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Chemical and Biometry Properties of Iranian Cultivated Paulownia Wood (*Paulownia fortunei)*

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Abstract: Chemical and biometry properties of Iranian cultivated paulownia (*Paulownia fortunei* L.) wood were investigated. Chemical properties such as holocellulose (80.1%), cellulose (51%), lignin (23.5%) and extractive (11.8%) and the morphological properties such as fiber length (996 ìm), fiber width (30.55 ìm), width of lumen (25.30 ìm) and cell wall thickness (5.25 ìm) were determined. Paulownia has acceptable Runkel, flexibility and slenderness coefficients are in the range of hard and softwood. In general, results based on the chemical and morphological analysis indicated that Iranian cultivated paulownia fibers are a promising fibrous raw material for the paper production.

Key words: *Paulownia fortunei* L · Chemical properties · Biometry properties

INTRODUCTION

P. fortunei was imported into Iran from China and was planted at different spacings in the forest of the north (Iran) for wood production. This exotic species has shown good adaptation to these environmental conditions. For example, the height and diameter of five years old tress paulownia at the Shastkalate-Grogan (Gloestan province) region are 10.24 m and 23.5 cm, respectively [1]. To use this material property and efficiently, it is necessary to know its different wood properties.

The chemical composition of wood changes broadly between 40 and 50% cellulose, 20 and 30% hemicelluloses, 20 and 35% lignin, 0 and 10% extractives. Variation of chemical composition is high between different species and, to a more limited extent, also within a species, as a result of environmental and genetic factors. Within a tree, age, growth and stress factors also influence the chemical composition. Although the structural components may vary in quantity and, in some cases, in composition (e.g. lignin and hemicelluloses), most of the chemical variability both in structure and concentration is found in extractives [2]. There is little information about chemical properties of paulownia wood, which were previously reported by Kalaycioglu *et al.* (2005, *P. fortunei*), Ashori and Nourbakhsh (2009, *P. fortunei*) and Ates *et al.* (2008, *P. elongata*) [3-5]. The objectives of this study are to examine the chemical and morphological characteristics of Iranian cultivated *Paulownia fortunei* and to assess its potential, using various indices, as a raw material for the paper production by comparing its examined properties with those of softwoods and hardwoods.

MATERIALS AND METHOD

Six trees of *Paulownia fortunei L.* were harvested from a plantation in the north of Iran (Fakhrabad Experimental Forest-Lashtnesha-Guilan province). The experimental area is located at an average altitude of 20 m. The mean annual precipitation of experimental area is 1347 about mm/year; the yearly average temperature is 17°C. The age, height and diameter of trees were 5 years-old, 7.2 meter and 41 cm. All climatic data were obtained from Iranian meteorology station located very near to the research area. Logs were cut between 2 and 4 m height of trees to obtain samples for different wood properties. North directions of logs were marked.

Chemical Properties:: A disk, 5 cm in thickness, was obtained from each log for evaluation of chemical properties. The chemical compositions of paulownia were determined following the standards outlined in the TAPPI test methods (2002). Hollocellouse was determined following the procedure of Wise and Karl (1962) and alpha-cellulose base by Tappi T 203 cm-99. Acid-insoluble (Klason) lignin content was determined by hydrolyzing

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the carbohydrated with 72% sulfuric acid as per T 222 om-02. The solubility properties were determined based on hot water (Tappi T 207 cm-99) methods. Four replicates were analyzed for each experiment [cited by 2 and 4].

Biometry Properties: A disk, 3 cm in thickness, was obtained from each log for evaluation of morphological properties. The samples for fiber maceration and fiber measurements were obtained from the middle sections of the stalks. The samples were macerated according to the modified Franklin method [6]. Firstly, they were boiled in a beaker containing water to remove all the air from the raw material. Air free pieces were placed in test tubes containing an equal amount of glacial acetic acid and 35% hydrogen peroxide. The test tubes were uniformly white. The pieces were washed thoroughly with distilled water, then placed in separate test tubes and shaken in an ethanol and distilled water mixture.

For this study 600 undamaged/unbroken fibers were measured in terms of their lengths (L), fiber widths (d), lumen diameters (c) and cell wall thickness (p), using a Quantimeter Image Analyzer equipped with a Leica microscope and Hipad digitizer. The fiber lengths were expressed as arithmetic average length. The calculations of Runkel ratio (2p/c), coefficient of flexibility (c / d× 100) and slenderness ratio (L/d) were carried out using the measured data. The values were compared to those of softwoods and hardwoods to assess the suitability of the plant raw materials for the paper production.

RESULTS AND DISCUSSION

Chemical Components: Lignocellulosic materials contain cellulose, hemicelluloses, lignin and extractives in various amounts and chemical compositions. The chemical properties and behavior of wood components during pulping are very important. A brief review of their characteristics is, therefore, necessary as background to the objectives of this study. Results of the chemical analyses of paulownia wood are presented in Table 1. The average holocellulose content of the samples was found to be 80.1% which is higher than that of hardwood (68-74%) [7]. Higher content of holocellulose for Iranian grown paulownia fiber provide higher pulp yield and probably strength property compared with hardwood. The holocellulose content for paulownia used in this study agrees with the content of 78.8% reported by Kalaycioglu *et al.* (2005) [3].

Paper strength depends on the cellulose content of raw wood materials. Wood materials with 40% and over of á-cellulose content were characterized as promising for pulp and paper manufacture, from chemical composition point of view [8]. The cellulose content of paulownia was found as 51%, which was at a satisfactory level, but well below the values for hardwood and softwood.

The lignin content of paulownia wood was 23.5%, which is comparable with hardwood and softwood. Higher lignin content in Paulownia indicates the need for more chemicals during chemical pulping. The extractive (hot water) of this species was 11.8%, which is higher than hardwood and softwood. In general, the chemical properties results of paulownia wood were previously reported by Kalaycioglu *et al.* (2005) and Ashori and Nourbakhshi (2009) [3-4].

Fiber Properties: Fiber is the basic component material in paper manufacturing which affects the paper properties. Fiber morphological characteristics play a key role in determining the suitability of any lignocellulosic raw material for pulp and paper manufacturing. All descriptive statistics are given in Table 2 for the anatomical and morphological properties of *P. fortunei* and in Table 3 for comparison with other fibrous material. The average fiber length of paulownia wood is 0.996 mm, which is shorter than softwoods (2.7- 4.6 mm) and close to the minimum value of hardwood fibers (0.7 - 1.6 mm), similar *P. fortunei* (Chamestan Experimental Forest - Nour in Iran) and is greater than *P. elongata* (in Turkey).

The fiber width of *P. elongota* averaged 30.55 ìm which was in the normal range when compared to hardwood fiber (approximately 20-40 ìm), but lower than *P. fortunei* (Chamestan Experimental Forest - Nour in Iran)

Table 1: Chemical properties of paulownia wood

Properties (%)	Method	*P. fortunei* [b]	Hardwood [cd]	Softwood [cd]
Holocellulose	Wise and Karl	80.1	68 - 74	70 -81
á-cellulose	T 203cm-99	51	58 - 64	55 - 61
Lignin [a]	T 203cm-99	23.5	17 - 26	25 -32
Extractive (hot water)	T 207 CM-99	11.8	2 -5	3 - 6

a: Klason lignin, b: This study; c: Eroglu (1998) [7]; d: TAPPI Test Methods (2002)

Table 2: Anatomical and morphological properties of paulownia wood

Properties	N [a]	Mean	Max and Min	SD
Fiber length (mm)	30	0.996	0.801 - 1.33	0.181
Fiber width (ìm)	30	30.55	25.12 - 37.09	4.55
Cell wall thickness (ìm)	30	5.25	3.54 - 7.54	1.16
Lumen width (ìm)	30	25.30	19.18 - 31.05	4.33
Slenderness ratio	30	33.10	21.59 - 41.66	6.48
Flexibility ratio	30	82.61	75.69 - 87.65	4.02
Runkel ratio	30	0.426	0.282 - 0.642	0.121

a; From each of samples were selected 30 fibers (in total: 600 fibers);

Table 3: Comparison of anatomical properties of Iranian paulownia with other tree species

Properties	*P. fortunei* [a]	*P. fortunei* [b]	*P. elongata* [c]	Softwood [d]	Hardwood [d]
Fiber length	0.996	1.002	0.82	2.7 - 4.6	0.7- 1.6
Fiber width	30.55	35.44	36.3	32 - 43	20 - 40
Cell wall thickness	5.25	6.47	8.6	-	-
Lumen width	25.30	26.49	19.2	-	-

a: present study; b: Ashori and Nourbakhsh (2009) [4], c: Ates (2008) [5], d: Atchison (1987) [13]

and *P. elongata* (in Turkey). The fiber cell wall thickness of *P. elongata* is also greater than other fibrous materials. In addition, the value of lumen width of *P. fortunei* (in the present study) is lower than *P. fortunei* (Chamestan Experimental Forest - Nour in Iran) and is higher than *P. elongata* (in Turkey). Overall, the physical properties of a pulp sheet are closely related to morphological properties of pulp fiber.

When Runkel's value is greater than 1, the fibers have thick wall and cellulose obtained from this type of fiber is least suitable for paper production. When the rate is less than 1, the cell wall is thin and cellulose obtained from these fibers is most suitable for paper production. There are positive relationships between Runkel value and burst and tensile strength and also between fiber length and tear resistance [4, 7]. Jang and Seth (1998) stated that materials having a Runkel value less than 1 would be suitable for papermaking, because they collapse (become ribbon like) and provide a large surface area for bonding [9]. Fibers having Runkel's proportion less than 1 are included in the flexible fibers category and these fibers are easily flattened during paper production and give stronger inter fiberous connections [10]. According to this classification, the Runkel ratio of paulownia wood is 0.426 and it is included in the thick wall fibers group. Overall, sheets made from short and thin-walled fibers of paulownia may be expected to give relatively dense papers which are weak in tearing strength, but are superior in burst and tensile properties. From this point of view, the fibers are suitable for papermaking.

The flexibility coefficient is the percentage of lumen width over fiber width. It expresses the potential of fiber to collapse during beating, or during drying of the paper. Collapsed-fibers provide more bonding area and subsequently stronger papers are produced. On the other hand, strength properties of paper such as tensile strength, bursting strength and folding endurance are affected mainly by the way in which individual fibers are bonded together in paper sheets. The degree of fiber bonding depends largely on the flexibility of individual fibers. According to the flexibility rate there are 4 groups of fibers [11]: 1) high elastic fibers having flexibility coefficient greater than 75, 2) elastic fibers having flexibility ratio between 50-75, 3) rigid fibers having flexibility ratio between 30-50 and 4) high rigid fibers having elasticity less than 30. The flexibility coefficient of paulownia wood fibers in this study is 82.61, thus it is included in high elastic fibers group.

Slenderness coefficient is the ratio of fiber length to fiber width. A high value of this ratio provides better forming and well-bonded paper. Generally, the acceptable value for slenderness ratio of papermaking fibers is more than 33 [12]. Referring to this term, this species of paulownia have a good slenderness coefficient with a value of 33.1.

CONCLUSION

In this study, the physical, chemical and mechanical properties of paulownia wood (*Paulownia fortunei*) at the Guilan region were determined and these results were compared with of other sites or other species in different regions in world. The following conclusions were obtained from this research:

Based on the findings in this study, average alpha-cellulose and lignin content were determined as 51 and 23.5%, respectively. These values are comparable with the values of typical hardwoods. With regard to chemical components, it is expected that paulownia fibers exhibit a number of properties that fulfill the requirements of a good raw material for papermaking, such as being relatively easy to delignify during pulping, giving dense paper with high pulp yield and high strength properties. However, the content of extractives compounds is much higher compared to hardwoods and softwoods, which it causes some problem in papermaking.

P. fortunei has short fiber length but can be used for paper production after mixing with long fibrous materials (from softwood fibers). The species has very good biometric coefficients, which is an important advantage in industrial papermaking. Therefore, it is suitable for this industry in this view.

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