ages.

Arundinaria alpina vascular bundles concentration and fiber sheath percentage showed significant correlation with basic density (Table 2). Table 2 further indicates that vascular bundles concentration and fiber sheath percentage were positively correlated (r = 0.59 and r = 0.60, respectively) with density. On the contrary, vascular bundles concentration and fiber sheath percentage were negatively correlated (r = -0.69 and r = -0.71, respectively) with moisture content. This showed that both variables had significant effects on basic density and moisture content. Similar findings were reported by earlier researchers (Abd. Latif and Mohd, 1992; Abd. Latif, 1996) on *Bambusa blumeana, Gigantochloa scortechini* and *Bambusa vulgaris.*

Table 2 Correlation coefficient of vascular bundles concentration and fiber sheath with basic density and moisture content

	Basic density	moisture content
vascular bundles concentration	0.59**	-0.69**
Fiber sheath percentage	0.60**	-0.71**
Bamboo age	0.51**	-0.40*

Note: ns= not significant, *= significant at p<0.05, **= significant at p<0.01,
Each value is the average of 27 specimens.

Initial moisture content

The initial moisture content of *A. alpina* culms were significantly different among three culm portions (basal, middle, top), and three age groups (1, 2, 3 year old). The initial moisture content of *A. alpina* culms showed a decreasing trend from basal portion towards the top (Fig. 5).

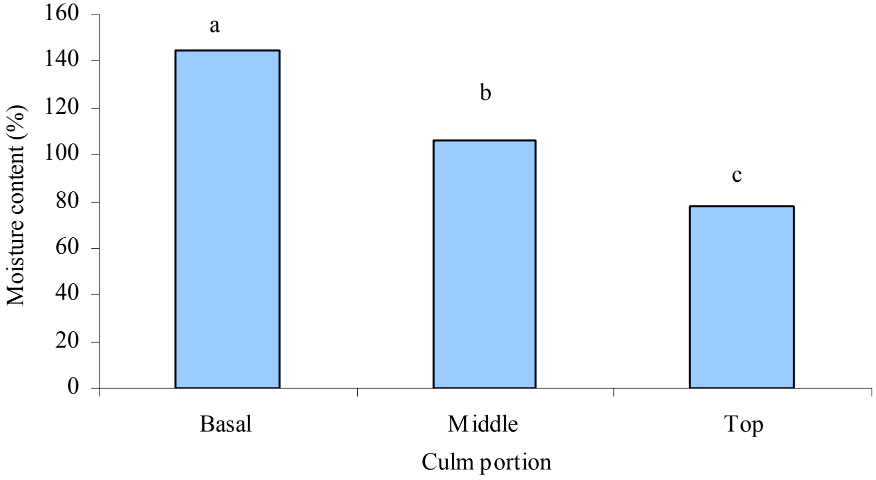

Fig. 5. Initial moisture content along *A.alpina* culm height

Note: Each value is the average of 27 specimens (9 specimens from each culm portions)

Means having the same letter were not significantly different at P<0.05

Significantly, higher initial moisture content (145%) was observed at basal portion while the top portion had lower moisture content (79%). This might be due to differences of vascular bundles and fiber sheaths concentration and concentration along the culm height. The concentration of vascular bundles and fiber sheaths increased from the basal portion towards the top. Lower concentration of these variables in culms basal portion increases the amount of parenchyma cells in this region that can hold more amount of moisture. On the other hand, the narrowing nature of the culm wall towards the top portion results in a reduction of its inner portion with less parenchyma cells, and high number of vascular bundles having small sizes. Due to this, culm top portion had high fiber content with high basic density, which resulted in low level of moisture. The results of *A. alpina* culms moisture content obtained along the culm height in this study is similar to other bamboo species reported by earlier researchers (Grosser and Liese, 1971; Liese, 1985; Abd. Latif, 1996). It was also observed that the ageing of *A. alpina* culms influenced the initial moisture content. The highest initial moisture content (132%) was observed in one-year-old culm while the lowest (94%) was in three-year-old culm ($P \leq 0.01$).

High moisture content variation among culms of different age groups might be due to differences and changes in anatomical feature of bamboo during its maturation period. In early maturing bamboo, fibers are relatively small in wall thickness. As Alvin and Murphy (1988) reported, the cell wall of both fiber and ground tissue parenchyma could go on thickening up to the third year. These increments in fiber wall might be the cause for further fiber diameter expansion that increased the density and thereby resulted in reduction of culm moisture content. The initial moisture content of *A.alpina* measured in this study was similar to other bamboo species such as *Phyllostachyas bambusoides, Bambusa vulgaris,* and *Gigantochloa scortechinii* reported by earlier researchers (Lee *et al.*, 1994; Abd. Latif, 1996; Jamaludin and Abd. Jalil, 2000; Abd. Latif and Mohd, 1992; Espiloy, 1992).

Basic density

The densities of bamboo (based on the oven-dry weight) were significantly different among the three culm portions (basal, middle, top), and the three age groups (1, 2, 3 year old) (Fig. 6 & 7). The density of bamboo increased with an increase in height of culm from basal towards top portion (Fig. 6).

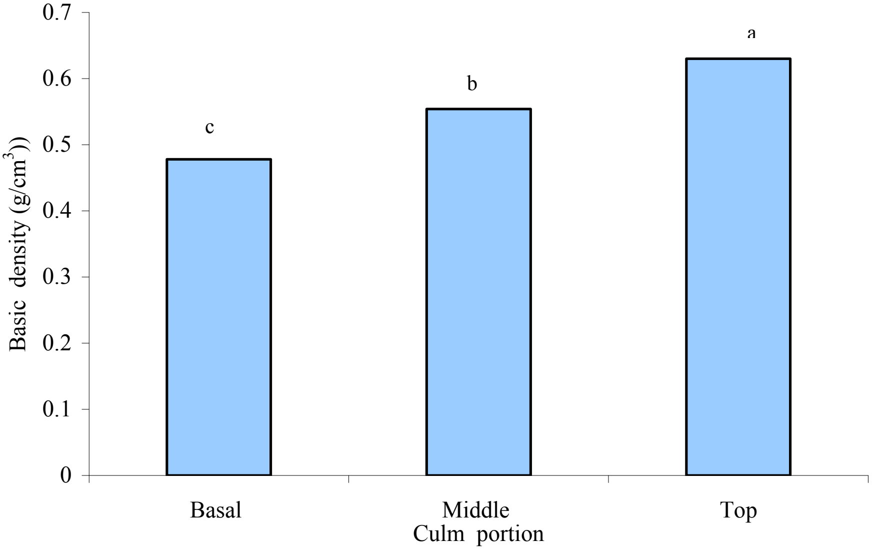

Fig. 6. Basic density of A.alpina culms along the culm height

Note: Each value is the average of 27 specimens (9 specimens from each culm portions)

Means having the same letter were not significantly different at $P<0.05$

Significantly higher density (630 kg/m^3) was found in the top portion while the basal portion had the lowest density (478 kg/m^3). The increase in concentration of vascular bundles, fiber sheaths percentage and amount of cell wall substance per unit volume from basal portion towards the top might be responsible for density increase in the top portion of the culms. Similar findings were reported by earlier researchers (Lee *et al.,* 1994; Grosser and Liese, 1971; Espiloy, 1985; Abd. Latif, 1996; Jamaludin and Abd. Jalil, 2000).

The density of bamboo increased significantly with an increase in age from one-year-old to three-year-old culms (Fig. 7).

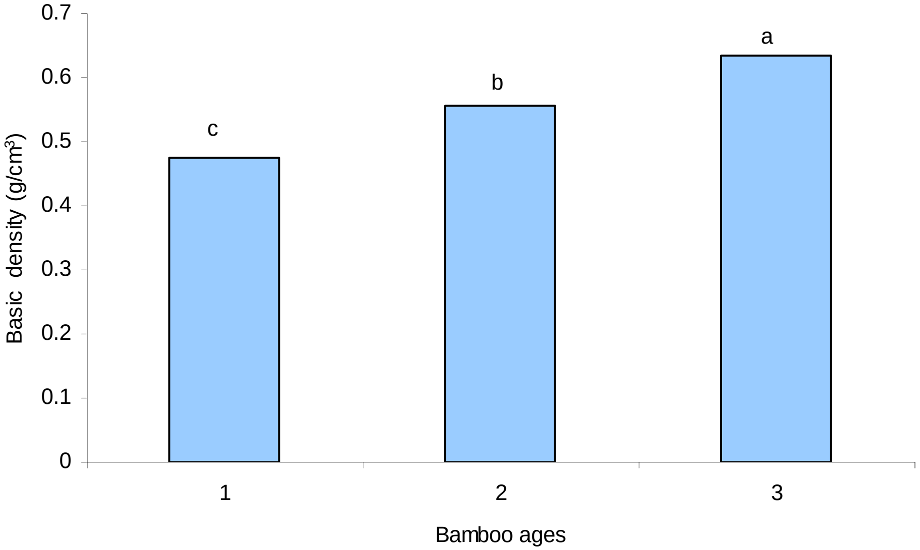

Fig. 7. Basic density of *A.alpina* among the age–groups

Note: Each value is the average of 27 specimens (9 specimens from 3 age-groups)

Means having the same letter were not significantly different at $P<0.05$

Significantly higher density (633 kg/m^3) was found in three-year-old culms while one-year-old culm had the lowest density (474 kg/m^3). The higher amount of cell wall substance formed in older age culm fiber wall thickening and expansion might be responsible for the increase in bamboo density. The presence of high amount of starch, extractives and ash content in older culms might be the other factors for increase of density. Sun and

Xie (1985) and Alvin and Murphy (1988) reported that the cell wall of both fiber and ground tissue parenchyma could go on thickening up to the third year. The wall thickening may explain the higher density of older culms. In early maturing bamboo, fibers are relatively small in wall thickness (Alvin and Murphy, 1988).

CONCLUSION

Based on the results of this study, the following conclusion may be drawn. The concentration of vascular bundles and fiber sheath percentages are influenced by the position of culm's portions. Lower portions of *A. alpina* culm with less vascular bundles concentration and more parenchyma cells contain nutrients and starch that could be a potential cause to attract beetles, insects, microbes and blue-stain fungi in comparison with the upper portion. Before using this culm portion for any application, there is a need for chemical treatment to avoid insect and fungi attacks. Due to its flexibility and low-density properties, this culm portion may be recommended for handicraft work, furniture and particleboards applications.

The upper part consists mainly of many smaller vascular bundles with a high portion of fibers, providing the superior strength. The higher ratio of fibers versus parenchyma has also significance for pulp production due to its higher yield in comparison with the base. Therefore, this portion of the culm could be suitable for paper manufacture, toothpick, match-stick and structural applications such as laminated floor boards, scaffolding and sleepers.

According to the basic density results obtained in this experiment *A. alpina* culms need about 3 years for complete maturation of tissues. Culms that complete their growth and rotation at the end of this period or stage may be considered satisfactory for industrial applications. In early maturing bamboo, fibers are relatively small in wall thickness. Wall thickening may explain the increase in density observed even in older culms. Immature culms with a low basic density can be more easily split and bend. They are preferred for handicraft work and furniture making. However, the harvest of young culms is detrimental for the vitality of the stand, since they have to produce and store the energy for the growth of the next year's generation. On the other hand, mature culms with high density could be suitable for paper manufacture, bamboo-based panel boards and structural applications.

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REFERENCES

Abd. Latif, M. (1996). Some selected properties of two Malaysian bamboo species in the relation to age, height, site and seasonal variation. PhD thesis, University Putra Malaysia. 282 pp.

Abd. Latif, M. and Amin, H.A. (1992). Effects of Anatomical characteris on the physical and mechanical properties of *Bambusa blumeana*. *J. Trop. For. Sci.* **6**(2): 159-170.

Abd. Latif, M. and Mohd, T.M. (1992). Variation in the anatomical properties of three Malaysian bamboos from natural Stands. *J. Trop. For. Sci.* **5**(1): 90-96.

Alvin, K.L. and Murphy, R.J. (1988). Variation in fiber and parenchyma wall thickness in culms of Bamboo *Sinobambusa toostik*. *IAWA Bull.n.s.* **9**:353-361

Anonymous (1994). TAPPI Testing Procedure. Technical Association of Pulp and Paper Industry, Atlanta, USA.

Anonymous (1996). Leica Qwin Image Processing and Analysis System. Leica Imaging System Ltd, Cambridge, England.

Anonymous (1997). Study on Sustainable Bamboo Management of Ethiopia. Final Report. Luso Consult.

EFAP (1994). Ethiopian Forestry Action Program. Ministry of Natural resources Conservation and Development, Addis Ababa. 71 pp.

Espiloy, Z.B. (1992). Properties affecting bamboo utilization: Bamboo and its use. In: **International Symposium and Industrial Use of Bamboo**, pp 139-142. Beijing China.

Espiloy, Z.B. (1985). Physico-mechanical properties and anatomical relationships of some Philippine bamboos. In: **Recent Research on Bamboos,** 257-264 (Rao, A.N., Dhanarajan, G., and Sastry, C.B., eds.), CAF, China and IDRC, Canada.

Grosser, D. and Liese, W. (1971). On Anatomy of Asian Bamboo with special reference to their vascular bundles. *Wood Sci. Technol.* **5**: 290-312.

Huang, L., Zhu, I.F. and Hu, A.Q. (1992). Study on Fiber length and Culm properties of Five Bamboo species in Hunan. **International Symposium and Industrial Use of Bamboo**, pp 129-143, Beijing, China.

Jamaludin, K., Abd. Jalil. A., Jalaludin, H., Zaidon, A., and Abd. Latif, M. (2001). Properties of three-layered urea-formaldehyde particleboard from Bamboo. *Journal of Tropical Forest Products* **7**(2**)**: 153-160.

Jamaludin, K. and Abd. Jalil. A. (2000). Physical attributes and chemical properties of bamboo. *Journal of Tropical Forest Products* **6** (1): 85-94.

Kassahun Embaye (2000). Royal Swedish Academy Science. The Indigenous Bamboo Forests of Ethiopia: an Overview. *Ambio.* **29**: 518 - 521

Latif, M. and Liese, W. (2001). Anatomical features of *Bambusa vulgaris* and *Gigantochloa scortechinii* from four harvesting sites in Peninsular Malaysia. *J. Trop. For. Sci.* **7** (1): 10-28

Lee, A.W.C. and Liu, Y. (2003). Selected Physical Properties of Bamboo Flooring. *Forest Prod. J.* **53** (6)**:** 23-25

Lee, A.W.C., Xuesong, B. and Perry, N.P. (1994). Selected physical and mechanical properties of giant timber bamboo grown in South Carolina. *Forest Prod. J.*

44(9)**:**40-46.

Lee, A.W.C., Xuesong, B. and Perry, N.P. (1996). Physical and mechanical properties of strand board made from moso bamboo. *Forest Prod. J.* **46** (11/12)**:** 84-88

Liese, W. (1998). The anatomy of bamboo culms. INBAR Technical Report No.18. International Network for Bamboo and Rattan, Beijing. 204 pp.

Liese, W. (1985). Bamboo-Biology Silivics, properties and utilization. Schriftenreihe der GTZ. 132 pp.

Liese, W. (1987). Anatomy and property of bamboo. In: **Research on bamboos: Proceedings of International Bamboo Workshop**, pp 196-208 (Rao, A.N., Dhananrajan, G. and Sastry, C.B. eds.), October 6-14, 1986. Hangzhou, China.

Londono, X., Camayo, G.C., Riano, N.M. and Lopez, Y. (2002). Characterization of the anatomy of *Guadua angustifolia* (Poaceae: Bambusoideae) culms. *The Journal of the American Bamboo Society* **16**(1): 18-31.

Naresworo, N. and Naoto, A. (2000). Development of structural composite products made from bamboo: Fundamental properties of bamboo Zephyr Board. *J. Wood Sci.* **46**: 68-74.

Panshin, A. J. and de Zeus (1980). **Textbook of Wood Technology**. MCGraw-Hill Book Co. Vol. I. 705 pp.

Phillips, S. (1995). **Flora of Ethiopia and Eritrea Vol.7. Poaceae (Gramineae).** The National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia and Department of Systematic Botany, Uppsala University, Uppsala, Sweden. 420pp.

Sun, C. and Xie, G. (1985). Fiber morphology and crystalline of Phyllostachys pubescens with reference to age. In: **Proceedings of the International Bamboo Workshop**, pp 247-249 (Rao, A.N., dhanarajan, G. and Sastry, C.B., eds.), October 6-14, 1985. Hangzhou ,China

Taihui, W. and Wenwei, C. (1985). A study on the anatomy of the vascular bundles of bamboos from China. In: **Proceedings of the Bamboo Workshop**, pp 230-236 (Rao, A.N., dhanarajan, G. and Sastry, C.B., eds.), October 6-14, 1985. Hangzhou, China.