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Physical Properties of Juvenile Wood of Two Paulownia Hybrids

Fizička svojstva juvenilnog drva dvaju hibrida paulovnije

ABSTRACT • *There is a growing trend in the world of planting fast growing species (rotations 5 to 10 years). Their primary purpose is the production of wood fibers and biomass, but they certainly represent the potential in making solid wood products as well. One of the fast-growing species is <u>Paulownia</u> sp., a species of extremely fast growing wood. Plantation breeding of <u>Paulownia</u> sp. in Croatia is increasing, although there is a little knowledge about the technical properties of <u>Paulownia</u> wood and its end use is questionable. This paper presents preliminary results of some physical properties of juvenile wood of two Paulownia hybrids planted in the area near the town of Glina in the Republic of Croatia. One hybrid is 9501 ((<u>Paulownia fortunei × Paulownia elongata</u>) × (<u>Paulownia fortunei × Paulownia tomentosa</u>)) and the other hybrid is Shan Tong (<u>Paulownia fortunei × Paulownia tomentosa</u>). The aim of this study was to investigate physical properties of juvenile wood of two Paulownia hybrids from one site in Croatia, to determine differences in physical properties of wood between two hybrids and to evaluate the correlation between density and shrinkages of each hybrid. Significant differences in oven dry density, basic density and density at maximum MC, between the two hybrids were determined. There is no statistically significant difference in longitudinal, radial, tangential and volumetric shrinkages between the two hybrids.*

Keywords: *hybrid 9501; hybrid Shan Tong; juvenile wood; Paulownia wood; physical properties*

SAŽETAK • *U današnje je vrijeme zamjetan sve češći trend sadnje brzorastućih vrsta drveća (ophodnje od 5 do 10 godina). Te su vrste primarno namijenjene proizvodnji drvnih vlakana i biomase, ali svakako je vidljiv i njihov potencijal u proizvodima od cjelovitog drva. Jedna od brzorastućih vrsta je <u>Paulownia</u> sp., koju odlikuje izrazito brz rast. Iako se malo zna o tehničkim svojstvima drva paulovnije, a njegova je krajnja upotreba upitna, u Hrvatskoj je u porastu plantažni uzgoj paulovnije. U ovom su radu prikazani preliminarni rezultati istraživanja nekih fizičkih svojstava juvenilnog drva hibrida paulovnije s lokaliteta u blizini grada Gline u Hrvatskoj. Prvi je hibrid 9501 ((<u>Pau-lownia fortunei × Paulownia elongata</u>) × (<u>Paulownia fortunei × Paulownia tomentosa</u>)), a drugi Shan Tong (<u>Pau-lownia fortunei × Paulownia tomentosa</u>). Cilj rada bio je istražiti fizička svojstva juvenilnog drva hibrida paulovnije s lokaliteta u Hrvatskoj, utvrditi razlike u fizičkim svojstvima drva tih hibrida te odrediti međusobni odnos gustoće i utezanja unutar hibrida. Utvrđene su značajne razlike u gustoći drva u apsolutno suhom stanju, u nominalnoj gustoći i gustoći pri maksimalnom sadržaju vode između tih dvaju hibrida. Među hibridima nisu utvrđene statistički značajne razlike u longitudinalnome, radijalnome, tangentnome ni volumnom utezanju.*

Ključne riječi: *hibrid 9501; hibrid Shan Tong; juvenilno drvo; drvo paulovnije; fizička svojstva*

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1 INTRODUCTION
1. UVOD

The trend of increasing demand for wood raw material is becoming of great global concern. The answer to this would be to plant more fast growing trees of different species, in order to conserve native forests and to ensure adequate supplies of wood. *Paulownia* sp. is an example of very adaptable genus requiring minimal management after the first few years (El-Showk, 2003). It has been cultivated throughout Asia for centuries, with China having the longest history (Ates *et al.*, 2008).

Paulownia wood is considered to be extremely fast growing, especially in the juvenile phase of growth. Under optimal conditions, *Paulownia* sp. trees can produce useful timber within five to six years, measuring 30-40 cm in diameter after ten years (Olson and Carpenter, 1982; Zhao-Hua *et al.*, 1986). It is widely used for various purposes, with excellent prospects for pulp and biomass (Vilotić *et al.,* 2015; Icka *et al.,* 2016; Vusić *et al.,* 2018). However, as a solid wood, it is suggested to be used in products that are not subject to great loads during exploitation (Šoškić *et al.,* 2003) and not for structural purposes (Koman *et al.*, 2017).

Due to its high adaptability, new markets are developing rapidly for plantation grown *Paulownia* sp. in many countries. In Croatia, the most commonly propagated are *Paulownia* hybrids Shan Tong and 9501. Currently, there are no Paulownia hybrid trees with known origin older than four years in Croatia. Drvodelić (2018) investigated their propagation by root cuttings, where the difference in rooting percentage between two hybrids depended on the cutting thickness and drying procedure. However, technical properties of hybrids 9501 and Shan Tong have not been investigated so far in Croatia. In addition, there are limited data on technical properties of wood of different *Paulownia* species (Ayhildiz and Kol, 2010; Kiaei, 2013; San *et al*., 2016; Komán *et al*., 2017).

Therefore, data on properties of *Paulownia* hybrid wood grown on the territory of the Republic of Croatia are needed. This information could determine whether *Paulownia* sp. is profitable for cultivation and use as a raw material for industrial purposes.

The aim of this study was to investigate physical properties of *Paulownia* hybrids 9501 and Shang Tong juvenile wood from one site in the Republic of Croatia, to determine differences in physical properties of wood between two hybrids and to evaluate the correlation between density and shrinkages of each hybrid.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For the purpose of this research, two 4-year old *Paulownia* hybrids were taken from the area near the town of Glina in Croatia. One hybrid is 9501 ((*Paulownia fortunei* × *Paulownia elongata*) × (*Paulownia fortunei* × *Paulownia tomentosa*)) and the other hybrid is Shan Tong (*Paulownia fortunei* × *Paulownia tomento-*

sa). Five test trees of each hybrid were taken from the experimental stand. All trees were chosen as representative of the stand according to HRN ISO 3129:2015.

Four disks were cut at breast height (1.3 m), upwards to the crown, from each tree. Disks were approximately 5 cm thick and 10 cm in diameter. Maximum number of test samples were cut from each disk, according to HRN ISO 3129:2015.

Physical properties determined in this study were density in absolutely dry condition, basic density and density at maximum moisture content (HRN ISO 13061-2:2015); longitudinal, radial and tangential shrinkage (ISO 13061-13:2016); volumetric shrinkage (ISO 13061-14:2016) and maximum moisture content (HRN ISO 13061-1:2015).

Statistical analysis of data and their comparison were carried out in Statistica 8. Data were analyzed and presented as the minimum, mean and maximum values, as well as standard deviation. The analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of investigated wood properties of two *Paulownia* hybrids. Duncan's multiple range test (DMRT) was applied to test statistical significance at $\alpha = 0.05$ level. The simple linear regression model was used to analyze the relationship between density and shrinkage.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Statistical values of Paulownia hybrids 9501 and Shan Tong juvenile wood, as well as the summary of analysis of variance (ANOVA) for oven dry density, basic density, density at maximum moisture content (MC), longitudinal, radial, tangential, and volumetric shrinkage are shown in Table 1, Table 3, Figure 1 and Figure 2.

Physical properties of wood, especially wood density and dimensional stability, are important factors affecting wood quality (Ištok *et al.*, 2016). Mean oven dry density of hybrid 9501 is 249 kg/m³ and of hybrid Shan Tong is 237 kg/m³ (Table 1). The analysis of variance (ANOVA) indicated that there is significant difference in oven dry density between the two hybrids (Table 3). However, these differences in mean values amounted only to about 6%. The values are similar to the findings on *Paulownia elongata*, 240 kg/m³ (Šoškić *et al*., 2003); *Paulownia tomentosa*, 276 kg/m³ (Komán *et al*., 2017); *Paulownia fortunei*, 274 kg/m³ (Šoškić *et al*., 2017) and 261 kg/m³ (Kiaei, 2013).

For hybrid 9501, the mean value of longitudinal shrinkage is 0.30 %, radial shrinkage 2.35 %, tangential shrinkage 4.95 % and volumetric shrinkage 7.62 % (Table 1). For hybrid Shan Tong, the mean value of longitudinal shrinkage is 0.35 %, radial shrinkage 2.47 %, tangential shrinkage 5.30 % and volumetric shrinkage 7.81 % (Table 1). The analysis of variance (ANOVA) indicated that there is no significant difference in shrinkages between the two hybrids (Table 3). Very high variability of longitudinal shrinkage is present. This could be explained by low age of investigated trees, closely to juve-

Table 1 Descriptive statistical analysis of physical properties between Paulownia hybrids 9501 and Shan Tong
Tablica 1. Deskriptivna statistička analiza fizičkih svojstava hibrida paulovnije 9501 i Shan Tong

Property *Svojstvo*	Hybrid *Hibrid*	Number of samples *Broj uzoraka*	Mean[a] *Srednja vrijednost[a]*	Standard deviation *Standardna devijacija*	Min	Max
Oven dry density *gustoća u apsolutno suhom stanju*	9501	34	0.249 a	0.016	0.221	0.295
	Shan Tong	34	0.237 b	0.019	0.201	0.277
Basic density / *nominalna gustoća*	9501	34	0.233 a	0.014	0.208	0.272
	Shan Tong	34	0.220 b	0.017	0.187	0.252
Density at maximum MC *gustoća pri maksimalnom sadržaju vode*	9501	34	0.719 a	0.078	0.600	0.917
	Shan Tong	34	0.669 b	0.063	0.562	0.850
Longitudinal shrinkage *longitudinalno utezanje*	9501	34	0.30 a	0.202	0.04	0.74
	Shan Tong	34	0.35 a	0.332	0.04	1.20
Radial shrinkage / *radijalno utezanje*	9501	34	2.35 a	0.489	1.61	3.42
	Shan Tong	34	2.47 a	0.631	1.67	4.69
Tangential shrinkage / *tangentno utezanje*	9501	34	4.95 a	0.643	4.05	6.26
	Shan Tong	34	5.30 a	0.969	3.80	8.02
Volumetric shrinkage / *volumno utezanje*	9501	34	7.62 a	0.966	6.07	9.38
	Shan Tong	34	7.81 a	1.409	5.13	11.21
Maximum MC / *maksimalni sadržaj vode*	9501	34	208 a	19.432	172	253

[a] Rresults with different letters have a significant difference with the Duncan's test. / *Rezultati s različitim slovima statistički se značajno razlikuju prema Duncanovu testu.*
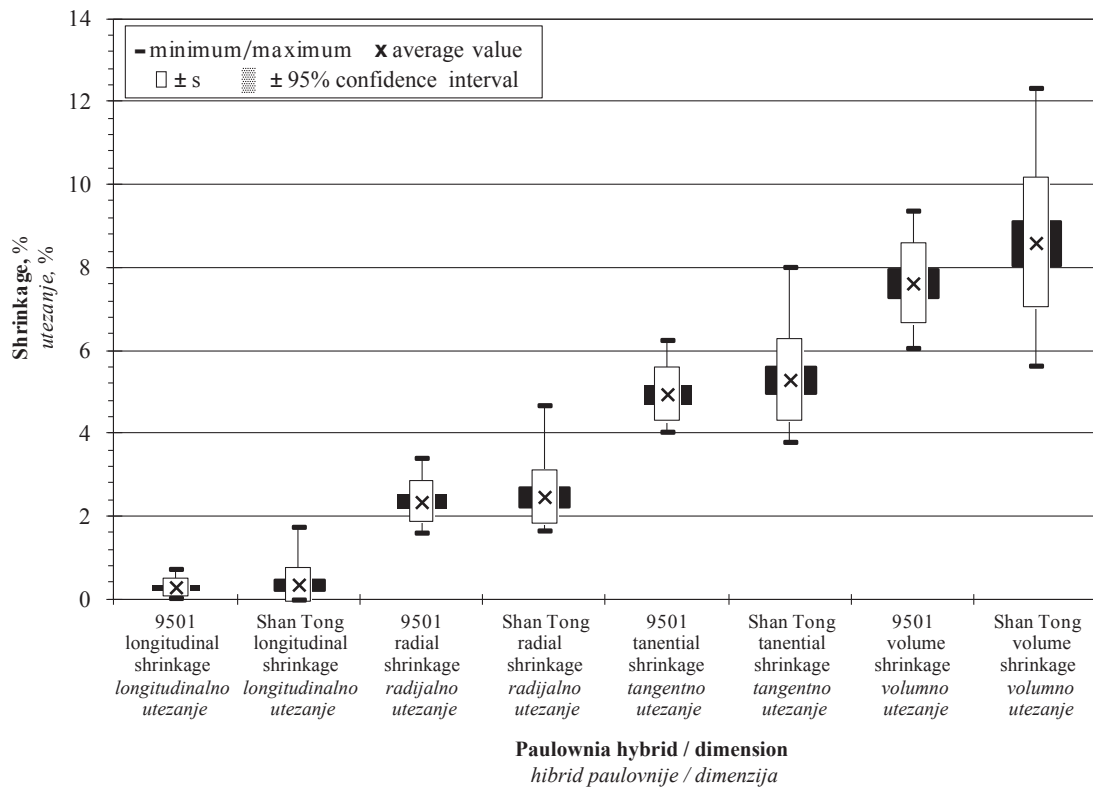

Figure 1 Statistical analyses of longitudinal, radial, tangential and volume shrinkage, between two paulownia hybrids
Slika 1. Statistička analiza longitudinalnoga, radijalnoga, tangentnoga i volumnog utezanja, dvaju hibrida paulovnije

Table 2 Comparison of shrinkage values with references
Tablica 2. Usporedba vrijednosti utezanja s rezultatima iz literature

Property *Svojstvo*	Hybrid 9501 (our research) *Hybrid 9501 (vlastito istraživanje)*	Hybrid Shan Tong (our research) *Hybrid Shan Tong (vlastito istraživanje)*	*P. elongata* (Šoškić et al., 2003)	*P. fortunei* (Šoškić et al., 2003)	*P. tomentosa* (Kiaei, 2013)	*P. fortunei* (Komán et al., 2017)
Radial shrinkage / *radijalno utezanje*	2.35	2.47	2.49	2.54	-	2.20
Tangential shrinkage / *tangentno utezanje*	4.95	5.30	4.74	4.79	-	3.89
Volumetric shrinkage / *volumno utezanje*	7.62	7.81	8.31	8.35	7.54	6.94

Table 3 Analysis of variance (ANOVA) results for physical properties between Paulownia hybrids 9051 and Shan Tong juvenile wood
Tablica 3. Analiza varijance (ANOVA) fizičkih svojstava juvenilnog drva hibrida paulovnije 9051 i Shan Tong

| Property *Svojstvo*	Effect *Varijabilnost*	Sum of squares *Suma kvadrata*	Degree of freedom *Stupnjevi slobode*	Mean square *Varijanca*	F	p
Oven dry density *gustoća u apsolutno suhom stanju*	Between Groups / *između grupa*	0.003	1	0.003	8.41	0.005
	Within Groups / *unutar grupa*	0.020	66	0.000		
	Total / *ukupno*	0.023	67			
Basic density *nominalna gustoća*	Between Groups / *između grupa*	0.003	1	0.003	12.67	0.000
	Within Groups / *unutar grupa*	0.015	66	0.000		
	Total / *ukupno*	0.018	67			
Density at maximum MC *gustoća pri maksimalnom sadržaju vode*	Between Groups / *između grupa*	0.043	1	0.043	8.649	0.005
	Within Groups / *unutar grupa*	0.329	66	0.005		
	Total / *ukupno*	0.372	67			
Longitudinal shrinkage *longitudinalno utezanje*	Between Groups / *između grupa*	0.513	1	0.051	0.678	0.413
	Within Groups / *unutar grupa*	4.990	66	0.076		
	Total / *ukupno*	5.503	67			
Radial shrinkage *radijalno utezanje*	Between Groups / *između grupa*	0.262	1	0.262	0.822	0.368
	Within Groups / *unutar grupa*	21.028	66	0.319		
	Total / *ukupno*	21.290	67			
Tangential shrinkage *tangentno utezanje*	Between Groups / *između grupa*	2.038	1	2.038	3.014	0.087
	Within Groups / *unutar grupa*	44.634	66	0.676		
	Total / *ukupno*	46.672	67			
Volumetric shrinkage *volumno utezanje*	Between Groups / *između grupa*	4.244	1	4.244	2.722	0.103
	Within Groups / *unutar grupa*	102.903	66	1.559		
	Total / *ukupno*	107.147	67			
Maximum MC *maksimalni sadržaj vode*	Between Groups / *između grupa*	233.0	1	233.0	0.628	0.430
	Within Groups / *unutar grupa*	24491.0	66	0.781		
	Total / *ukupno*	24724.0	67			
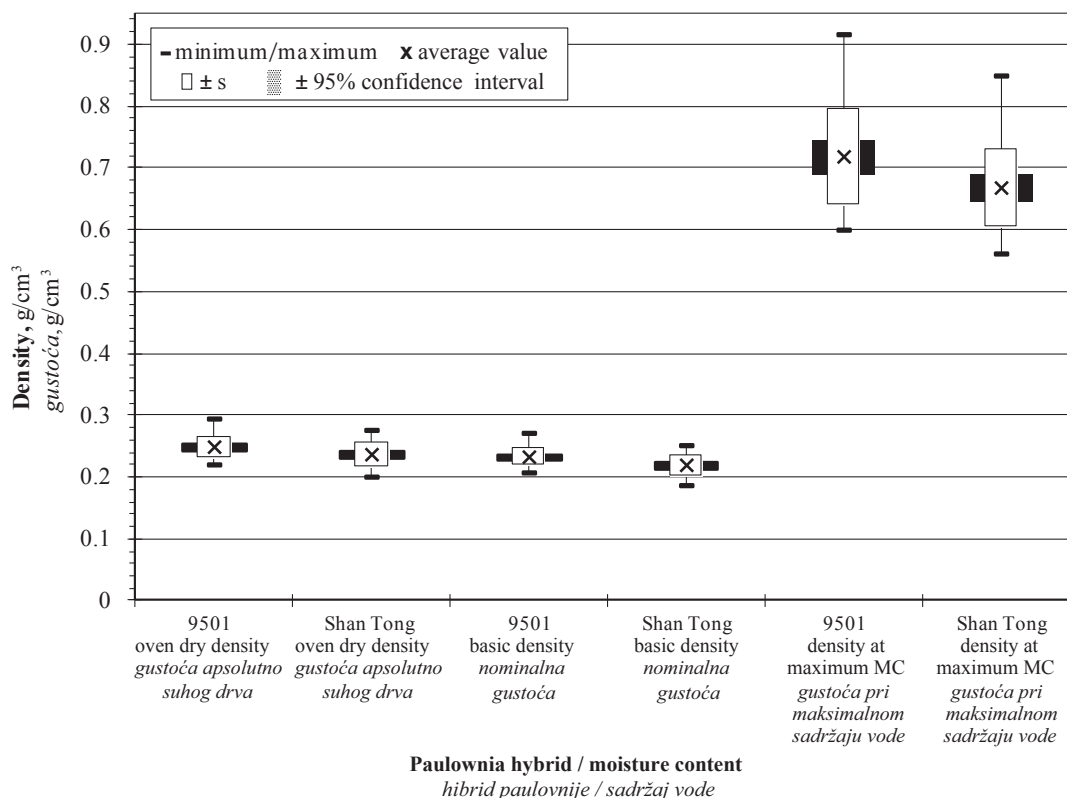
Figure 2 Statistical analyses of oven dry density, basic density and density at maximum MC, between two paulownia hybrids
Slika 2. Statistička analiza gustoće u apsolutno suhom stanju, nominalne gustoće i gustoće pri maksimalnom sadržaju vode, dvaju hibrida paulovnije

Table 4 Relationship between oven dry density and shrinkage of Paulownia hybrids 9051 and Shan Tong juvenile wood
Tablica 4. Odnos između gustoće i utezanja juvenilnog drva hibrida paulovnije 9501 i Shan Tong

	R	Equation / *Jednadžba*	*F*ᵃ	*p*
Relationship between oven dry density and shrinkage (9501)				
Odnos između gustoće u apsolutno suhom stanju i utezanja (9501)				
Longitudinal shrinkage / *longitudinalno utezanje*	0.02		0.113 ᴺˢ	0.916
Radial shrinkage / *radijalno utezanje*	0.4635		8.751 *	0.006
Tangential shrinkage / *tangentno utezanje*	0.3073		3.334ᴺˢ	0.077
Volumetric shrinkage / *volumno utezanje*	0.5014		10.745*	0.003
Relationship between oven dry density and shrinkage (Shan Tong)				
Odnos između gustoće u apsolutno suhom stanju i utezanja (9501)				
Longitudinal shrinkage / *longitudinalno utezanje*	0.0980		0.311ᴺˢ	0.581
Radial shrinkage / *radijalno utezanje*	0.3468		4.375*	0.045
Tangential shrinkage / *tangentno utezanje*	0.3045		3.268ᴺˢ	0.080
Volumetric shrinkage / *volumno utezanje*	0.3183		3.609ᴺˢ	0.067

*significant at level < 0.05 / *značajno pri < 0,05*
ᴺˢnot significant / *nije značajno*

nility of wood. Irregularity and large variations in longitudinal shrinkage were reported by many authors (Welch, 1932 and 1934; Kelsey, 1963; Hann, 1969; Skaar, 1988). Based on the work of Harris and Meylan (1965), the major cause of the variation in longitudinal shrinkage is varying microfibril angle.

Table 2 shows the comparison of investigated values of shrinkage with other authors.

In this study, regression equations between oven dry density and shrinkage, as well as, statistical significance between two properties are shown in Table 4. The relationship between oven dry density and shrinkage is statistically significant only for radial and tangential shrinkage of hybrid 9501 and radial shrinkage of hybrid Shan Tong. Negative correlation between oven dry density and longitudinal shrinkage in both hybrids was determined. Radial, tangential and volumetric shrinkage showed positive correlation with oven dry density. Measured shrinkages showed weak correlation coefficient with oven dry density, except radial and volumetric shrinkage of hybrid 9501. Similar results were reported by Šoškić *et al.* (2003) for *Paulownia elongata* and *Paulownia fortunei* wood.

4 CONCLUSIONS
4. ZAKLJUČAK

Preliminary result of juvenile wood of two *Paulownia* hybrids showed statistically significant differences between mean values of some investigated physical properties.

Significant differences in oven dry density, basic density and density at maximum MC, between hybrid 9501 and hybrid Shan Tong were determined. However, these differences in mean values of densities amounted only to about 6 %.

There is no statistically significant difference in longitudinal, radial, tangential and volumetric shrinkages between the two hybrids.

Radial, tangential and volumetric shrinkage values of both investigated hybrids are similar to references for some *Paulownia* wood species.

Both hybrids should be investigated after five to ten years when they reach larger diameters.

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