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Variation along culm length and influence of growing location on physical and mechanical properties of Ethiopian lowland bamboo (*Oxytenanthera abyssinica*)

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Abstract: The main aim of this study was to evaluate the influence of growing sites on selected physical and mechanical properties of *Oxytenanthera abyssinica*. A total of 36 solid culms from three natural bamboo forest growing sites of Ethiopia namely Asosa, Dedesa and Pawe were harvested. The results indicate significant variation along the length of the culms and influence of geographical locations on basic density and initial moisture content. The basic density of this bamboo increases from bottom towards the middle portion and then decreased towards the top and the initial moisture content decreases from bottom towards the middle and then increased at the top. Basic density and initial moisture values varied with growing location due to environmental variations. All culms internodes were tested with and without nodes. The strength values of modulus of rupture (MOR) and the modulus of elasticity (MOE) with nodes showed decreasing trends from bottom towards the top portions. On the other hand, compression strength parallel to the grain increased from bottom to middle and then deceased towards the top. Internodes with nodes had inconsistent variation along the culms portion and growing locations. The presence of nodes highly decreased the compression strength and the MOR values. Inconsistent tangential and radial shrinkage were observed on all culms. Culms from Pawe showed low strength values and high shrinkage than culms from Asosa and Dedesa.

Keywords: growing location, culm portion, physical property, mechanical property

INTRODUCTION

The lowland bamboo, *Oxytenanthera abyssinica* (A. Richard) Munro is the most widely distributed bamboo in western lowlands of Ethiopia and over 850,000 ha of bamboo resource in the country is covered by this species. *O. abyssinica*, belonging to a monotypic genus, is a clumping (sympodial) type with solid culm at maturing age. It has an average culm diameter of 5 cm, and is 7 m tall. This species grows at an elevation between 1000 to 1800 m above sea level and is widely distributed in lowland areas of the country. It grows naturally in warm climates with average temperature of 35^{o} C and mean annual rainfall between 900 to 1400 mm (Anonymous, 1997).

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The average stocking density of this species in the forests is 8000 culms per hectare and the average annual increment of culm oven-dry matter is 8.5 tons per hectare (Anonymous, 1997). This bamboo is a valuable economic resource, because its culms are used for various types of construction and furniture applications due their straight, strong and solid culm characteristics. Now days due to shortage of other timber resources this bamboo has attained substantial commercial importance. However, the qualities of bamboo poles harvested from different growing sites are not the same. There is a lack of information on physical and mechanical properties of these bamboo culms. Evaluating properties and identifying the growing sites are essential to utilize this bamboo for construction purposes. As several earlier researchers have proved, growing sites have significant effects on wood and bamboo properties due to environmental variations (Abd.Latif, 1996). As Wiemann and Williamson (2002) reported, geographical locations (altitude and temperature) may have a great influence on basic density of wood. Moore *et al*. (2009) also reported that elevation has been found the most important factor affecting variation in wood properties between sites of Sitka spruce plantations growing in northern Britain.

The influence of growth conditions on bamboo has been found marked differences in technological properties that exist among individual culms from the same stand and even more among those from different localities. For example, *Gigantochloa pseudoarundinacea*, growing on the slope, showed higher specific gravity, bending and tensile strength than those growing in the valley (Soeprayitno *et al.,* 1988).

Several studies have demonstrated that the physical and mechanical properties of bamboo mostly depend on the species, site, silvicultural treatment, harvesting season, felling age, density and position of the sample with respect to the height (Espiloy, 1992; Lee *et al*., 1994; Abd. Latif, 1996; Liese and Weiner, 1996).

Based on these concepts, the objective of this study was to investigate the influences of growing locations and culm portions on selected physical and mechanical properties of *O.abyssinica*.

MATERIAL AND METHODS

Sample collection

O. abyssinica culms used in this study were harvested from three major lowland bamboo growing sites (Asosa, Dedesa and Pawe) in Ethiopia. Geographical location, annual temperature annual rainfall and latitude of these areas are shown in Table1.

Four year-old bamboo stands were selected from each growing site for this study. The age of culms was estimated based on visual inspection of color and sheaths in culms

Table 1. Geographical location and climate of three major *O. abyssinica* growing areas

Site	Location		Temperature	Elevation	Precipitation
	Latitude	longitude	(°C)	(m)	(mm)
Asosa	10.03°'N	34° 59' E	14-27	1590	950-1208
Dedesa	9.10°'N	35° 47'E	13-24	1845	1400-1703
Pawe	11.09°'N	36.03° E	16-32	1050	1200-1585

Source: Anonymous, 1988

by experienced field personnel familiar with this bamboo species. Twelve representative culms from each growing location and a total of 36 culms were harvested in January 2009. Based on the minimum solid culm wall thickness at the top of bamboo stem, the merchantable length of the culm was fixed at 7.5 m. Each culm was cut into 2.5 m length equal portions, *viz.* bottom, middle, and top portions. Replicates of green samples with the dimension of 3 cm length were taken from the middle parts of the first internodes of each portion to investigate basic density and moisture variation along the culm height and among growing sites. Samples from all portions were kiln-dried to 12% moisture content before testing.

Sample preparation for mechanical properties

From each section, two 30 cm long pieces, one with the node at the midsection and the other without node were cut for testing mechanical properties. All pieces were split into halves and minimum planing was done on inner and outer perimeters to make the samples rectangular. Eighteen samples from each culm portions and a total of 162 samples each from 3 growing sites were prepared for testing the modulus of rupture (MOR) and modulus of elasticity (MOE) and compression parallel to grain (MCS). Samples with dimension 25 x 6 x 300 mm were used for bending test and 13 x 6 x 50 mm for compression parallel to the grain.

Bending and compression tests were conducted following the ISO 3133 (1975) and ISO 3387 (1976) standard procedures. After the bending test was conducted, a 10 mm wide by 50 mm long specimen was cut from each portion for measuring radial and tangential shrinkages according to ISO 4469 (1981) standard. Since longitudinal shrinkage was considered negligible, the results were not reported in this paper.

Experimental design and analyses

Completely randomized design (CRD) with factorial experiment was used to conduct this experiment. Analysis of variance (ANOVA) was used to evaluate the influence of bamboo growing locations and culm height on physical and mechanical properties of *O. abyssinica.* Further analysis of the means was carried out by Duncan Multiple Range Test.

RESULT AND DISCUSSION

Basic density and moisture content

This study has shown that there is considerable variation in density and initial moisture content of *O. abyssinica* grown in three sites and at three culm heights. The analysis of variance (Table 2) indicates that there are highly significant ($p \leq 0.01$) differences in basic density and moisture content among the three sites where the bamboo grows.

Table 2. Summary of analyses of variance on physical properties of *O. abyssinica*

Source of variation	DF	Mean square and statistical significances	
		Density	Moisture content
Site	2	0.138**	8414.81**
Height	2	0.014**	268.57**
site x height	4	0.004**	187.32**

Note: ns- not significant at p=0.01, *Significant at $p \leq 0.05$, **highly Significant at $p \leq 0.01$

The interaction effects of culm length with bamboo growing sites had highly significant ($p \leq 0.01$) effects (Table 2) on basic density and moisture content.

As indicated in Table 3 the highest mean density (700.91 kg/m^3) was observed at the middle portion of culms grown in Pawe, while the lowest (516.75 kg/m^3) was observed at the top portion of culms grown in Asosa. In general, the basic density of this bamboo showed increasing trend from bottom towards the middle portion and then decreased at the top. Regardless of culm height, the average density of *O. abyssinica* for 3 growing sites was in the range of 532.27 to 657.58 kg/m^3. On the other hand, initial

Table 3. The mean basic density and moisture content from 3 culm heights and 3 growing sites.

Measured variables	Sites	Culm positions			Mean
		bottom	middle	top	
Density (kg/m^3)	Asosa	536.58 [0.01]	552.50 [0.01]	516.75 [0.01]	535.28
	Dedesa	609.33 [0.01]	619.33 [0.01]	614.58 [0.00]	614.41
	Pawe	648.00 [0.02]	700.91 [0.09]	623.83 [0.01]	657.58
Moisture content (%)	Asosa	90.85 [3.08]	86.67 [2.93]	98.38 [5.17]	91.97
	Dedesa	65.66 [1.52]	64.61 [1.80]	65.20 [1.77]	65.16
	Pawe	70.52 [6.91]	62.24 [10.33]	64.71 [4.79]	65.82

Note: Numbers in parentheses are standard deviations moisture content showed decreasing trend from bottom towards the middle portion and then increased at the top. Significantly higher moisture content (98.38 %) was recorded at the top portion of culms grown in Asosa where as moisture content was low (62.24 %) at the middle portion of culms grown in Pawe. As indicated in Table 3 culms grown in Pawe had high basic density (657.58 kg/m^3) than culms grown in Asosa and Dedesa (535.28 kg/m^3 and 614.41kg/m^3, respectively).

High annual temperature (32^{o}C), precipitation (1585 mm) and low altitude (1050 m) may be responsible for high amount of cell wall substance per unit volume for bamboo growing in Pawe. From the results obtained (Table 3), it is apparent that there is a wide range of density and moisture variation among bamboo growing sites. Wiemann and Williamson (2002) and Moore *et al*. (2009) reported that geographical locations (altitude and temperature) may have a great influence on basic density of wood. Variation in basic density and initial moisture contents of culms among 3 major bamboo growing areas has an important implication for the various end use applications of this bamboo species.

Mechanical properties and shrinkage

In this study, static bending, compression parallel to grain, radial and tangential shrinkage tests were conducted from 3 culms heights and 3 growing sites. Evaluating mechanical properties of bamboo helps to analyze culm behavior when subjected to loads. Static bending test is the key parameter for engineers when designing structures. Therefore, information on bamboo strength properties obtained from this study may be used to identify the best growing site where high quality culms can be harvested. The analysis of variance shown in Table 4 indicates that bamboo growing site and culm height as well as their interaction effect had high significant effects on MOR, MOE, MCS ($p \leq 0.01$) and tangential shrinkage except the interaction effect of MOE which had significant effect at ($p \leq 0.05$). However, growing site and culm height did not show significant effect on radial shrinkage ($p=0.01$) but their interaction had high significant ($p \leq 0.01$) effects.

Table 4. Summary of ANOVA on mechanical properties and shrinkages

Source of variation	DF	MOR	MOE	MCS	Radial shrinkage	Tangential shrinkage
Site	2	14671.79**	1.39E-7**	2272.08**	6.17ns	64.03**
Height	2	10602.90**	2.31E-7**	5668.72**	4.37ns	20.72**
Site x height	4	2753.82**	1.58E-7*	745.86**	14.85**	17.93**

Note: ns- not significant, at p=0.01, *Significant at p≤0.05, ** Significant at p≤0.01

The influence of culm height on mechanical properties and shrinkage

The mechanical properties and shrinkage results of 3 culm site with nodes and without nodes obtained from 3 bamboo growing sites are listed in Table 5.

Table 5. Average strength and shrinkage values of culms with node and without node from 3 height levels.

Measured variables	Locations	Culms without node			Culms with node		
		Bottom	middle	top	bottom	middle	top
Modulus of rupture (N/mm^2)	Asosa	172.86	172.66	157.50	151.27	164.11	142.33
		[22.07]	[23.71]	[15.93]	[35.45]	[19.98]	[26.05]
	Dedesa	190.16	172.66	165.66	113.94	126.77	126.38
		[18.99]	[26.91]	[19.03]	[38.03]	[20.85]	[13.99]
	Pawe	144.08	155.55	113.94	120.94	132.22	124.22
		[21.20]	[17.03]	[53.77]	[26.87]	[122.18]	[18.23]
Modulus of elasticity (N/mm^2)	Asosa	14534.95	13550.73	11664.34	12953.63	14150.77	10668.96
		[2326.13]	[2025.41]	[1991.82]	[2968.12]	[1977.68]	[2050.81]
	Dedesa	12206.87	11553.04	10995.91	11886.67	13280.09	12103.79
		[30.829]	[1295.91]	[1840.62]	[3993.06]	[2302.94]	[3849.69]
	Pawe	11626.72	11257.22	10911.62	9313.58	9842.37	8140.37
		[4548.52]	[1917.15]	[2174.93]	[1640.07]	[2061.50]	[2680.34]
Compression parallel to the grain (N/mm^2)	Asosa	73. 10	84.06	56.16	43.41	49.11	53.29
		[16.74]	[13.06]	[11.66]	[6.88]	[13.51]	[15.58]
	Dedesa	78.23	79.16	76.35	52.39	62.16	48.52
		[11.57]	[8.35]	[6.12]	[10.80]	[10.12]	[6.51]
	Pawe	65.32	73.13	51.76	52.15	35.51	51.71
		[18.68]	[11.34]	[22.21]	[7.43]	[6.86]	[7.65]
Radial shrinkage (%)	Asosa	9.66	9.06	8.60	10.39	10.30	8.44
		[1.79]	[1.87]	[2.79]	[2.72]	[4.97]	[1.88]
	Dedesa	6.64	6.95	9.61	6.35	7.58	8.05
		[1.58]	[1.69]	[3.37]	[2.49]	[2.85]	[4.67]
	Pawe	6.41	8.76	7.04	8.79	10.97	7.85
		[2.79]	[3.03]	[2.82]	[2.64]	[2.58]	[2.07]
Tangential shrinkage (%)	Asosa	8.20	7.04	6.54	7.98	7.49	5.79
		[1.75]	[1.63]	[1.48]	[1.98]	[1.72]	[2.52]
	Dedesa	5.93	6.21	6.69	6.37	7.47	6.87
		[0.99]	[1.91]	[1.70]	[0.64]	[2.02]	[3.96]
	Pawe	6.14	5.75	7.34	6.67	9.38	6.38
		[1.81]	[4.29]	[2.07]	[1.85]	[2.90]	[1.61]

Note: Numbers in parentheses are standard deviations

As depicted in Table 5, culm position had significant effect on modulus of rupture. Culms obtained from Asosa and Dedesa had showed a decreasing trend of MOR from bottom towards top portions. The results of MOR for culms obtained from Pawe increased from bottom to middle portion and decreased at top. Similarly, the MOR values of culm with nodes from all portions increased from bottom to middle and decreased at top. In addition, the presence of nodes significantly decreased the MOR values, especially in the bottom 12-60% culm portions.

Significantly higher MOR (190 MPa) was found in the bottom portion of culms obtained from Dedesa while the lowest MOR (114 MPa) was observed in the top portion of culms from Pawe. Regardless of growing sites, the MOR values of culms with nodes falls within the range of 124 MPa to 164 MPa.

Culm without nodes showed decreasing trend of MOE from bottom towards the top portion. On the other hand, the results of MOE for culms with nodes increased from bottom to middle portion and deceased again at top. The presence of nodes had non-significant effect on the MOE values. Regardless of growing site, culm heights and the presence of nodes the MOE values falls within the range of 8140 to 14535 MPa. Large diameter and long fibers might be responsible for high values of MOR and MOE in bottom and middle portions of *O. abyssinica*. Bamboo has long fibers in the bottom portion of the culms (Liese, 1985; Liese and Weiner, 1996; Seyoum, 2009).

Compression strength parallel to the grain (MCS) of culms without nodes from all the growing locations increased from bottom to middle and then deceased towards the top portion (Table 5).On the other hand, culms with nodes showed inconsistent MCS values along the height. Generally it is observed that the presence of nodes tend to reduce the compression strength of the culms. Compressive strength reduced from 21% to 51% in bottom and middle portions. For culms without node, the highest values of MCS were observed in the middle portion. Regardless of culm position and the presence of nodes, compressive strength obtained in this experiment falls within the ranges of 36 to 84 MPa. Long fiber length and higher fiber wall thickness might be responsible for high values of compressive strength in the middle and bottom portions of the culms (Espiloy, 1987).

As indicated in Table 5, the results of radial and tangential shrinkages showed inconsistent variation along the culm portions. High radial shrinkage values were observed than tangential shrinkages in this study. The distributions and sizes of vascular bundles in the outer part of bamboo culm wall than inner parts may responsible for higher radial shrinkages than tangential. According to Liese (1985) the inner part of bamboo culm wall has more thin walled parenchyma and conducting cells which are responsible for high shrinkages.

Regardless of culms position and the presence or absence of nodes, the radial and tangential shrinkage obtained in this study falls within the ranges of 6.41 - 11% 5.75 - 9.38%, respectively.

The effect of bamboo growing sites on mechanical properties and shrinkage

Bamboo growing sites had significant impacts on mechanical properties and shrinkage. As indicated in Table 6 culms obtained from Dedesa had high MOR values (176 MPa) than culms obtained from Asosa (168 MPa) and Pawe (138 MPa).

The presence of nodes reduced the value of MOR 6%, 9% and 30% respectively for culms from Asosa Pawe and Dedesa. On the other hand, culms from Asosa exhibited high modulus of elasticity (13250 MPa) than culms from Dedesa (11601MPa) and Pawe (9099 MPa). The presence of nodes had insignificant variation of MOE for

Table 6. Average mechanical and shrinkage values of *O. abyssinica* culms from three bamboo growing sites

Measured variables	Locations	Culms without node	Culms with node
Modulus of rupture (N/mm^2)	Asosa	167.67	157.57
	Dedesa	176.16	122.63
	Pawe	137.86	125.79
Modulus of elasticity (N/mm^2)	Asosa	13250.01	12591.12
	Dedesa	11601.39	12423.52
	Pawe	9098.77	11265.19
Compression parallel to the grain (N/mm^2)	Asosa	71.11	48.60
	Dedesa	77.91	54.35
	Pawe	63.40	46.45
Radial shrinkage (%)	Asosa	9.11	9.71
	Dedesa	7.73	7.32
	Pawe	7.40	9.20
Tangential shrinkage (%)	Asosa	7.26	7.08
	Dedesa	6.28	6.90
	Pawe	6.41	7.47

culms from Asosa and Dedesa. However, for culms form Pawe the MOE value was reduced to 24%. The lower MOR and MOE strength properties were observed on culms from Pawe compared to the other two sites. Similarly culms from Pawe had lower compressive strength, MCS (63 MPa) than culms from and Dedesa (78 MPa) and Asosa (71 MPa). On the other hand, the presence of nodes reduced the MCS from 27 to 32%.

It was reported in several studies that the geographical locations where the bamboo grow may have a great influence on its properties. As Wiemann and Williamson (2002), Moore, *et al.,* (2009) and Harris (1996) reported, altitude, annual rainfall, temperature and soil type are the major factors for variability in wood properties. The lower altitude (1090 m) and high temperature (16-32°C) of Pawe may have impacts to increase the density of culms in Pawe. These conditions might have negative influence for the culms fiber length increment in this site. The other factor for strength variation in each growing location might be the soil variability. According to FAO (1984) the three bamboo growing sites have similar soil types such as vertisols, chronic and orthic luvisols, acrisols, and calcaric and eutric fluvisols. Deep clayish red soil (Dytstric nitosols) predominates in most of the south zone of the Blue Nile River.

The presence of nodes increased the radial shrinkages of culms from Asosa (6%) and Pawe (20%) and also tangential shrinkage increased from Dedesa (9%) and Pawe (14%). In general, the radial shrinkage showed 6 to 27% higher values than the tangential shrinkages for all the sites. On the other hand, culm with nodes from Pawe had high tangential shrinkage (7.47%) than the other two sites. This may happen due to high amount of lignin and less cellulose in the nodal section of culms grown in Pawe.

Selected mechanical properties and shrinkage values of *O. abyssinica* were compared with some bamboo species in Table 7 to ranks the results obtained in this experiment with other findings (Gnanaharan, 1991; Gnanaharan, 1993).

Table 7. Comparisons of mechanical properties and shrinkages of *O.abyssinica* with some bamboo species.

No	Species	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)	MCS (N/mm^2)	Tangential shrinkages (%)	Radial shrinkages (%)
1	*Bambusa tulda*	640	120	12618	64	-	-
2	*Dendrocalamus giganteus*	730	51	9584	49	-	-
3	*Bambusa vulgaris*	790	76	11720	47	22.45	-
4	*Melocanna baccifera*	817	56	14617	49	-	-
5	*Bambusa nutan*	693	85	12315	70		
6	*Phyllostachys bambusoides*	-	103	10687	42	9.25	18.25
7	*Bambusa burmanica*	780	103	11655	52	-	-
8	*Oxytenanthera abyssinica* (culm with nodes from Asosa)	535	158	12591	49	7.08	9.71

Sources: Gnanaharan, 1991; Gnanaharan, 1993; Mansur, 2000.

The MOR of *O. abyssinica* was higher by 68%, 52% and 35% respectively than *Dendrocalamus giganteus, Bambusa vulgaris and Phyllostachys bambusoides*. Similarly the MOE values were also higher by 24%, 11% and 15% respectively. On the other hand, *O. abyssinica* showed equal compression value with *D. giganteus,* higher by 4% and 14% than *B.vulgaris* and *P. bambusoides* respectively. *O. abyssinica* showed less tangential and radial shrinkages than the above mentioned bamboo species. Due to the influences of environmental effects and suitability of growing sites *O. abyssinica* grown in Ethiopia showed better strength and shrinkage values than some bamboo species grown in other countries.

CONCLUSION

Identifying variations of bamboo properties among growing locations helps to manipulate the desirable characteristics of bamboo utilization. The results of strength values in this experiment revealed that culms obtained from Asosa and Dedesa locations has high MOR, MOE and MCS values than culms from Pawe. Culm from Dedesa has lower shrinkage value than other two locations. The presences of nodes decreased the value of compressive strength by 27-32% due to less amounts of cellulose content in the nodal section. Based on these results it is recommended that removing nodes at the end of culms when culms used as a column or attached with beam can give high compressive strength. In general, the presence of nodes reduced MOR and shrinkage values. However, nodes have insignificant impact on MOE values of culms from Asosa and Dedesa.

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