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Some technological properties and uses of paulownia (*Paulownia tomentosa* Steud.) wood

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Abstract: *The aim of this study is to determine some physical and mechanical properties of Paulownia tomentosa wood grown in Turkey. The samples trees harvested from Kargi in Corum. Physical properties including air-dry density, oven-dry density, basic density, swelling, shrinkage and oven-dry and air-dry thermal conductivity coefficients; mechanical properties including bending strength, modulus of elasticity in bending, compression strength parallel to grain, hardness, bonding strength were analyzed. Paulownia tomentosa wood's air dry and oven dry densities were determined as 0.317 and 0.294 g cm^{-3}; basic density was determined as 0.272 g cm^{-3}; volumetric shrinkage and swelling were determined as 7.78 and 8.41%; tangential, radial and longitudinal air-dry thermal conductivity coefficients were determined as 0.089, 0.090 and 0.133 kcal/mh°C, respectively. Fiber saturation point (FSP) was found 28.79%; bending strength, Modulus of elasticity in bending, compression strength parallel to grain and Brinell hardness values (parallel and perpendicular to grain) were determined as 43.56 N mm^{-2}, 4281.32 N mm^{-2}, 25.55 N mm^{-2}, 2.01 kgf mm^{-2} and 0.88 kgf mm^{-2}, respectively. Consequently, paulownia wood can be widely used for various purposes such as house construction, furniture making, pulp and paper and handicrafts.*

Key words: *Paulownia tomentosa, Technological properties, Thermal conductivity*
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Introduction

Paulownia is a deciduous tree capable of achieving very high growth rates under favorable conditions. *Paulownia tomentosa* Steud. is a fast growing tree species introduced in Turkey from China, where it is a widely spread species.

The genus *Paulownia* (Scrophulariaceae) includes nine species of fast-growing trees, indigenous to China and East Asia (Zhu *et al*., 1986). These trees were also introduced to North America, Australia, Europe and Japan. It could be considered as a low demand water plant, in spite of not growing in barren zones (Caparros *et al*., 2008). *Paulownia tomentosa* Steud. (Scrophulariaceae) is an ornamental tree widely distributed throughout China, Korea and Japan. Paulownia's characteristics of rot resistance, dimensional stability and a very high ignition point ensure the popularity of this timber in the world market (Bergmann, 1998; Silvestre *et al*., 2005).

Most species of paulownia are extremely fast growing and can be harvested in 15 years for valuable timber. Low quality lumber can easily be produced from 6-7 years old tree. A full grown paulownia can reach a height of 10 to 20 meters and grows up to 3 meters in one year under ideal conditions. A 10-year old tree can measure 30-40 cm diameter at breast height (DBH) and can have a timber volume of 0.3-0.5 m^3 (Flynn and Holder, 2001). Each paulownia tree could produce a cubic meter of wood at the age of 5–7 years; it may grow in intensive plantations with about 2000 trees per ha. Based on the above one can calculate that an annual production would be 330 ton ha^{-1}, a more conservative number would be about 150 ton ha^{-1} (Caparros *et al*., 2008).

The wood of paulownia is soft, lightweight, ring porous straight grained, and mostly knot free wood with a satiny luster. Average specific gravity of the wood is reported as 0.35 g cm^{-3} (Kalaycioglu *et al*., 2005; Flynn and Holder, 2001). Paulownia timber is easily air-dried without serious drying defects. It has a high strength-to-weight ratio, a low shrinkage coefficient, and does not easily warp or crack. Machining and finishing properties of the wood are excellent. In China and some of the other Asian countries, paulownia wood is used for a variety of applications such as furniture, construction, musical instrument, shipbuilding, aircraft, packing boxes, coffins, paper, plywood, cabinetmaking, and molding (Flynn and Holder, 2001; Clad and Pommer, 1980). Paulownia wood is marketed primarily for specialty solid wood products, oriented strand board, veneer, and for pulp to produce fine papers (Bergmann, 1998; Rai *et al*., 2000). Its stem bark has been used in Chinese herbal medicine as a component of remedies for infectious diseases such as gonorrhea and erysipelas (Kang *et al*., 1999; Asai *et al*., 2008). Aside from its continuing ornamental use, the species has value for its small sawn timbers that are in demand for specialty products. It is also used among Chinese folks to treat bronchitis, dysentery, bacterial dysentery, acute enteritis, parotitis and acute conjunctivitis, etc. (Liao *et al*., 2008). Some studies were done related to growth of Paulownia spp. in Turkey by Ulu *et al*. (2002) and Ayan *et al*. (2006) and similar studies going on.

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The main objective of this study is to determine some of the properties of *Paulownia tomentosa* wood, grown in Turkey as a fast growing species and to facilitate optimal utilization fields of this species.

Materials and Methods

For the present study, the sample tree of *Paulownia tomentosa,* 6 years-old and with a diameter at breast height diameter (DBH) of 30-40 cm tree, was harvested from Kargi the district of Corum on the north part of Turkey. The experimental area is located at an average altitude of 450 m. The tree of about 6.0-7.5 m high was cut into 0.5-2.0 m wood logs that were air-dried. Sections (1.5 m) were cut between 2 and 4 height of tree to obtain samples for the properties. The lumber was cut in parallel to grain directions from the logs in sawmill according to Turkish Standard (TS 4176, 1984). Afterwards cutting the lumbers were dried in uncontrolled air until at air dried moisture content about 12%.

Paulownia lumber was planed and then small clear specimens were cut for moisture content (MC), air-density (D_{12}) and oven-dry density (D_0) and basic density (D_b) and maximum moisture content (MMC) (20×20×30 mm), shrinkage (β) and swelling (α) (30×30×15 mm), oven-dry and air dry thermal conductivity coefficient (20×50×100 mm), compression strength parallel to grain ($\sigma_{c//}$) (20×20×30 mm), bending strength (σ_{sb}) and modulus of elasticity (MOE) in bending (20×20×320 mm), Brinell-hardness (H_B) (50×50×50 mm). Thermal conductivity measurements were performed based on ASTM C 1113-99 (ASTM, 2004) hot-wire method. The all other experiments were done according to Turkish Standards to determine densities (TS 2472, 1976), shrinkage (TS 4083, 1983) and swelling (TS 4084, 1983), compression strength parallel to grain (TS 2595, 1977), bending strength (TS 2474, 1976) and modulus of elasticity in bending (TS 2478, 1976), Brinell-hardness (TS 2479, 1976). Number of samples is used 30 samples in each test.

The wood samples were conditioned in a conditioning cabin at 20±2°C temperatures and 70±5% relative humidity to reach Equilibrium Moisture Content (EMC) throughout 8 weeks (TS 642, 1997). Afterwards conditioning, mechanical properties and thermal conductivity coefficients of Paulownia wood were determined. At the end of mechanical experiment, MC of all samples was measured according to TS 2471 (1976).

Quality values were calculated based upon a relationship between strength and density. Static (I_s) and specific (I_{sp}) quality values were calculated:

$$I_s = \sigma_{c//12} / D_{12} \times 100$$

$$I_{sp} = \sigma_{c//12} / (D_{12})^2 \times 100$$

where $\sigma_{c//12}$ is the compression strength parallel to grain in 12% MC (N mm^{-2}) and D_{12} is the air-dry (12%) density (g cm^{-3}) (Korkut and Guller, 2008; Bozkurt and Goker, 1987).

Basic density (D_b) was determined by using the following equation:

$$D_b = M_0 / V_g \quad (\text{g cm}^{-3})$$

where M_0 is the oven-dry weight of the samples (g) and V_g is the green volume of the samples (cm^3).

Percentage of the cell wall (V_c) and percentage of the porosity (V_H) were also calculated by using the following equations:

$$V_c = D_0 / D_c \times 100 \quad (\%)$$

$$V_H = 100 - V_c \quad (\%)$$

where D_0 is oven dry density and D_c is oven dry density of the cell wall (1.5 g cm^{-3}).

Fiber saturation point (FSP) and maximum moisture content (MMC) were calculated by using the following equations:

$$FSP = \beta v / D_b \quad (\%)$$

$$MMC = (1.5 - D_b) / (1.5 \times D_b) \quad (\%)$$

where D_b is basic density and βv is the volumetric shrinkage (%).

Results and Discussion

Air-dry density (D_{12}), oven-dry density (D_0) and basic density (D_b) values were given Table 1. Arithmetic mean (X), maximum value (Max.), minimum value (Min.), standard deviation (SD), Variance (V), coefficient of variance (CV) were given for all properties.

Descriptive statistics for shrinkage (β) and swelling (α), fiber saturation point (FSP) and maximum moisture content (MMC) of *Paulownia tomentosa* were given Table 2.

The air-dry thermal conductivity coefficients were given in Table 3. According to the results, thermal conductivity in longitudinal direction was higher than those in the transverse direction. However, no significant difference was found between radial and tangential values.

Descriptive statistics for compression strength parallel to grain ($\sigma_{c//}$), bending strength (σ_{sb}), modulus of elasticity (MOE) in bending and Brinell-Hardness (H_B) of paulownia wood were given Table 4.

Percentage of the cell wall and percentage of porosity were calculated as 19.6% and 80.4% respectively.

Results were compared to values of paulownia ssp. grown in China. The results were also compared to some species of which have similar anatomical properties (Table 5).

Paulownia tomentosa grown in Turkey has quite low density because of fast growing and low percentage of cell wall. So, it has quite high percentage of porosity (80.4%). Decreasing

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Table - 1: Basic statistics for air-dry density (D_{12}), oven-dry density (D_0) and basic density (D_b) (g cm^{-3})

Properties	Arithmetic mean (X)	Maximum value (Max.)	Minimum value (Min.)	Standard deviation (SD)	Variance (V)	Coefficient of Variation (CV)
D_{12}	0.317	0.357	0.263	0.021	0.0004	6.657
D_0	0.294	0.333	0.232	0.021	0.0005	7.269
D_b	0.272	0.311	0.226	0.018	0.0003	6.587

Table - 2: Basic statistics for shrinkage (β), swelling (α), fiber saturation point (FSP) and maximum moisture content (MMC) (%)

Properties	Arithmetic mean (X)	Maximum value (Max.)	Minimum value (Min.)	Standard deviation (SD)	Variance (V)	Coefficient of Variation (CV)
β –						
Radial	2.770	4.012	2.145	0.508	0.258	18.354
Tangential	5.013	6.369	3.238	0.803	0.645	16.019
Volumetric	7.783	9.004	6.679	0.528	0.279	6.786
α –						
Radial	2.480	3.518	2.014	0.409	0.167	16.481
Tangential	5.925	3.518	3.882	0.810	0.657	13.677
Volumetric	8.405	9.408	7.157	0.622	0.386	7.396
FSP	28.791	36.241	23.854	3.084	9.513	10.713
MMC	302.908	335.852	279.463	16.565	274.393	5.469

Table - 3: Basic statistics for thermal conductivity coefficients (kcal mh°C)

Properties	Arithmetic mean (X)	Maximum value (Max.)	Minimum value (Min.)	Standard deviation (SD)	Variance (V)	Coefficient of Variation (CV)
Tangential	0.089	0.095	0.077	0.0088	7.8E-5	9.89
Radial	0.090	0.101	0.081	0.0049	2.4E-5	5.44
Longitudinal	0.133	0.145	0.114	0.0122	1.5E-4	9.17

Table - 4: Basic statistics for compression strength ($\sigma_{c//}$), bending strength (σ_{sb}), modulus of elasticity (MOE), Brinell-hardness (H_B), static (I_s) and specific (I_{sp}) quality values

Properties	Arithmetic mean (X)	Maximum value (Max.)	Minimum value (Min.)	Standard deviation (SD)	Variance (V)	Coefficient of Variation (CV)
$\sigma_{c//}$ (N mm^{-2})	25.55	29.42	20.35	2.253	5.077	0.088
σ_{sb} (N mm^{-2})	43.56	60.37	33.36	7.006	49.080	0.161
MOE (N mm^{-2})	4281.32	5900.25	3338.30	783.366	613662.591	0.183
H_B kgf mm^{-2}						
Radial	0.84	0.99	0.73	0.094	0.009	0.112
Tangential	0.92	1.31	0.45	0.233	0.054	0.255
End-grain	2.01	2.92	1.53	0.374	0.140	0.186
I_s	8.10	10.31	6.93	0.818	0.669	0.101
I_{sp}	2.58	3.92	2.01	0.398	0.159	0.155

the ratio of cell wall increases the porosity, decreases the wood density. Consequently, maximum moisture content was found 302.9% which can be considered as a high value. Density closely correlates with physical, mechanical, hardness, transportation, heat value of wood, abrasion resistance, machining, electrical, acoustical and drying properties. Machining of high density wood is relatively difficult (Goker *et al*., 1999).

The density of paulownia was found 0.317 g cm^{-3}. So, paulownia can be called as light wood according to Bozkurt and Erdin's (1990). Lightness is a major advantage of paulownia wood (Anon., 1986). According to Table 5, *Paulownia tomentosa* grown in Turkey has the lowest density value among all of the species grown in Turkey. However, naturally grown paulownia species have almost same density value. Thus, it can be say that paulownia grown in Turkey have same physical and mechanical properties because most mechanical properties of wood are closely correlated to density (Anon., 1999). The existence of a strong relationship between wood density and strength has been demonstrated by several investigators (Kollmann and Cote, 1984; Pernestal *et al*., 1995; Hernandez, 2007).

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Table - 5: Comparison of physical and mechanical properties of *Paulownia tomentosa* with other tree species

Species	D_{12} g cm^{-3}	D_0 g cm^{-3}	D_b g cm^{-3}	β_v %	α_v %	FSP %	$\sigma_{c//}$ N mm^{-2}	MOE N mm^{-2}	σ_{sb} N mm^{-2}	H_B kgf mm^{-2} //	H_B kgf mm^{-2} ⊥	Reference
Paulownia tomentosa	0.317	0.294	0.272	7.78	8.41	28.79	25.55	4281.32	43.56	2.01	0.88	
Paulownia tomentosa	0.315	0.236		9.24[a]			21.87	4707.19	39.82	1.83	1.26	Anonymous, 1986
Paulownia elongate	0.264	0.209		8.12[a]			15.59	4118.79	28.34	1.25	0.85	Anonymous, 1986
Paulownia fortunei	0.309	0.258		8.96[a]			18.44	6178.19	39.72	2.15	1.24	Anonymous, 1986
Populus tremula	0.450	0.420		12.8			39.23	7649.19	50.99	2.3	1.1	Bozkurt and Erdin, 1997
Alnus glutinosa	0.511	0.502	0.434	13.24	14.14	30.5	41.48 55.35*	8611.81	77.53 95.10*	2.89 3.06*	1.50 1.53*	*Ay, 1998; Ors and Ay, 1999;Guller and Ay, 2001
Castanea sativa	0.540	0.508	0.448	11.47		25.59	57.07		77.47	4.25	1.72	Ay and Sahin, 2002a Ay and Sahin, 2002b
Fagus orientalis L.	0.669	0.645	0.538	16.21	17.84	30.13	56.09	12829.3	110.13	5.49	2.75	Malkocoglu, 1994

[a] The values given as coefficient were converted to percentage

Table - 6: Comparison of thermal conductivity of *Paulownia tomentosa* with other tree species

Wood species	Density g cm^{-3}	Thermal conductivity (kcal mh^{-1o}C) Longitudinal	Radial	Tangential	Reference
Paulownia tomentosa	0.317	0,133	0,090	0,089	
Populus tremula	0,382	0,156	0,130	0,099	Ors and Senel, 1999
Fagus orientalis	0,687	0,261	0,171	0,145	

Volumetric shrinkage and swelling of paulownia wood were found lower than that of similar species. Radial, tangential and volumetric shrinkage of paulownia wood has been took place the class of low shrinkage wood (Bozkurt and Erdin, 1990). This property provides very important advantage in different use of field as furniture. Fiber saturation point was found 28.8% that is normal value for all species.

Thermal conductivity of *Paulownia tomentosa* grown in Turkey was found very low thus giving it excellent heat/cool insulation properties (Table 6). So, Paulownia can be used as a material in construction where the isolative is required.

The hardness of paulownia was also determined to be low value ($H_{B//}$ 2 kgf mm^{-2} and $H_{B\perp}$ 0.88 kgf mm^{-2}). So, paulownia wood can be classified as very low according to Bozkurt and Erdin's (1990) classification. In addition to this, the wood can be classified very soft wood according to hardness classification ($H_{B\perp}$) (Ors and Keskin, 2001). The pliable wood has low strength. Thus, it is not suitable for using as building components that usually require high strength (Anon., 1986).

However, the compression strength (25.55 N mm^{-2}) and bending strength (43.56 N mm^{-2}) values of paulownia were found higher than that grown in China. So, it is suitable for some uses requiring soft but relatively high strength wood. Modulus of elasticity of paulownia was found lower than that of compared species. The wood can be classified very low and low for compression strength, MOE and bending strength respectively according to Bozkurt and Erdin's (1990) classification.

Hardwoods can be classified as low (I_s<6), fair (6<I_s<7) and good (7<I_s) quality according to their static quality value (I_s). Limit values for the classification change depend on density and hardness of species (Kollmann and Cote, 1984). According to this classification, *Paulownia tomentosa* (I_s=8.10) has a good quality wood.

Paulownia wood is not suitable for uses which require mechanical strength, but it is widely used for houses as roof beams and purlin. Paulownia wood is light, rot-resistant and free of warping, cracks and knots, so, it can be used for model air-planes, aircrafts, gliders and building material for plywood chairs and tables. Due to increased delivery volume it can be used for packing boxes.

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