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Physical and mechanical properties of *Paulownia tomentosa* (Thunb.) Steud. wood under the conditions of the Western Forest-Steppe of Ukraine

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Abstract

The forest raw material base of Ukraine needs a long-term recovery, caused by current shortage of wood and in the long-term perspective, as well. One of the ways to solve this problem is to create plantations of *Paulownia tomentosa* (Thunb.) Steud., which are able to accumulate in a very short time a significant stock of wood, suitable for industrial use. Determination of the physical and mechanical properties was carried out on samples of standard sizes. It has been established that the density of paulownia wood, grown under the conditions of the Western Forest Steppe of Ukraine, ranges from 329–342 kg·m^{-3} (sapwood, heartwood) to 416 kg·m^{-3} (middle part between the sapwood and heartwood). Under the conditions when only air moisture influences the wood, the moisture content increases up to 12.9 %. Static bending strength, compressive strength parallel to grain, static hardness, modulus of elasticity of sapwood and heartwood parts of the trunk are characterized by minimum values, and the middle part (between the sapwood and heartwood) – by maximum ones. Therefore, in terms of appearance and texture, the wood has the most similarity with the wood of common ash; considering its density value, paulownia wood resembles the wood of Norway spruce and silver fir, but due to lower moisture absorption and the content of tannins, it is more resistant to decay than the mentioned species; the middle part according to some mechanical indicators is close to common pine wood, therefore, it can be widely used in building industry. *Paulownia tomentosa* wood is advisable to be used as a promising material for the production of firewood and wood pellets. The data we have obtained can be taken into account by specialists in the woodworking, furniture and agricultural industries when planning the creation of plantations and the use of its wood.

Key words: modulus of elasticity, moisture content, plantations, porosity, shrinkage, strength, swelling.

Introduction

In terms of the total area of forest resources and wood stocks, Ukraine belongs to the countries with insufficient forest resources. Forests on the territory of the country are situated unevenly – most of them are distributed in Polissia and the

Ukrainian Carpathians (Gensiruk 1992). Due to a number of geographical, historical and economic factors, the restoration of the forest resource base of Ukraine is long-term process. According to the latest data of the State forest cadastre of Ukraine, on the areas, covered by forests, young trees and middle-aged plantations dominate, while share of mature and over-mature ones has only 23–24 % in total. The reason for such distribution by age classes is the excessive felling of stands in recent decades and reforestation on the resulting logs.

The age of the main felling for most forest-forming species (common oak, pine, European (common) beech, Norway spruce and silver fir) is 80–100 years. In this regard, the main problem is not the predominance of young and middle-aged plantations, but a long period for cultivation of autochthonous tree species that causes a shortage of commercial timber now and in the future.

One of the ways to solve this problem is to set up plantations of fast-growing introducers, which are able to accumulate a significant supply of wood suitable for industrial use in a very short time (5–10 years) and do not pose a biological threat to native species and biodiversity. *Paulownia tomentosa* (Thunb.) Steud. is one of such potentially promising introducers for cultivation in Ukraine on an industrial scale.

The plant species is considered an invasive one in some countries and is not recommended for cultivation there (Jakubowski 2022). In Ukraine, since 2023, paulownia is prohibited for use in reforestation (Order No 184 of the Ministry of Environmental Protection and Natural Resources of Ukraine), but not prohibited for growing on plantations.

As a promising trend for the application of raw plant materials of *Paulownia tomentosa* is considered the medical and pharmaceutical industry, in particular as a source of anti-inflammatory and antibacterial herbal drugs (Darmohray and Lysiuk 2021, Sławińska et al. 2023).

Most species of the genus Paulownia are native to East and Southeast Asia – Japan, Korea, China, Laos, Vietnam (Vorobyov 1982, Zayachuk 2014). In Ukraine, *Paulownia tomentosa*, which grows quite quickly and whose wood has high heat transfer rates, can potentially be used as a raw material for the production of sawdust, biofuel, ethanol, etc. The effective duration of the use of its plantations with benefits for the economy and the environment comprises 20–50 years. After each felling of trees, which can be carried out on plantations regardless of the season at intervals of 4–8 years, the trees are regenerated with stump sprouts. With proper care, after 7 years, one can get 240–350 m^3 of high-quality wood from 1 ha, while the wood, which accumulates a large amount of tannins, is resistant to the effects of many pests and diseases.

The physical properties of wood are revealed during its interaction with the external environment and significantly affect the technological processes of wood processing. The main physical properties that are important for various technological processes of wood processing and largely determine its use comprise appearance, density, moisture, drying and swelling, thermophysical properties of wood (Ali et al. 2021, Nowak et al. 2021, Tomec and Karižˇ 2022).

The properties of *Paulownia tomentosa* wood are described in a limited number of scientific sources and contain rather contradictory data. The majority of scientific works highlight the problem of plantation cultivation and the conditions of culti-

vation of the wood species. Thus, Icka et al. (2016) describe the results of the cultivation of *Paulownia tomentosa* in the forest vegetation conditions of south-eastern Albania, indicating the rapid growth and high adaptability of the species to different climate conditions.

Sobhani et al. (2011) note that paulownia is a promising wood species for production of sandwich panels due to its low density (0.26 $g \cdot cm^{-3}$) and high strength to weight ratio of wood.

While investigating the morphology and anatomy of cells, the physical and mechanical properties of the wood of the new hybrid Green Paulownia, San et al. (2016) recommend the wood of the species as a material for the manufacture of furniture and cellulose production.

The density of hybrid paulownia (Shan Tong) wood, grown in Poland, as determined by Kozakiewicz et al. (2020), in an absolutely dry state is about 250 $kg \cdot cm^{-3}$. Researchers point to the high porosity of Paulownia wood (85 %) and consider it as a good thermal insulation material that has favourable resistance properties, characterized by a modulus of elasticity of 4.05 GPa.

Based on the studies of the physical and mechanical properties of Paulownia COTE−2 wood, grown in Granada (region of Spain), Lachowicz and Giedrowicz (2020) found that Paulownia wood is very light, its density is 270 $kg \cdot cm^{-3}$. The static bending was 38 MPa and the compressive strength parallel to grain was 24 MPa.

Cultivation of *Paulownia tomentosa* on plantations in Hungary has been practiced for the last 10–15 years. Koman et al. (2017) compared *Paulownia tomentosa* wood with poplar wood in terms of basic mechanical properties. These authors, after establishing the low density of paulownia wood (300 $kg \cdot m^{-3}$) and low indicators of its strength (static bending strength 42 MPa, compressive strength parallel to grain 22 MPa, tensile strength 33 MPa, impact strength 1.6 $j \cdot cm^{-2}$), don`t recommend it for the production of structural materials.

Akyildiz and Kol (2010) determined the mechanical properties of *Paulownia tomentosa* wood, grown in Turkey, in particular, the wood's static bending strength (43.56 $N \cdot mm^{-2}$), modulus of elasticity (4281.32 $N \cdot mm^{-2}$), compressive strength parallel to grain (25.55 $N \cdot mm^{-2}$). The authors of the study characterize paulownia wood as relatively light that has an increased resistance to decay, undergoes no deformation, without cracks, and they recommend it for the manufacture of furniture, decoration of cars, airplanes, as well as for the paper industry.

There is no information at all about the characteristics of *Paulownia tomentosa* wood, grown in Ukraine. Mainly, the scientific works of a number of researchers in the field of wood science are devoted to the study of the physical and mechanical properties of the wood of autochthonous and other introduced coniferous and deciduous species in Ukraine.

The study of the properties of paulownia wood, grown in the conditions of Ukraine, would enable to compare it with autochthonous species, give an assessment of quality and determine the prospects for use in the industry.

The object of the research is *Paulownia tomentosa* wood, grown in the conditions of the Western Forest Steppe of Ukraine.

The subject of the study comprises the physical and mechanical properties of *Paulownia tomentosa* wood, grown in the conditions of the Western Forest Steppe of Ukraine.

The purpose of the work is to investi-

gate the physical and mechanical properties of *Paulownia tomentosa* wood, grown in Ukraine, and to make an assessment of its suitability for the industrial uses.

To achieve this goal, the following main research tasks were planned: to determine the density, porosity, moisture content, shrinkage and swelling, strength of wood; make a comparative assessment of the physical and mechanical properties of *Paulownia tomentosa* wood with autochthonous species.

Materials and Methods

The 10-year-old *Paulownia tomentosa* model trees were harvested in the conditions of Lviv district of Lviv region. Wood samples of standard sizes for studying the physical and mechanical properties were prepared from selected model trees of paulownia, in accordance with the requirements of the applicable standards (Ugolev 1965, Leontiev 1970, Borovykov and Ugolev 1989). Test samples of wood were made from three different ridges within the trunk to detect changes in wood properties and selected along the trunk radius to determine wood properties within the diameter.

Determination of the physical and mechanical properties of the wood of *Paulownia tomentosa* was carried out on samples of standard sizes in the wood science laboratory at the Department of Botany, Wood science and Non-wood Forest Products of the Ukrainian National Forestry University on the universal electromechanical testing machine IR 5057-50.

The absolute and relative moisture content of the wood was determined, according to the standard (ISO 3129:2012).

Determination of wood shrinkage was carried out according to standard methods on samples, sizes 20×20 mm, 30 mm high with a tolerance of +1 mm, in which the annual layers are parallel with two margins of the selected samples on the transverse plane and perpendicular to two opposite borders. The selected wood samples were soaked in distilled water at room temperature to reach the saturation limit of the cell membranes for 25 days. Two repeated control measurements were carried out within three days. If the difference in measurements was less than 0.02 mm, the selected wood samples were considered saturated. Then the selected samples were dried for 48 hours at a temperature of 103 ±2 °C in a drying cabinet. Drying of wood samples was stopped when the difference between the control measurements of the samples was less than 0.02 mm. Dried wood samples were cooled in hermetically sealed vessels and their minimum dimensions were measured. The calculation of complete linear shrinkage in the radial, tangential directions and volumetric shrinkage was carried out, in accordance with the standard formulas (Ugolev 1965, Borovykov and Ugolev 1989, Vintoniv et al. 2007).

To determine the density of wood, standard samples of 20×20×30 mm were used, weighed to an accuracy of 0.001 g and their dimensions were measured with a digital caliper with a measurement accuracy of 0.01 mm. Determination of density indicators was carried out, according to the standard formulas (Barnett and Jeronimidis 2003, Vintoniv et al. 2007).

The wood porosity was determined in the basic and completely dry states, in accordance with the standard formulas (Barnett and Jeronimidis 2003, Vintoniv et al. 2007).

Determination of the compressive strength parallel to grain was carried out on a special device, in accordance with

the current standard (ISO 3129:2012). A wood sample measuring 20×20 mm and 30 mm high with a tolerance of +1 mm was uniformly loaded with force at such a speed that the destruction of the wood sample occurred after 0.5–1.5 min after the start of the load. The moment of failure of the test sample was recorded on a digital force gauge. The value of the compressive strength parallel to grain was determined, according to the standard formulas, with the further calculation to moisture content of 12 %.

Determination of the wood modulus of elasticity in static bending was carried out in accordance with the applicable standard. Wooden blocks 20 mm thick × 20 mm wide × 300 mm long were used for research (Poluboyarinov 1976). The samples were placed on two supports, which are symmetrically located relative to the middle of the sample's length. Efforts were directed tangentially to the annual layers. The samples were loaded to 800 N and smoothly unloaded to 300 N six times, measuring for 10 s deflection with an accuracy of 0.01 mm. The modulus of elasticity of wood in static bending is determined by the standard formulas with a conversion to 12 % moisture content.

Determination of the static hardness of wood was carried out on the device of A. H. Pevtsov. Wooden blocks 20 mm thick × 20 mm wide × 150 mm long parallel to grain were used for research (Poluboyarinov 1976). The static hardness of wood was determined on the radial plane of the sample by the size of the imprint through the copy paper from the three-time drop of a steel ball with a diameter of 25 mm from a height of 500 mm. The static hardness of wood was determined, according to the standard formulas, with conversion to 12 % moisture content.

Results and Discussion

The wood of *Paulownia tomentosa* is classified as quite valuable and is used for the manufacture of furniture, musical instruments, in shipbuilding and aviation industry, as well as in many other industries (Komán 2023) where there is a need for lightweight and light-coloured wood, with a beautiful texture (Fig. 1).

Fig. 1. The texture of *Paulownia tomentosa* wood.

As it can be seen from Figure 1, the wood of *Paulownia tomentosa* has a light colour from light coloured honey to steel gray shades with a characteristic silky shine. Among native species, in terms of appearance and texture, common ash (*Fraxinus excelsior* L.) wood is the most similar to *Paulownia tomentosa*.

Due to its relatively low density, *Paulownia tomentosa* wood has a soft surface. This facilitates the mechanical processing

of wood, but leads to the appearance of scratches during exploitation.

On the cross-section of the vessels of the secondary xylem of *Paulownia*, round or elliptical, mostly uniform medullary rays are clearly visible, some of which may have a spindle-like shape and well-developed parenchyma cells. Also, the presence of a small amount of tracheids is a feature of the wood of *Paulownia*. Libriform fibres appear in annual rings at the early stages of development and are arranged in vertical rows 550–1700 μm long (Ates et al. 2008).

We have conducted a number of studies of the physical properties of the *Paulownia tomentosa* wood. The obtained results are shown in Table 1.

Table 1. Physical properties of the *Paulownia tomentosa* wood.

Indicator	***N*, pieces**	***M* ±*m***	±σ	***V*, %**	***P*, %**
Wood density, kg·m^{-3}:					
sapwood	100	329 ±3.99	39.87	12.1	1.2
middle part	100	416 ±7.49	74.88	18.0	1.8
heartwood	100	342 ±5.57	55.72	16.3	1.6
Shrinkage, %:					
tangential	100	3.6 ±0.05	0.46	12.8	1.3
radial	100	2.4 ±0.04	0.42	17.5	1.8
volumetric	100	5.9 ±0.07	0.77	13.0	1.3
Coefficient of shrinkage:					
tangential	100	0.12 ±0.002	0.02	16.7	1.7
radial	100	0.08 ±0.001	0.01	12.5	1.2
volumetric	100	0.20 ±0.004	0.04	20.0	2.0
Wood porosity, %	100	77.65 ±0.90	8.96	11.5	1.1

Note: *M* – average arithmetic value; *m* – error of the average value; σ – mean square deviation, *V* – coefficient of variation, %; *P* – accuracy of the experiment, %.

The data, presented in Table 1, indicate that with a relatively low wood density and a relatively high porosity index, the shrinkage of *Paulownia tomentosa* wood in both the tangential and radial directions is less than for most native timbers. So, according to the index of density, the wood of *Paulownia tomentosa* is similar to the wood of Norway spruce and silver fir, for which it is 410–460 kg·m^{-3}, respectively. However, the tangential shrinkage for these timbers is on average 7.6–7.8 %, and the radial shrinkage is 3.6–3.8 %, while for *Paulownia tomentosa*, according to our data, the tangential shrinkage is 3.6 %, and the radial one – 2.4 %. Practically it means that during drying of *Paulownia tomentosa* wood, it will change its linear dimensions and volume much less, which in turn reduces the manifestation of internal stresses in the wood and the appearance of such typical wood defects as shrinkage cracks and warping. When drying paulownia wood at high temperatures in drying chambers for 24–48 h, the moisture content can reach a level of 10–12 % without visible signs of deformation, warping and twisting of lumber.

We prepared cross-sections of *Paulownia tomentosa* wood and dried them in a drying cabinet at a temperature of 120 °C, as well as by the open-air method directly in the sun. After drying them, we did not observe any signs of warping or shrinkage cracks (Fig. 2).

a **b**

Fig. 2. The appearance of cross-sections of *Paulownia tomentosa* wood after drying: a) in the drying cabinet; b) in the open air.

The wood of deciduous species, in particular *Paulownia tomentosa*, is characterized by such a characteristic as moisture absorption upon repeated exposure to moisture after drying. We conducted a study to check the repeated impact of moisture on the wood of *Paulownia tomentosa* (Table 2).

Table 2. The results of research on the repeated influence of moisture on *Paulownia tomentosa* wood.

Day of observation	Number of samples	Average indicator			
		Initial moisture content of the sample, %	Moisture content of the sample after drying to a completely dry state, %	Moisture content of the sample after repeated wetting, %	
				in a desiccator on a grid over water	in a desiccator in water
1st	50	21.2	0	-	-
10th	50	-	-	11.6	46.2
20th	50	-	-	11.9	48.2
30th	50	-	-	12.9	51.9

As it can be summarized from the data in Table 2, in conditions where wood is affected only by moisture, present in the air, *Paulownia tomentosa* wood behaves atypically, compared to native timber species. During all 30 days of observation, the moisture content of samples, placed in a desiccator on a grid above water, increased only to a value of 12.9 %. Such a percentage is quite acceptable under

the conditions of constant exploitation of wood or products, made from it, and carrying out technological processes of wood processing and indicates the absence of the need for repeated drying of raw materials or products. Under conditions of complete immersion in water, *Paulownia tomentosa* wood, like most timber species, has achieved significant moisture absorption, but its feature is a relatively low indicator of the final value of wood moisture – 51.9 %.

Thus, the results of our research make it possible to recommend *Paulownia tomentosa* wood for using it in industries where the wood needs quick drying and application in conditions of significant influence of moisture in the air.

Paulownia tomentosa wood is recommended as a promising raw material for the production of firewood and pellets (Ryabchuk et al. 1996, Ryabchuk et al. 2000, Matskevych et al. 2019). Important aspects in the drying of firewood comprise the duration of drying and the optimal selection of the drying mode. In order to determine the duration of drying for *Paulownia tomentosa* wood, we selected samples of wood chips from two-year-old paulownia trunks, which were rejected from experimental crops during maintenance, and due to their sizes were suitable for using as a fuel (Fig. 3).

The selected samples were divided into two groups, uniform in quantity and composition and physical size, and dried under different drying modes: the first group – natural drying in an open space in the dried air mode, the second group – the dried air mode with preliminary drying in drying cabinet at a temperature of 90 °C. The results of the research showed that with the dried air mode of drying in sunny, dry weather, *Paulownia tomentosa* wood chips reach the optimal moisture content for burning after 7–9 days, and preliminary dried ones in a drying cabinet – after 3–4 days. The absence of any shrinkage cracks can also be considered a characteristic feature of this type of wood. In combination with the above-described property of wood not to re-absorb mois-

Fig. 3. Samples of *Paulownia tomentosa* wood chips after drying.

ture after drying, it can be considered a promising species for the production of wood fuel. However, its thermophysical properties require further study and clarification.

As it can be concluded considering data, presented in Figure 4, according to its main averaged values of the density, the wood of *Paulownia tomentosa* is close to Norway spruce and silver fir wood, but due to the content of tannins, it is more resistant to decay than the specified species. It should also be noted that the middle part of the trunk of *Paulownia tomentosa* by some indicators is close to the wood of Scots pine, and therefore, it can be widely used in construction.

The mechanical properties of wood by its very nature represent ability to resist the action of external forces that cause temporary or permanent deformations, and at extreme (maximum) loads destroy wood. The main characteristic of such resistance is the strength of wood, which is closely related to the concepts of compression, stretching and bending, the modulus of elasticity. The strength characteristics are necessary indicators for establishing the practical and economical use of wood in various industries.

We have conducted a number of studies of the main mechanical properties of *Paulownia tomentosa* wood, according to typical methods (Ugolev 1965, Poluboyarinov 1976) and the obtained results are given in Table 3.

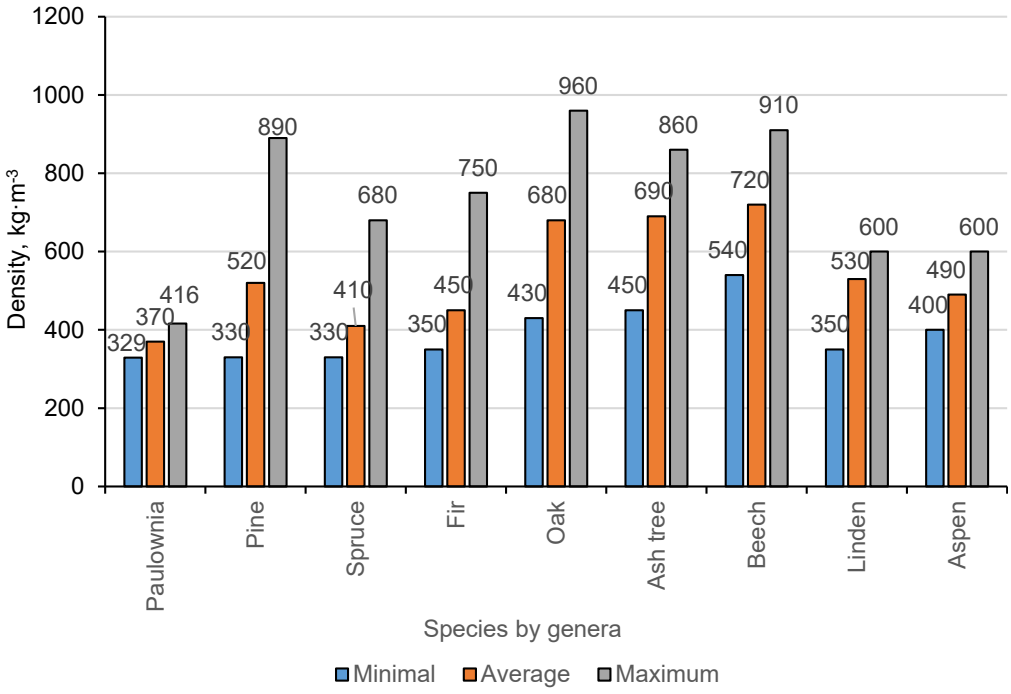


Fig. 4. Comparative data of *Paulownia tomentosa* wood density with other species.

Note: The data for all species, except *Paulownia tomentosa*, are adopted from EN 350:2016 (2016).

Table 3. The main mechanical properties of *Paulownia tomentosa* wood.

Indicator	*N*, pieces	*M*±*m*	±σ	*V*, %	*P*, %
Compressive strength parallel to grain, N·mm^{-2}:					
sapwood	100	22 ±0.42	4.18	19.0	1.9
middle part	100	29 ±0.32	3.26	11.2	1.1
heartwood	100	18 ±0.29	2.87	15.9	1.6
Static bending strength, N·mm^{-2}:					
sapwood	100	26 ±0.60	5.95	22.9	2.3
middle part	100	72 ±1.79	17.93	24.9	2.5
heartwood	100	24 ±0.31	3.12	13.0	1.3
Static hardness, N·mm^{-2}:					
sapwood	30	11 ±0.54	2.96	26.9	2.7
middle part	30	46 ±1.92	10.53	22.9	2.3
heartwood	30	16 ±0.62	6.42	21.4	2.1
Modulus of elasticity, N·mm^{-2}:					
sapwood	100	5200 ±67.39	673.92	13.0	1.3
middle part	100	11450 ±274.46	2744.56	24.0	2.4
heartwood	100	7300 ±109.43	1094.27	15.0	1.5

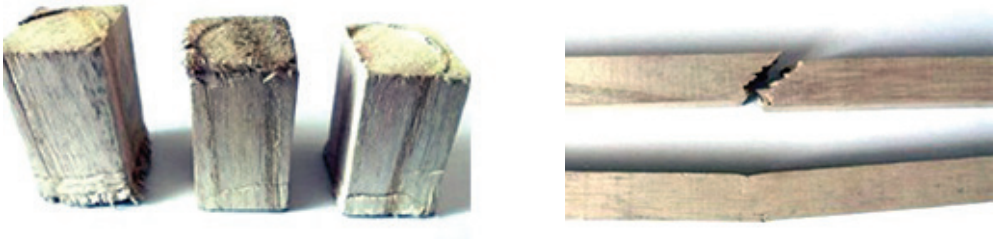
Note: *M* – average arithmetic value; *m* – error of the average value; σ – mean square deviation, *V* – coefficient of variation, %; *P* – accuracy of the experiment, %.

The data presented in Table 3 indicate that the main mechanical indicators of *Paulownia tomentosa* wood are not very high, which can be explained by wide annual growth rings, and as it is known, fast-growing tree species, mainly, have low indicators of the mechanical properties of wood. A characteristic feature of *Paulownia tomentosa* wood is a significant difference in the strength indicators between the sapwood and the heartwood, which are in a close range of values, and the middle part of the trunk, the strength of which is much higher, sometimes, as in the case of the static bending strength and hardness, even by a factor of three. It means that for further practical application it should be considered, that in products, which are subject to significant loads, is advisable to use only the middle part of *Paulownia tomentosa* trunk between the heartwood and the sapwood.

The tendency of a sharp change in the mechanical properties of *Paulownia tomentosa* wood within the diameter of the trunk is clearly visible when the samples are destroyed during tests (Fig. 5). Thus, when tested for static bending, the wood of the heartwood and sapwood parts gives characteristic sharp cracks, but the middle part of the trunk bends, but without sharp cracks, that confirms our recommendations for the practical use of *Paulownia tomentosa* wood in various products and constructions that require strength under static bending.

For more accurate and objective comparison of the properties of *Paulownia tomentosa* wood, we present its characteristics in comparison with native coniferous and deciduous species (Table 4).

Data presented in Table 4 reveal that *Paulownia tomentosa* is characterized by a sharp change in the mechanical properties of wood within the diameter of the trunk. Indicators of the main mechanical



a b

Fig. 5. Characteristics of damages of *Paulownia tomentosa* wood samples: a) compressive, parallel to grain; b) static bending.

Table 4. Comparative characteristics of mechanical properties of *Paulownia tomentosa* wood and autochthonous species.

Indicator	Wood species								
	Paulownia	Pine	Spruce	Fir	Oak	Ash tree	Beech	Linden	Aspen
Modulus of elasticity, $N \cdot mm^{-2}$	7700 (5200–11450) (heartwood – middle part)	12000	12500	11000	13000	13400	16000	9000	7800
Compressive strength parallel to grain, $N \cdot mm^{-2}$	22 (18–29) (heartwood – middle part)	55	44	47	61	52	60	48	33
Static bending strength, $N \cdot mm^{-2}$	46 (24–72) (heartwood - middle part)	100	95	73	88	120	123	98	56
Static hardness, $N \cdot mm^{-2}$	28 (11–46) (heartwood – middle part)	40	32	30	64	65	72	39	22

Note: The data for all species, except *Paulownia tomentosa*, are adopted from EN 350:2016 (2016).

properties of the heartwood and sapwood parts are characterized by minimum values, and of the middle part of the trunk (between the heartwood and sapwood) by maximum ones. So, if in terms of its main averaged characteristics, the wood of *Paulownia tomentosa* is close to the wood of aspen, then the wood of its middle part of the trunk is closer to the wood of conifers, which are widely used in construction.

Conclusions

In terms of appearance and texture, the wood of *Paulownia tomentosa* is the most similar amongst the native species to the wood of common ash. *Paulownia tomentosa* wood, in terms of density, resembles the wood of Norway spruce and silver fir, but due to the content of tannins, it is more resistant to decay than the mentioned species.

During drying, *Paulownia tomentosa* wood changes its linear dimensions and volume much less, which in turn reduces the manifestation of internal stresses in the wood and the appearance of such typical wood defects as shrinkage cracks and warping. The shrinkage of *Paulownia tomentosa* wood in the tangential and radial directions is less than for most native timber species.

When using *Paulownia tomentosa* wood in products that are subjected to significant loads, it is advisable to use only the middle part of the cross-section of the trunk between the heartwood and the sapwood. The middle part of paulownia wood is close to common pine wood, according to some indicators and, therefore, it can be widely used in construction.

The scientific novelty of the obtained research results is that there was no information in the analyzed printed and electronic publications about the physical and mechanical properties of *Paulownia tomentosa* wood grown in Ukraine.

The practical significance of the research results includes the data obtained by us, which can be further taken into account by specialists in the woodworking, furniture and agricultural industries when planning the creation of plantations and the uses of *Paulownia tomentosa* wood.

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