An Investigation on the Physical, Chemical, and Biometrical Properties of Planted Bamboo

Ramin Vaysi [a] and Milad Tajik [b,*]

This research investigates the biometrical, physical, and chemical properties of bamboo planted in the Noshahr forest, located in Northern Iran. To prepare the samples, six culms of *Phyllostachys nigra* bamboo were randomly obtained from the planted bamboo forest. Three disc samples were then taken from each of the culms, with an interval of L/3. The bamboo culm flour was used to determine cellulose, lignin, ash, and acetone soluble extractive contents. Inorganic compounds and acetone soluble extractives were analyzed using Atomic Absorption Spectroscopy (AAS) and Gas Chromatography–Mass Spectroscopy (GC-MS) methods, respectively. The results showed that the amounts of oven dried density, basic density, shrinkage, and swelling increased toward the middle of the disc in the longitudinal direction, and then decreased. Furthermore, the middle and lower parts of the disc samples were found to have the highest and the lowest values of the mentioned properties, respectively. The biometrical measurements indicated that fiber length and diameter increased in the longitudinal direction, while porosity decreased towards the crown. In addition, the most variations in the fiber parameters were observed in the longitudinal direction. According to the results of the AAS and GC-MS analyses, the studied bamboo species consisted of 7 inorganic ions and around 114 various organic compounds.

Keywords: Bamboo; Physical properties; Fiber biometry; Longitudinal direction

*Contact information: a: Department of Wood and Paper Science and Technology, Chalous Branch, Islamic Azad University, Chalous, Iran; b: Young Researchers and Elite Club, Chalous Branch, Islamic Azad University, Chalous, Iran and M.sc, Department of Cellulose Technology, New Technology Engraining Faculty, Shahid Beheshti University; *Corresponding author: milad.tajik67@ yahoo.com*

INTRODUCTION

Bamboo is one of the most important members of perennial non-wood plants. This special natural resource belongs to the family of treelike grasses i.e. *Poaceae* and subfamily of *Bambusoideae*. Bamboos contain over 1400 different species which can be found in Asia, Australia, North and South America and Sub-Saharan Africa. With maximum growth rate of as much as two feet in a day, bamboo is referred to be as the fastest growing plant in the world. They can flourish on different altitudes and under various climates ranging from tropical and subtropical to mild temperate regions but ecologically it prefers tropical climate.

Botanically bamboos are not categorized among true woody plants. In fact, the vascular cambium which is responsible for wood formation and diameter growth in angiosperm and gymnosperm trees never develops in these non-wood species. This means bamboos are not able to produce woody tissues similar to dicots and conifers. The main stem of bamboo, known as culm, is typically a hard hollow cylindrical structure and anatomically contains parenchyma, xylem, fiber tissue, and phloem. The mature culms of bamboo are important raw materials for the wood and paper industries (Latif 1995; Vaysi 2008).

Fig.1. Bamboo in Iran (*Phyllostachys nigra*).

In such a tough situation from raw materials supplying point of view, the wood and paper industries should consider other lignocellulosic resources (biomasses) as alternatives to alleviate the need for woody raw materials (Latibari 2012; Kumar *et al.* 2013). Agricultural lands in Iran cover more than 12.7 million hectares, from which over 2.6 million hectares have cultivated fruit trees. Every year about 35 million fruit tree seedlings are produced and dispersed across different regions of the country (Kiaei *et al.* 2014; Tajik *et al.* 2015b). The lignocellulosic materials typically used in Iranian pulp and paper mills are hornbeam, beech, aspen, iron wood, alder, bagasse, and waste paper. The fiber biometry of these lignocellulosic materials is not well suited. Annually, about 50,000 tonnes of bamboo are produced from natural and planted forests in Northern Iran. The annual consumption of paper and paperboard in Iran amounts to 1,120,000 tonnes, while the total production capacity of domestic paper industry reaches 600,000 tonnes per year.

There have only been a few studies conducted analyzing bamboo properties (Kollman 1968; Lindstom 1997; Barzan 2008). Latif *et al.* (1995) reported that there were not significant differences between age and bamboo culm longitudinally. Razake *et al.* (1995) reported that radial shrinkage and swelling in Culcutta were not statistically different from tangential shrinkage and swelling. Vaysi (2008) studied the fiber biometry of the bamboo Kraft, finding that it is possible to partially replace imported long-fiber pulp with bamboo Kraft pulp.

EXPERIMENTAL

In this study, six culms of *Phyllostachys nigra* bamboo were randomly selected from the Noshahr bamboo forest located in Northern Iran. From each culm, three discs were separated, with an interval of L/3 of the culm length (Fig. 2). In the first stage, samples were prepared to measure the physical properties and fiber biometrical parameters using ASTM Standard test methods and the Franklin (1946) procedure, respectively. The physical properties, including the oven dried density, basic density, shrinkage, swelling, porosity, and the equilibrium moisture content (EMC), were intended to be measured. The specific gravity measurements were conducted in accordance with ASTM D 2395-93. EMC is an important in-service factor as wood and other lignocellulosic materials, such as bamboo, are subject to both short-term and long-term moisture variations due to the changes in the surrounding temperature and relative humidity. Similar to moisture conditioning of wood and wood-based materials, conditioning bamboo to a specific moisture content could be performed according to ASTM D 4933-91. Bamboo is assumed to shrink and swell similar to wood, and therefore could be investigated using the standard method for testing small clear specimens of timber, ASTM D 143-94.

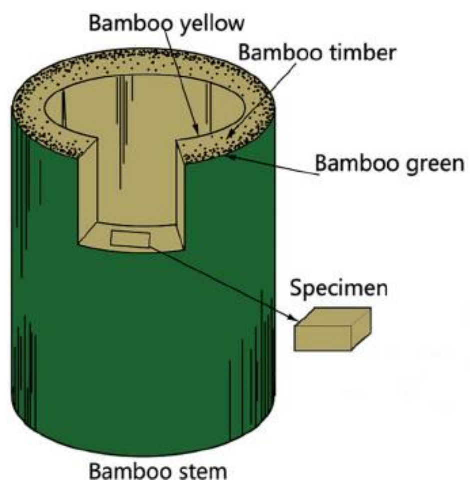


Fig. 2. Schematic figure describing the sampling

The important equations used in this study are as follows,

$$Do = \frac{Wo}{Vo} \qquad Db = \frac{Wo}{Vs} \qquad Sw = \frac{Vs - Vo}{Vo} * 100 \qquad Sh = \frac{Vs - Vo}{Vs} * 100$$

where *Do*, *Db*, *Wo*, *Vo*, *Sw*, *Vs*, and *Sh* are denoted as oven dried density, basic density, dry weight, dry volume, swelling, saturated volume, and shrinkage, respectively. The biometrical parameters of *Phyllostachys nigra* bamboo species (*i.e.* fiber length, fiber width, lumen diameter, and fiber wall thickness) were measured, and the runkel and flexibility coefficients were also calculated. Then, the data obtained in the longitudinal direction were statistically analyzed. The important equations for calculating the aforementioned coefficients are as follows,

$$R = 100 * 2P/C \qquad F = 100 * C/d$$

where *R*, *F*, *P*, *C*, and *d* are denoted as the runkel ratio, flexibility ratio, fiber wall thickness, lumen diameter, and fiber width, respectively.

Lignin, ash, and acetone soluble extractives were determined using bamboo culm flour, and according to TAPPI T 264 om-88, T 222 om-88, T 211 om-88, and T 204 om-88, respectively. The cellulose content of bamboo was determined according to the nitric acid method (Rowell and Young 1997; TAPPI 1999; Fadavi *et al.* 2012). All measurements were conducted in three replicates. The inorganic compounds were extracted from the bamboo flour ash using 63% nitric acid method for 1 h. Then, organic and inorganic compounds of bamboo were identified using an Atomic Absorption Spectrophotometer, model SpectrAA 200, Varian, UK. The acetone soluble extractives were obtained from bamboo flour and added to the BSTFA[1] reagent. The samples were kept in a Ben Marry Bath at 70 °C for 1 h, and analyzed using a GC-MS[2] model HP 6890 Gas Chromatograph, equipped with a split/split less injector and a 5973 Mass Selective Detector (MSD). The column oven was programmed as follows: Chromatography was performed on a HP-5MS capillary column (SGE, 30 m, 0.25 mm). In regards to the carrier gas, helium with a flow of 1 mL/min and a temperature program between 60 and 260 °C was utilized, with temperature increasing at a rate of 6 °C/min. In order to identify the organic compounds, GC diagrams were used, indicating the abundance and retention time of each compound, as well as calculations of retention indices and Adams table (Adams 1997; Adams 2007; Vaysi 2013; Tajik *et al.* 2015a).

RESULTS AND DISCUSSION

In this research, the physical, chemical and fiber biometrical variations were investigated in the bamboo culms' longitudinal direction. The results showed that the amounts of oven dried density, basic density, shrinkage, and swelling increased toward the middle of the disc in the longitudinal direction, and then decreased. The higher mentioned properties were observed in the middle of the disc, decreasing in the lower parts of the bamboo culm. The fiber length, fiber diameter, and EMC increased in the longitudinal direction, while the amount of porosity decreased towards the crown. The results showed that there were significant differences between the biometrical properties and most of the physical properties, but there were no significant differences between the EMC and oven dried density. These variations occurred in the longitudinal direction (Figs. 3 to 5). The average amounts of 33.8, 8.94, 10.3, 0.632 g/cm^3, 0.594 g/cm^3, 21.28%, 57.83%, 15.28%, 1675 micron, and 353.4 were obtained for cellulose, lignin and ash contents, oven dried density, basic density, shrinkage, porosity, EMC, fiber length, and the Runkel coefficient, respectively (Tables 1 to 3).

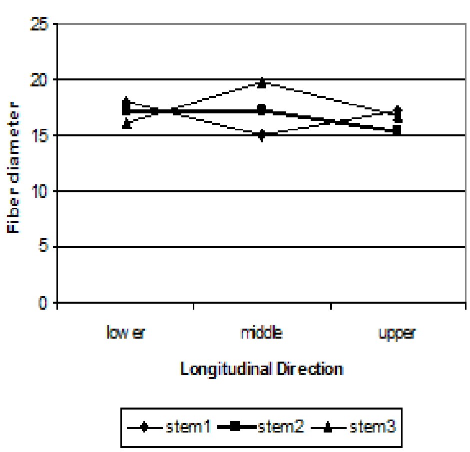
[1] Bis (trimethylsilyl) trifluoroacetamide
[2] Gas chromatography mass spectrophotometer

Table 1. Comparison of Average Biometrical Properties in Bamboo with Softwoods and Hardwoods

Properties	Fiber Length (Micron)	Fiber width (Micron)	Lumen Diameter (Micron)	Slenderness Ratio	Flexibility Ratio (%)	Runkel Ratio (%)
Bamboo (this study)	1675	16.97	6.76	98.7	40.07	150.44
Bamboo Atchison (1996)	2700	14	5.32	192	38	163.15
Softwoods	2500-4000	20-45	10-14	-	-	-
Hardwoods	800-1500	20-40	8-12	-	-	-

Table 2. Comparison of Average Biometrical Properties in Bamboo (*Phyllostachys nigra*) with Softwoods and Hardwoods

Properties	Dry Density (g/cm3)	Swelling (%)	Porosity (%)	Basic Density (g/cm3)	EMC (%)	Shrinkage (%)
Bamboo	0.632	27.9	57.8	0.594	15.28	21.28
Softwoods (Enayati 2010)	0.3-0.5	12-14	-	0.2-0.4	7-17	10-12
Hardwoods (Enayati 2010)	0.4-1.23	7-20	60-80	0.3-0.9	7-17	6-13



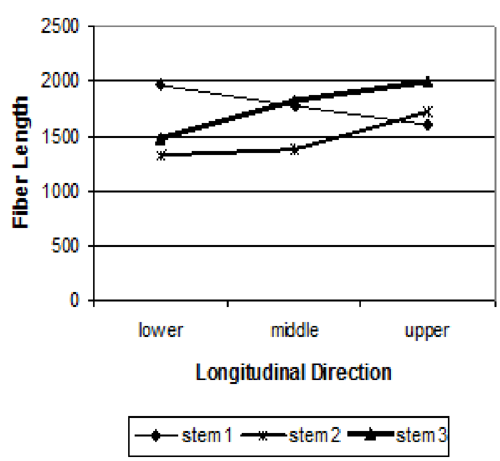


Fig. 3. Fiber length and diameter variation in the bamboo culm

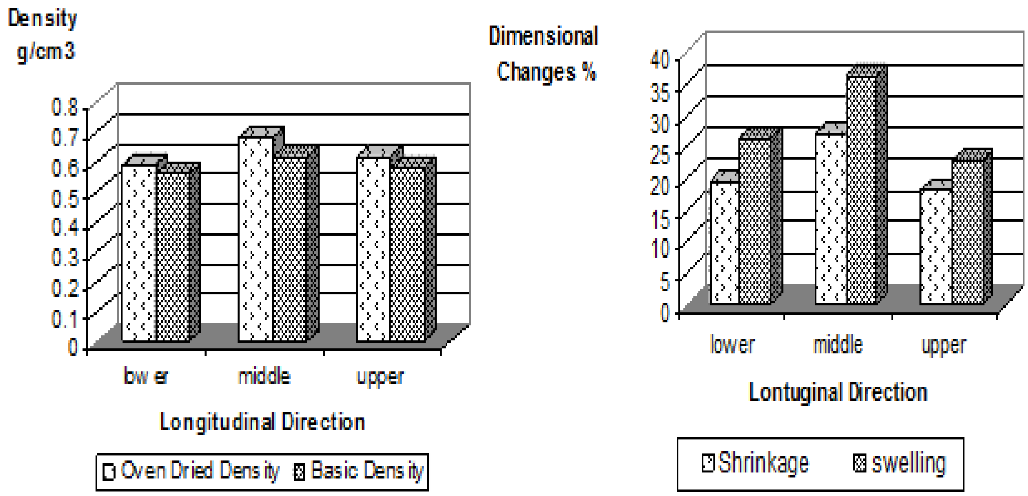


Fig. 4. Density and dimensional change variations in bamboo culm

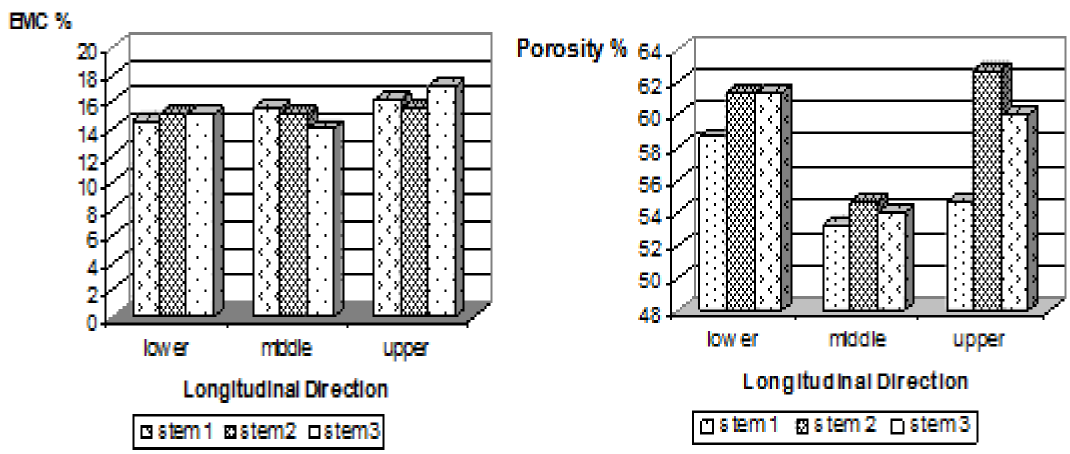


Fig. 5. EMC and porosity variations in the bamboo culm

Table 3. Comparison of Average Chemical Properties in Bamboo (*Phyllostachys nigra*) with Softwoods and Hardwoods

Chemical Properties	Cellulose (%)	Lignin (%)	Pentosan (%)	Extractive (%)	Ash (%)	Silicon dioxide (%)
Bamboo (this study)	33.8	8.94	-	15.43	10.3	2.4
Bamboo Atchison (1996)	35	26	21	-	3.5	0.7
Softwoods**	40-45	26-34	7-14	0.5-6	<1	-
Hardwoods**	38-49	23-30	19-26	1-8	<1	-

** Paper and Composites from Agro-Based Resources (Rowell Roger M., 1996)

According to the atomic absorption results, the averages for Mg, Cu, K, Fe, Zn, Mn, and Pb ions were 1.87, 0.006, 1.894, 0.026, 0.071, 0.006, and 0.003 ppm, respectively. The GC-MS results suggest that 114 compounds were identified in the bamboo culm, and banzaldehyde (43.86%), xylene (1.79%), iron, monocarbonyl (1.94%), 1,2-benzenedicarboxylic acid (1.23%), bibenzyl (1.58%), eicosane (1.47%), and benzoic acid (0.46%) were the most abundant and important compounds present. These compounds are very important in durability and utilization of bamboo (Vaysi 2008).

CONCLUSIONS

The results showed that the oven dried density, basic density, shrinkage, and swelling increased toward the middle of the disc in the longitudinal direction of the culm, then subsequently decreased. High parameters were observed in the middle disc and had the least impact in the lower part of the disc. The fiber length, fiber diameter, and EMC increased in the longitudinal direction, while the porosity decreased towards the crown. The largest variations were observed in the longitudinal direction. The results showed that the fiber biometry and chemical properties of the bamboo were very suitable. Using mixed bamboo instead of the typical raw materials used in the wood, paper, and board industry in Iran will prevent the outflow of currency and will have benefits with respect to pulp properties and job opportunities.

REFERENCES CITED

Adams, R. P. (1997). "Identification of essential oil components by gas chromatography/ mass spectroscopy," *Journal of the American Society for Mass Spectrometry* 6(8), 671-672.

Adams, R. P. (2007). *Identification of Essential Oil Components by Gas Chromatography/ Mass Spectrometry*, Allured Publishing Corporation.

Atchison, J. E. (1996). "Twenty-five years of global progress in non-wood plant fiber repulping," *Tappi Journal* 79(10), 87-95.

Barzan, A., and Soraki, S. (2002). *Procedure for Experimental*, Mazandaran Wood and Paper Industries, Sari, Iran, 111-121.

Enayati, A. A. (2010). *Wood Physics*, University of Tehran Press, 2nd Edition, p. 317.

Fadavi, F. Kermanian, H., and Resalati, H. (2012). "Effect of fiber fractionation on refinability and strength properties of wheat straw soda-AQ pulp," *Lignocellulose* 1(2), 153-163.

Franklin, G. L. (1946). "A rapid method of softening wood for microtome sectioning," *Tropical Woods* 88, 35-36, Yale School of Forestry, New Haven, CT, USA.

Jahan Latibari, A. (2012). "Non-wood Fibers and the 21st Century," *Lignocellulose* 1(2), 81-82.

Kiaei, M., Tajik, M., and Vaysi, R. (2014). "Chemical and biometrical properties of plum wood and its application in pulp and paper production," *Maderas, Ciencia y Tecnología* 16(3), 313-322.

Kiaei, M., and Tajik, M. (2013). "Identification of acetone extractable component from Iranian elm (*Ulmus glabra huds*) wood," *Lignocellulose* 2(2), 363-368.

Kollman, F. P. and Wilfred, A. (1968). *Principles of Wood Science and Technology*, Vol. 1, New York.

Kumar, A., Sharma, A. K., Jain, R. K., and Singh, B. P. (2014). "The use of banana (*Musa sapientum*) and ankara (*Calotropis procera*) in the handmade paper industries," *Lignocellulose* 2(1), 269-281.

Lindstom, H. (1997). "Fiber length, tracheid diameter, and late wood percentage in Norway spruce, development from pith outwards," *Wood and Fiber Science* 21(1), 21-34.

Latif, M. (1995). "Bamboo in Malaysia, past, present and future research," *Proceeding of 4th International Bamboo Workshop*, Thailand.

Razak, O. (1995). "Planting and utilization of bamboo in peninsular Malaysia," *Malaysia Forest Research Institute*.

Rowell, R. M., and Rowell, J. (1996). *Paper and Composites from Agro-based Resources*," CRC press, pp. 31-47.

Tajik, M., Vaysi, R., and Kiaei, M. (2015a). "Extraction, identification and comparison of organically chemical components in extractive of eucalyptus bark and wood by gas chromatography- mass spectrometry," *Iranian Journal of Wood and Paper Science Research* 29(4), 640-647.

Tajik, M., Kiaei, M., and Torshizi, H. J. (2015b). "Apricot wood – A potential source of fibrous raw material for paper industry," *Comptes Rendus de l'Académie Bulgare des Sciences* 68(3).

TAPPI Test Method (1999). Technical Association of Pulp and Paper Industry, p. 135.

Vaysi, R. (2013). "The effects of cooking and bleaching on organic chemical compounds in CMP pulp and newsprint," *Lignocellulose Journal* 2(2), 377-385.

Vaysi, R. (2008). "Investigation and comparative of the paper properties from imported long-fiber and bamboo kraft pulps," *International Conference on Tropical Forestry Change in a Changing World*, Bangkok, Thailand.

Article Submitted: February 27, 2015; Peer review completed: May 2, 2015; Revised version received and accepted: June 6, 2015; Published: June 15, 2015.