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STUDY OF SOME PHYSICAL AND MECHANICAL CHARACTERISTICS OF PAULOWNIA TOMENTOSA S. WOOD PLANTED IN NORTHERN IRAQ

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Abstract

This study was conducted at the College of Agriculture, University of Kirkuk to determine the physical and mechanical characteristics of the wood of the *Paulownia tomentosa* S. tree grown in northern Iraq as an input species for wood production. Eight-year-old trees were selected as this species is characterized by its rapid cutting cycles. Its dry density of 0.2968 g/cm^3 and basic density of 0.2745 g/cm^3 were almost low values, negatively affecting their mechanical and physical properties. The ratios of volumetric shrinkage, volumetric swelling, fiber saturation point, immersion moisture content, and maximum moisture content stood at 7.6440, 8.2783, 27.8775, 156.0845 and 298.9300%, respectively. This is considered as having good dimensional stability which reduces the risk of cracking and warping upon drying. The percentage of wood in the cell wall reached 19.79% while its porosity was 80.21%, consistent with other findings on the physical attributes of this tree species. Mechanical strength values in terms of MOE, MOR, tension parallel to the grain, hardness, and compression parallel to the grain were 4002, 57.1285, 36.03, 15.75, and 31.025 N/mm^2, respectively. Based on these values this wood is suitable for low-load purposes such as insulation

partitions in construction, packaging materials, furniture, and agricultural supplies

Keywords: Paulownia tomentosa, Physical characteristics, Mechanical characteristics.

دراسة بعض الخصائص الفيزيائية والميكانيكية لخشب Paulownia tomentosa S. المشجرة في شمال العراق

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الخلاصة

أجريت هذه الدراسة في مختبرات كلية الزراعة في جامعة كركوك بهدف تحديد الصفات الفيزيائية والميكانيكية لخشب أشجار *Paulownia tomentosa* S. المشجرة في شمال العراق كنوع مدخل لإنتاج الأخشاب، اختيرت الأشجار بعمر 8 سنوات حيث يتميز هذا النوع بدورات قطع سريعة، بلغت قيمة الكثافة الجافة لها 0.2968 غم/سم^3 والكثافة الأساسية لها 0.2745 غم/سم^3 وهي قيم منخفضة تقريباً واثرت سلباً على الصفات الميكانيكية والفيزيائية، بلغت نسب (الإنكماش الحجمي والإنتفاخ الحجمي ونقطة تشبع الألياف والمحتوى الرطوبي الغاطس وأقصى محتوى رطوبي) لخشب الباولونيا (7.6440، 8.2783، 27.8775، 156.0845، 298.9300)% على التوالي وتعد جيدة فيما يتعلق بثباتية الأبعاد مما يقلل من خطر التشقق والإلتواء عند التجفيف، أما نسبة الخشب في جدار الخلية فقد بلغت 19.79% في حين بلغت نسبة المسامية لخشب لهذا النوع 80.21% لتتفق مع ما ذكره الباحثون عن صفات الفيزيائية لهذا النوع. قيم القوى الميكانيكية (معامل المرونة، معامل الكسر ، الشد الموازي على التعريق، الصلادة، الضغط الموازي على التعريق) فقد بلغت (4002، 57.1285، 36.03، 15.75، 31.025) نيوتن/ملم^2 على التوالي وهي قيم منخفضة وبالإستناد للنتائج المستحصلة توصى بإستخدام خشب هذا النوع في المجالات التي لا تتحمل أحمال عالية كقواطع عازلة في البناء ومواد للتغليف والأثاث والمستلزمات الزراعية.

كلمات مفتاحية: الباولونيا، الصفات الفيزيائية، الصفات الميكانيكية.

Introduction

Iraq is largely unforested with wooded areas comprising only 825 hectares or approximately 1.90% of its total area (9). The rate of increase in forest area is low at 0.7 hectares per year, compared to the forest area in 1990 which amounted to 804 hectares. Logging is mostly prohibited in these forest areas which are considered protected areas or for tourism. In 2022, the volume of imported timbers and wood products reached 386,461.3 tons (8). The current gap between supply and demand for wood in the market generates an increasing need to increase forest areas, especially for productivity. On the other hand, the common local tree species have long growth periods, and climate fluctuations make it important to plant new and fast-growing species.

Paulownia tomentosa Steud., one of the fastest growing tree species (18), is among those recently introduced to Iraq and planted in the northern regions for its wood (1). Its native habitat is in central and northern China, but was cultivated in ancient times in Japan and South Korea. In Europe and the United States, it was used as a type of ornamental species and for wood production in Brazil, Paraguay, Argentina, and Australia (21). Paulownia includes between 6-17 species and belongs to the Paulowniaceae family. The most important species in this genus are *P. albiphloea*, *P. australis*, *P. catalpifolia*, *P. elongata*, *P. fargesii*, *P. fortunei*, *P. ka-wakamii*, *P. tomentosa* (6).

Paulownia is a deciduous tree capable of reaching very high growth rates under favorable climatic conditions (7). It tends to form many branches if grown in an open space, while in the forest it tends to form a single straight trunk (15). It can be propagated by seeds or from root and vegetative shoots (13 and 17). The height of an adult tree ranges from 10 – 20 m, increasing by 3m per year in the ideal conditions, which allows exploitation in short rotation periods. At 10 years, the diameter of the trees is 30 - 40 cm and the volume of wood 0.3 - 0.5 m^3 per trunk. The trees can also be harvested within 6 - 7 years to obtain low-quality wood and within 15 years to obtain worthwhile wood (2). Unlike most fast-growing tree species, *P. tomentosa* increases its biological productivity during the second cycle or after the first cutting cycle (11).

The properties of wood reflect their structure, and their physical and mechanical properties explain the behavior of this material at different loads (5). The main physical properties that are important for various technological processes of wood processing and largely determine their use include appearance, density, moisture, drying, swelling and thermophysical (16). Paulownia wood is a semicircular, porous-to-finely porous wood, devoid of knots. Often with an average density of less than 300 kg/m^3, the wood is light colored, soft, lightweight, easy to handle, dries quickly and pliable. These properties recommend its use in industrial applications such as furniture, construction timber, packaging, plywood, insulation, for sculptures, crafts and as a reinforcement filler for thermoplastic composites. It has also been observed that products made from paulownia wood do not warp, crack, or decompose easily and are resistant to mold (4). The high wood porosity of this genus, which in some species reaches about 83%, results in low densities and weights. Due to its low weight, the wood is particularly suitable for lightweight construction applications (14).

As an introduced species to Iraq, information is currently lacking on paulownia wood to accurately determine the scope of its uses, especially with its successful cultivation and rapid spread, and adaptation to the prevailing climate and nature of the region. This study thus investigated the physical and mechanical properties of paulownia wood to determine the effect of the types of hardwood and sapwood on the studied characteristics.

Materials and Methods

The study samples were obtained from one of the forests in Erbil Governorate in northern Iraq. The felled 8-year-old trees were transported to the Wood Science Laboratory at the College of Agriculture, University of Kirkuk, and left to air dry. Samples for the study were taken at 1.33m from the base of the main stem for both types of hardwood and sapwood.

Physical characteristics: An 8-cm-thick wooden disc was cut from each log and the bark removed from the wood. Some phenotypic observations of the wood were recorded in the cross- and radial-sections. The sapwood and heartwood were separated and cubed into 2-cm dimensions. They were immersed in water for 72 hours to ensure the saturation point of the fibers was reached and the wet weight of the samples were then determined individually. Volume was measured using the water displacement method. The samples were left to air dry for 72 hours in June, then dried in an oven at 103$\pm$2 °C until the weight was stable, and their dry weight determined immediately after that. Molten paraffin wax was used to create an insulating layer on the samples during dry volume measurement using the water displacement method.

The following equations were used to determine the physical properties according to the method employed by (12):

1. Dry density (g/cm^3) = dry weight/dry volume.
2. Basic density (g/cm^3) = dry weight/wet volume.
3. Volumetric shrinkage % = (wet volume – dry volume)/wet volume × 100.
4. Volumetric swelling % = [(wet volume – dry volume)/dry volume] × 100.
5. Fiber saturation point % = volumetric shrinkage/basic density.
6. Green moisture content % = [(wet weight – dry weight/dry weight] × 100.
7. Maximum moisture content % = [1.5 – basic density/1.5 × basic density] × 100.
8. Percentage of wood in the walls % = [(kiln dry density/1.5)] × 100.
9. Porosity % = 100 - wood percentage %.

Mechanical characteristics: The mechanical properties of both the sapwood and heartwood samples were determined based on the German standard DIN52186 for testing static bending [Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)], the American standard ASTM 143-52 for testing the tensile strength perpendicular to the grain, the strength of hardness, and the German standard DIN 52185 for compression parallel to the grain.

Tests were conducted at a tool testing company in Erbil and the strength determined using the equations for each specification, according to (3):

- MOR = $3P_{max}.L/2WH^2$
- MOE = $PL^3/4YWH^3$

- Tension perpendicular to grain = P/A
- Hardness = P (pressure applied with half an iron ball of 1.128 cm diameter on the tangential side of the sample.
- Compression parallel to the grain = P/Fo

Where, P = maximum load (N), L= distance between the two supports (mm), Y= amount of deviation (mm), W= width of sample (mm), H= sample thickness (mm), A= cross-sectional area of a tensile sample (mm^2), Fo = cross-sectional area (mm^2).

Note: All samples had a moisture content of 12% when tested.

Results and Discussion

Appearance: *Paulownia tomentosa* is characterized by a straight, cylindrical trunk. It begins to branch at 4.5 m for 8-year-old trees. The bark is light, about 2 mm in thickness. The wood is of a homogeneous color, tending to a light yellow that gradually turns to light gray brown in the heartwood area, which constitutes 70 - 80 % of the tree trunk. The growth rings appear clearly with a gradual transition from the spring to the late wood. The pores appear clearly and can be observed with the naked eye. In the center of the trunk in cross section is the pith cavity, which is one of the distinctive features of this species, ranging from 0.8 - 1.1 cm.

In the radial section it appears in the form of chambers, but they are intermittent along the trunk and fill with age and as they go downward (Figure 1). The wood is lightweight, has a smooth texture, is almost odorless, has a distinctive shine, and has little cracking and warping. It has a high ability to dry in the oven over 24 – 36 hours. It accepts paint with preservatives and polishes, depending on the quantity and viscosity of the material used, as large quantities of it are absorbed due to the porosity of the wood. This is consistent with what was mentioned by (1, 16 and 18).

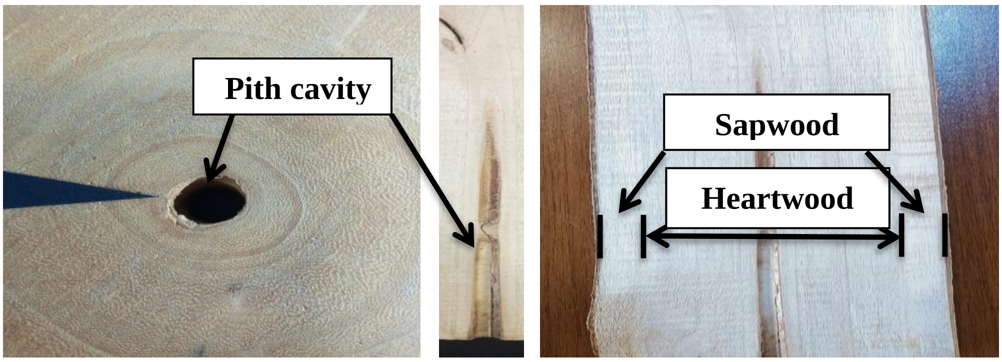

Fig. 1: Radial and cross-section of a *P. tomentosa* stem at a height of 1.33 m.

Physical characteristics: Table 1 shows the values of some of the main physical properties of the *P. tomentosa* wood, including oven dry density, basic density, volumetric shrinkage, volumetric swelling, fiber saturation point, green moisture content, maximum moisture content, and cell wall and porosity percentages for both sapwood and hardwood.

Oven-dry and basic densities (g/cm^3): Density is an indicator of quality and is closely related to mechanical properties, resistance, and thermal energy. It varies greatly from pith to bark, especially in fast-growing trees (21). In this study, the average dry density of *P. tomentosa* wood was 0.29685 g/cm^3, and its basic density was 0.2745 g/cm^3. Heartwood excelled in dry and basic density values reaching 0.3102 and 0.2882 g/cm^3, respectively while sapwood registered 0.2835 and 0.2603 g/cm^3, respectively (Figure 2). The low-density values of this species are consistent with those mentioned by (4, 14, 16 and 19). Variations in heartwood and sapwood densities depend mainly on the growth and fluctuation of the ring structure and on the compositional and chemical changes resulting from the formation of heartwood (20).

Table 1: Physical characteristics of P. tomentosa wood.

Physical characteristics	Units	Sapwood	Heartwood	Average
Oven dry density	g/cm^3	0.2835	0.3102	**0.29685**
Basic density	g/cm^3	0.2603	0.2882	**0.2745**
Volumetric shrinkage	%	8.1874	7.0970	**7.6422**
Volumetric swelling	%	8.9175	7.6392	**8.2783**
Fiber saturation point	%	31.130	24.625	**27.8775**
Green moisture content	%	156.280	155.889	**156.0845**
Maximum moisture content	%	317.546	280.314	**298.930**
Percentage of cell wall	%	18.9	20.68	**19.79**
Percentage of porosity	%	81.1	79.32	**80.21**

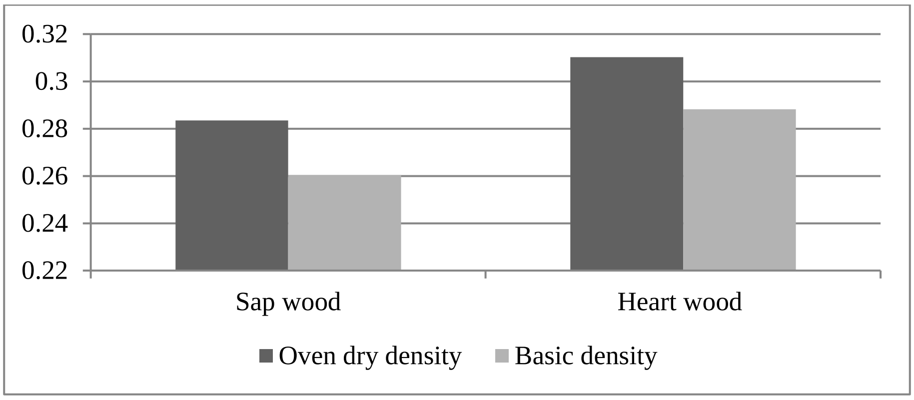

Fig. 2: Oven-dry and basic densities (g/cm^3) for both heartwood and sapwood.

Volumetric shrinkage and swelling: The volumetric shrinkage rate of *P. tomentosa* wood was 7.6422% and its swelling rate was 8.2783%. The respective rates for sapwood were higher at 8.1874 and 8.9175%, respectively compared to solid wood at 7.0970 and 7.6392%, respectively (Figure 3). In this regard, (16) indicated lower shrinkage values in all directions for this type compared to other types of wood according to density indicators. Therefore, this phenomenon will lead to fewer dimensional changes when drying the wood, reducing defects and cracks. All values recorded for the characteristics are consistent with (2 and 19) when they studied the technological properties of paulownia wood, deeming that a good trait for making furniture.

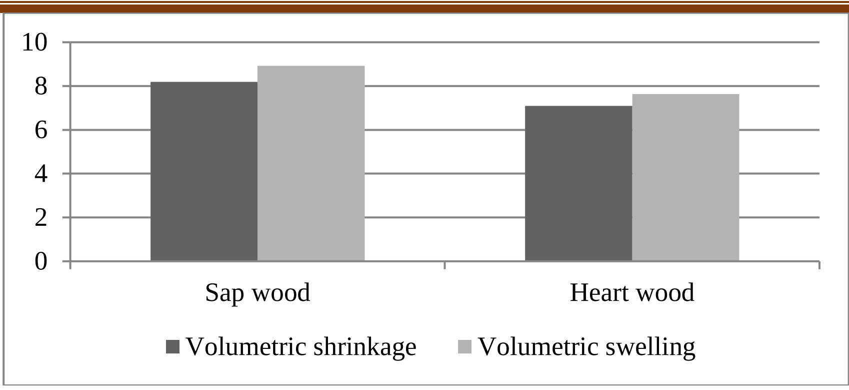

Fig. 3: Volumetric shrinkage and swelling percentages of P. tomentosa wood.

Green and maximum moisture content and fiber saturation point: The immersion moisture content of paulownia wood reached 156.0845%, while its maximum moisture content was 298.930%. Sapwood was relatively superior to heartwood, as the immersion moisture content for both reached 156.280 and 155.889% and the maximum moisture content was 280.314 and 298.930%, respectively (Figure 4). The high moisture content may be due to the wood's low density, the spread of pores, and the high porosity (Table 1).

As for fiber saturation point, it reached 27.8775%, with sapwood recording a higher value at 31.130% compared to 24.625% for solid wood (Figure 4). This superiority could be due to the moisture content of the wood and the saturation point of the fibers, as well as swelling from the readings being affected by several factors, such as density and microscale direction (10).

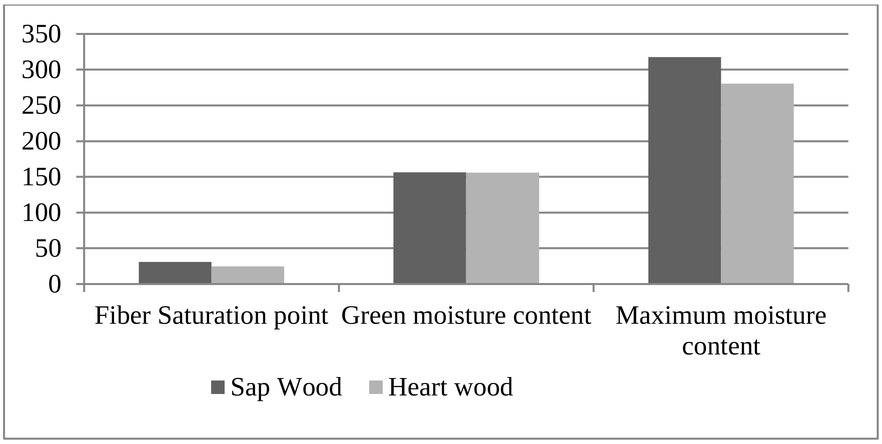

Fig. 4: Percentage of green and maximum moisture content and fiber saturation point of P. tomentosa wood.

Cell wall and porosity: An inherent trait of this type of wood is its high porosity, which is usually associated with a low percentage of cell walls. The cell walls for this type reached 19.79%, which gave it a high porosity estimated at 80.21%, consistent with the findings of (14 and 19). Regarding the effect of the two types of wood on cell walls and porosity, sapwood contained a lower percentage of both (Figure 5).

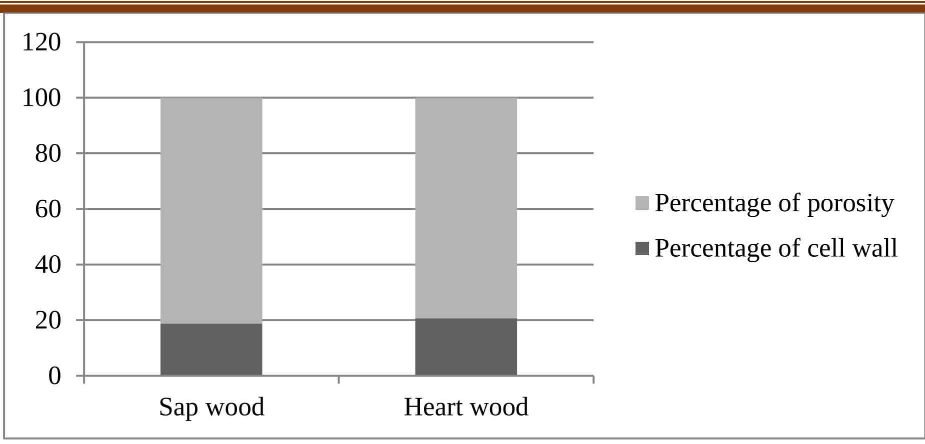

Fig. 5: Cell wall and porosity percentages of P. tomentosa wood.

Mechanical characteristics: The mechanical properties of the wood are listed in Table 2. In this study, the average values of the modulus of rupture were 57.1285 N/mm^2 while that for elasticity was 4002 N/mm^2. There were no significant differences between the strengths for both the sapwood and heartwood, which had MOR values of 57.050 and 57.207 N/mm^2 and MOE of 4061 and 3943 N/mm2 respectively.

The average values for tension parallel to the grain was 36.03 N/mm^2, while those for hardness and pressure parallel to the grain were 15.75 N/mm^2 and 15.75 N/mm^2, respectively. The heartwood outperformed the sapwood for all the tested parameters, due to its increased density over the latter. This is consistent with the findings on the relationship between the density and mechanical properties of wood by (3).

Table 2: Mechanical characteristics of P. tomentosa wood.

Mechanical characteristic	Units	Sapwood	Heartwood	Average
Static bending				
Modulus of Rupture	N/mm^2	57.050	57.207	**57.1285**
Modulus of Elasticity	N/mm^2	4061	3943	**4002**
Tension perpendicular to grain	N/mm^2	33.23	38.83	**36.03**
Hardness	N/mm^2	15.80	19.70	**15.75**
Compression parallel to the grain	N/mm^2	26.719	35.331	**31.025**

All the obtained values were not of high strength and may be a result of the low-density values obtained in this study. This can be explained by the wide annual growth rings and the fact that fast-growing species are characterized by a decrease in their mechanical strength values (16), as noted by the findings of (5, 17 and 18).

Conclusions

The wood was characterized by good dimensional stability, as it showed small rates of volumetric swelling and shrinkage, which reduces the effect of internal pressures that cause cracks and warping to occur. The low density of the wood is due to its light weight and the purpose of growth rings. The high porosity and low cell-wall value gives this type of wood good thermal and sound insulation and electrical conductivity, making its suitable for building insulation, appliances, and machines. The low values of the wood's mechanical properties preclude its use for structural work in construction or in bearing loads. No clear differences appeared in most of the studied traits as a result of their influence on the types of sapwood and hardwood.

Supplementary Materials:

No Supplementary Materials.

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All team members participated in all parts of the research.

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Data Availability Statement:

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The authors declare no conflict of interest.

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