Paulownia Tree as an Alternative Raw Material for Pencil Manufacturing

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The Paulownia tree is one of the most important fast growing species in the World and is an ideal multipurpose tree. In this study, the potential use of Paulownia wood (*Paulownia elongata*) as a raw material for the pencil manufacturing industry is investigated. Currently, poplar, cedar, and juniper species are most commonly used in this industry. However, Paulownia wood is a fast growing species that can be used in the industry after 5 years on the plantation. Paulownia (*Paulownia elongata*), poplar (*Populus tremula*), and juniper (*Juniperus excelsa*) wood specimens were used in this study. The specimens were prepared according to related standards, and physical, mechanical, and technological properties were investigated. The data obtained from these measurements were compared statistically using ANOVA and Duncan's Multiple Range Test. As a result, Paulownia wood exhibited favorable properties, suggesting that it would be a useful alternative raw material for the pencil manufacturing industry.

Keywords: Fast-growing species; Pencil manufacturing industry; Raw material; Paulownia wood

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INTRODUCTION

The rapid increase in population and industrialization has created an increased demand for natural resources, and deforestation is a serious consequence. Deforestation, as a result of unlawful clearing of forests, has unfavorable consequences related to the inappropriate and ecologically harmful practices involved. These practices do not take into consideration the social and economic functions of forests. Therefore, this causes the loss of several economic, ecological, and social values, and these cannot be regained with new forestation. The effects of deforestation are vast; pollution, desertification, climate change, the threat to biodiversity, and hunger, have increased the demand for improved forestry practices in the late 20th century. Turkey is featured as one of the rare countries capable of increasing forestry development. Radical changes have been implemented with the aim of improving the management of natural resources in line with international developments, protection of biologically diverse forests, improvement of forest public relations, and protection of clean air and clean water resources.

In the 21st century, borders between countries have been removed, and globalization has affected the economic, cultural, and social structures of the world in ways that have increased dependence on technology. Technological advances have increased the demand for forestry products in other industries. The rapid deforestation and destruction of forests have necessitated a more productive use of wooden materials. Today, extending forest plantations by incentivizing, and thus increasing, the production of raw wood are of great importance with regard to securing the production of natural forests. Therefore, it will be possible to lessen this demand by implementing the production of new wood resources outside the current forestry regions.

According to the Food and Agriculture Organization (FAO) of the United Nations, the total demand for wood products is expected to rise; this is attributed to the growth in population, income, wood consumer products, and use of wood for energy (*i.e.*, cellulosic biofuel). Europe exceeds the nation in paperboard construction for exportation. The heightened demand for wood residues and recycled products will reduce the need for roundwood by 50 to 70% and increase the production of raw-material equivalents (WRMEs). FAO estimates that the demand for total wood and wood fiber will increase in the future, such that upwards of 4 billion cubic meters of WRME may be needed to supply world paper and paperboard products demand (Table 1, FAO 2009).

Table 1. Production and Consumption of Industrial Roundwood

REGION	Amount *(million m³)*					Average annual change *(%)*			
	Actual			**Projected**		**Actual**		**Projected**	
	1965	1990	2005	2020	2030	1965-1990	1990-2005	2005-2020	2020-2030
Production									
Africa	31	55	72	93	114	2.4	1.8	1.8	2.0
Asia and the Pacific	155	282	273	439	500	2.4	- 0.2	3.2	1.3
Europe	505	640	513	707	834	0.9	- 1.5	2.2	1.7
Latin America and the Caribbean	34	114	168	184	192	5.0	2.6	0.6	0.4
North America	394	591	625	728	806	1.6	0.4	1.0	1.0
Western and Central Asia	10	9	17	15	11	- 0.6	4.5	- 0.8	- 3.0
World	**1128**	**1690**	**1668**	**2166**	**2457**	**1.6**	**- 0.1**	**1.8**	**1.3**
Consumption									
Africa	25	51	68	88	109	2.9	1.9	1.8	2.1
Asia and the Pacific	162	315	316	498	563	2.7	0.0	3.1	1.2
Europe	519	650	494	647	749	0.9	- 1.8	1.8	1.5
Latin America and the Caribbean	33	111	166	181	189	4.9	2.7	0.6	0.4
North America	389	570	620	728	808	1.5	0.6	1.1	1.0
Western and Central Asia	10	10	19	22	19	- 0.2	4.4	1.1	- 1.3
World	**1138**	**1707**	**1682**	**2165**	**2436**	**1.6**	**- 0.1**	**1.7**	**1.2**

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The high demand for wood species and decline in juniper production has contributed to the interest in an alternative raw material for use in the pencil production industry. There are several studies (Kaygin *et al*. 2009a,b; Si *et al*. 2011; Garcia *et al*. 2011; Latibari *et al*. 2012; Radeva *et al*. 2012; Si *et al*. 2013; Tisserat *et al*. 2013) that have used Paulownia wood in other project designs because of its favorable qualities. Paulownia wood has a multitude of uses: house construction, furniture making, handicrafts, farm implements, flower vases, statues, medal boxes, dressing boxes, TV and radio boxes, medicine, paper pulp, *etc*. However, Paulownia wood has not been studied for use in the pencil industry until this study.

Paulownia wood is a rapidly growing tree species, planted to a great extent within the scope of private forestry in China and Japan. Paulownia is an exotic species in Turkey, and under favorable environmental conditions it can grow 4 to 5 cm per year (Kalaycioglu *et al*. 2005; Akyildiz and Kolsahin 2010; Akyildiz 2014). The cultivation of Paulownia wood is not practiced in Turkey in comparison to other areas the world. While Paulownia species have been grown in parks and gardens for ornamental purposes in Turkey, other applications have not been explored. Poplar and juniper trees are preferred woods for the pencil industry because of their mechanical strength, density, and favorable structural properties. The main objective of this study was to explore the potential use of Paulownia wood as a new raw material alternative for the pencil industry by comparing its mechanical and structural integrity with that of the *Populus tremula* and *Juniperus excelsa* species.

EXPERIMENTAL

Paulownia elongata, Populus tremula, and *Juniperus excelsa* trees were obtained from Mugla, Bartin, and Denizli, Turkey, respectively. Lumber was prepared at a sawmill factory located at the Forestry Faculty of Bartin University, in Turkey. Sampling methods and general requirements for the physical and mechanical tests of the lumber were carried out based on TS 53 (1981) and TS 2470 (1976) translated from ISO 3129 (1975). The lumber was planed with a knife angle of 45°, and then small clear specimens were cut with the dimensions 20 x 20 x 30 mm (L x W x H) for density measurements; these were taken according to the TS 2471 (1976) translated from ISO 3130 (1975) and TS 2472 (1976) modulus translated from ISO 3131 (1975), with a bending strength of 20 x 20 x 360 mm according to the TS 2478 (1976) modulus, an elasticity in bending and brittleness 20 x 20 x 360 mm according to TS 2478 (1976) translated from ISO 3349 (1975), and a Brinell hardness of 50 x 50 x 50 mm according to the TS 2479 (1976) modulus translated from ISO 3350 (1975).

Chipping and adhesion tests were carried out according to TS 5171 (1987) translated from ASTM D 3363-74 (1974). According to the TS 5171 (1987) pencil standard, the pencils produced from juniper, poplar, and Paulownia were sharpened with a sharpener and evaluated. According to the standard, it is required that pencils be easy to sharpen and display and have an even and smooth surface. In addition, the graphite-wood adhesion test was conducted by holding the tip of the sharpened pencils over a surface and the pencils were pushed down on the surface until the graphite tip was broken. The overflow of the graphite from the tip of the pencils was evaluated. In the wood-wood adhesion test, pencil samples were horizontally dropped from 1.5 m height to a concrete floor 5 times and the separation of the wooden part of the pencil from the adhesion places was evaluated.

After the samples were prepared, physical (oven-dry and air-dry density), mechanical (bending strength and elasticity in bending and brittleness), and technological (Brinell hardness) tests were conducted. 50 samples for each test were used. All parameters were analyzed using multiple comparisons and analysis of variance (ANOVA). The significant differences between the mean values of control and treated samples were evaluated using Duncan's Multiple Range Test. Measurements obtained from the ANOVA tests, mean, standard deviation, variance, minimum, and maximum values were calculated using the SPSS 10.1 computer software program (IBM, USA). Significance was accepted at $P < 0.05$.

RESULTS AND DISCUSSION

Physical, Mechanical, and Technological Results

Analysis of variance and Duncan's Multiple Range Tests showed that there were significant differences between the properties of the *Paulownia elongata*, *Populus tremula*, and *Juniperus excelsa* samples. According to the data obtained from the tests, *Paulownia elongata* had lower values in terms of air-dried and oven dry densities and yielded values more similar to *Populus tremula* (Fig. 1).

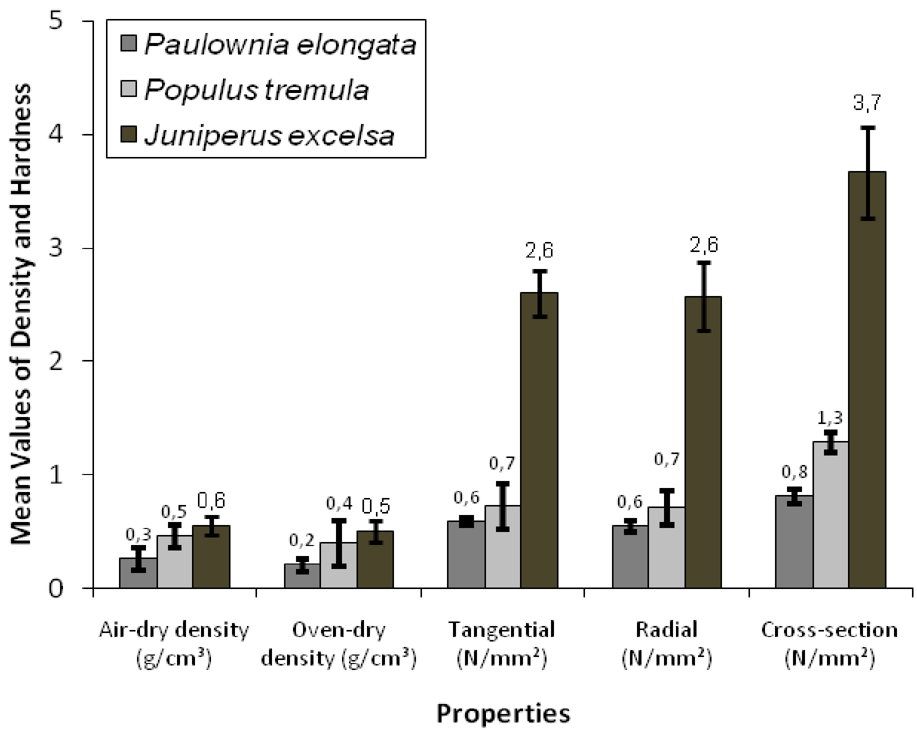

Fig. 1. Mean values of density (air-dry and oven-dry) and Brinell hardness (tangential, radial, and cross-sectional)

The bending stiffness and bending modulus of elasticity for *Paulownia elongata*, *Populus tremula*, and *Juniperus excelsa* woods were achieved through mechanical analysis. According to the results, the *Paulownia elongata*, *Populus tremula*, and *Juniperus excelsa* samples exhibited different values in terms of bending stiffness and bending modulus of elasticity, and it was found that *Paulownia elongata* had less structural integrity than *Populus tremula* and *Juniperus excels* samples, although it yielded values more close to *Populus tremula* (Fig. 2).

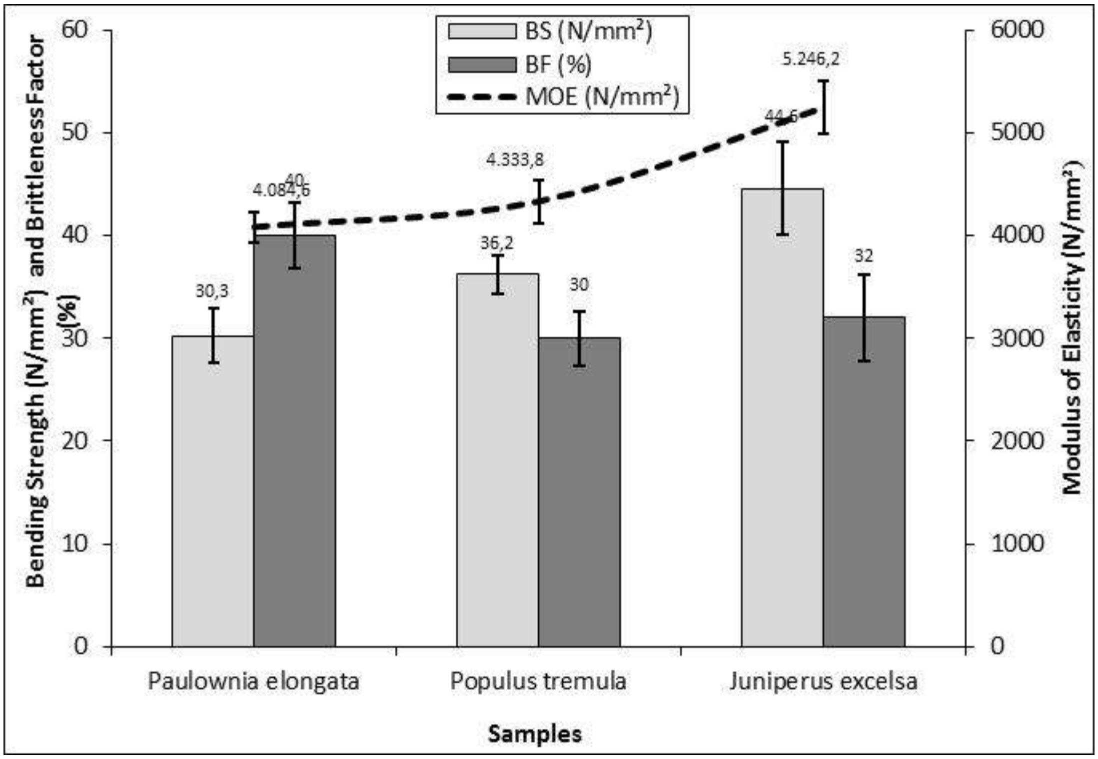

Fig. 2. Mean estimates for bending strength (BS), modulus of elasticity (MOE), and brittleness factor (BF)

The mean estimates for bending strength and modulus of elasticity (brittleness) were 30.27 N/mm^2 and 4084.61 N/mm^2, respectively. In previous research (Lu and Xiong 1986), mean estimates of bending strength and modulus of elasticity for *Paulownia elongata* have been reported as 28.00 N/mm^2 (289.0 kgf/cm^2) and 4118.79 N/mm^2 (42000 kgf/cm^2), respectively. Therefore, *Paulownia elongata* wood grown in Turkey and *Paulownia elongata* wood grown in China have similar bending strength and modulus of elasticity properties.

The brittleness factor of the tree species was measured, and it was found that the most brittle tree species was the *Paulownia elongata*, then *Juniperus excels*, and lastly *Populus tremula*. The characteristics required in trees used for the pencil industry are a nice scent, redness of color, and brittleness for easy sharpening. Also, latewood layers should appear as little as possible in the annual ring, which is dense and hard, to achieve smooth processed surfaces. Although the brittleness of the wood is an undesirable characteristic for some areas of utilization, it is a useful characteristic in the pencil industry. Because brittleness is the opposite of elasticity for bending, a pencil made of a brittle tree does not bend and prevents the central graphite mine from being broken while writing. On the other hand, if a pencil is made from a tree with a high bending ability, the mine can be easily broken by the force of writing. The results achieved in the study are indications that Paulownia wood may be a suitable alternative raw material for pencil manufacturing relative to its favorable brittleness factor and bending stiffness.

Brinell hardness mean estimates were different between species, and it was found that *Paulownia elongata* had the lowest values compared to the other two species and provided estimates more comparable to *Populus tremula* (Fig. 1).

Adhesion and Sharpening Experiments

The results achieved in the sharpening and adhesion tests of the pencil samples, according to the TS 5171 (1987) pencil standard, are shown in the Table 2.

Table 2. Adhesion and Sharpening Tests

Tree species	Pencil chipped		Adhesion			
			Between graphite-wood		**Between wood-wood**	
	Good (%)	Bad (%)	Good (%)	Bad (%)	Good (%)	Bad (%)
Paulownia elongate	85	15	88	12	92	8
Populus tremula	82	18	91	9	90	10
Juniperus excels	88	12	87	13	93	7

The most important characteristics for pencil fibers is that they are smooth and parallel to one another, not curly, and free of knots. If pencil fibers contain imperfections, this prevents the ease of sharpening and causes the graphite mine to be broken more easily when the pencil is sharpened. Therefore, fiber curliness (spiral fibrousness) may cause pencils to work irregularly, become distorted, or bend. Moreover, wood defects are rarely desired in the pencil industry and are the reason this sector has a need for a new suitable raw material. According to observations and findings of this study, the *Juniperus excelsa* samples contained more wood defects than the other *Paulownia elongate* and *Populus tremula* samples. It was found that the *Populus tremula* contained more wood defects than the *Paulownia elongata* and *Juniperus excelsa* species, possibly due to the trunk and branch structure. Paulownia wood does not contain branching at the trunk level; therefore, less wood defects may occur in these trees compared to the *Populus tremula* and *Juniperus excels* species.

CONCLUSIONS

Paulownia wood is a suitable raw material alternative for the pencil industry compared to juniper and poplar wood, which are currently utilized. This was determined using physical, mechanical, and technological pencil tests. As a result, it was found that Paulownia wood can be utilized as an alternative raw material source in the pencil industry since it meets several required characteristics in the standards. If future studies yield positive results from Paulownia wood in pencil manufacturing, it is suggested that plantation forests for this species be cultivated in suitable areas. In this way, it will be possible to create new wood production outside the current forestry areas. The result will be reduced deforestation of mature forests.

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