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 Paulownia sp., a species of extremely fast growing wood. Plantation breeding of Paulownia sp. in Croatia is increasing, although there is a little knowledge about the technical properties of Paulownia 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 ((Paulownia fortunei × Paulownia elongata) × (Paulownia fortunei × Paulownia tomentosa)) and the other hybrid is Shan Tong (Paulownia fortunei × Paulownia tomentosa). 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 svečešći 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo često uzgaja i sadnja. Plantacija Paulownia sp. u Hrvatskoj je u porastu, a ovo preduvjeti primjerak znanstvenih istraživanja svečešću trend sadnje novih 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo često uzgaja i sadnja. Plantacija Paulownia sp. u Hrvatskoj je u porastu, a ovo preduvjeti primjerak znanstvenih istraživanja svečešću trend sadnje novih 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo često uzgaja i sadnja. Plantacija Paulownia sp. u Hrvatskoj je u porastu, a ovo preduvjeti primjerak znanstvenih istraživanja svečešću trend sadnje novih 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo često uzgaja i sadnja. Plantacija Paulownia sp. u Hrvatskoj je u porastu, a ovo preduvjeti primjerak znanstvenih istraživanja svečešću trend sadnje novih 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo često uzgaja i sadnja. Plantacija Paulownia sp. u Hrvatskoj je u porastu, a ovo preduvjeti primjerak znanstvenih istraživanja svečešću trend sadnje novih 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 proizvodnji cjelovitih drvenih proizvoda. Jedna od brzorastućih vrsta je Paulownia sp., a vrsta je jedna od vrsta na kojoj se u Hrvatskoj vrlo často u...
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., 2018).

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; Ikaei, 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 Shan 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 tomentosa). 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 α = 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 (Ikaei, 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 juvenile age between two hybrids. This information could determine differences in physical properties of wood of different hybrids. The aim of this study was to investigate physical properties of wood, especially wood density, density at maximum moisture content (MC), longitudinal, radial, tangential, and volumetric shrinkage.
Table 1 Descriptive statistical analysis of physical properties between Paulownia hybrids 9501 and Shan Tong

| Property                          | Hybrid 9501 | Number of samples | Mean ± Standard deviation | Min | Max |
|----------------------------------|-------------|-------------------|---------------------------|-----|-----|
| Oven dry density                 | 9501        | 34                | 0.249 ± 0.016             | 0.221 | 0.295 |
|                                  | Shan Tong   | 34                | 0.237 ± 0.019             | 0.201 | 0.277 |
| Basic density / nominalna gustoča| Shan Tong   | 34                | 0.220 ± 0.017             | 0.187 | 0.252 |
| Density at maximum MC            | Shan Tong   | 34                | 0.669 ± 0.063             | 0.562 | 0.850 |
| Longitudinal shrinkage           | Shan Tong   | 34                | 0.35 ± 0.032              | 0.332 | 0.412 |
| Radial shrinkage / radijalno utezanje | Shan Tong | 34             | 2.47 ± 0.631             | 1.67  | 4.69  |
| Tangential shrinkage / tangentno utezanje | Shan Tong | 34             | 5.30 ± 0.966             | 3.80  | 8.02  |
| Volumetric shrinkage / volumno utezanje | Shan Tong | 34             | 7.81 ± 1.409             | 5.13  | 11.21 |
| Maximum MC / maksimalni sadržaj vode | Shan Tong | 34             | 208 ± 19.432            | 172   | 253   |

*Results 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

Table 2 Comparison of shrinkage values with references

| Property                          | Hybrid 9501 (our research) | Hybrid Shan Tong (our research) | P. elongata (Šoškić et al., 2003) | P. fortunei (Šoškić et al., 2003) | P. tomentosa (Kiacci, 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

| Property                           | Effect              | Sum of squares | Degree of freedom | Mean square | F      | p     |
|------------------------------------|---------------------|----------------|-------------------|-------------|--------|-------|
| Oven dry density                   | 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                      | Between Groups / između grupa    | 0.003          | 1                 | 0.003       | 12.67  | 0.000 |
| nominalna gustoća                 | Within Groups / unutar grupa      | 0.015          | 66                | 0.000       |        |       |
|                                   | Total / ukupno                  | 0.018          | 67                |             |        |       |
| Density at maximum MC             | Between Groups / između grupa    | 0.043          | 1                 | 0.043       | 8.649  | 0.005 |
| gustoća pri maksimalnom sadržaju vode | Within Groups / unutar grupa      | 0.329          | 66                | 0.005       |        |       |
|                                   | Total / ukupno                  | 0.372          | 67                |             |        |       |
| Longitudinal shrinkage            | Between Groups / između grupa    | 0.513          | 1                 | 0.513       | 0.678  | 0.413 |
| longitudinal utezanje             | Within Groups / unutar grupa      | 4.990          | 66                | 0.076       |        |       |
|                                   | Total / ukupno                  | 5.503          | 67                |             |        |       |
| Radial shrinkage                  | Between Groups / između grupa    | 0.262          | 1                 | 0.262       | 0.822  | 0.368 |
| radijalno utezanje                | Within Groups / unutar grupa      | 21.028         | 66                | 0.319       |        |       |
|                                   | Total / ukupno                  | 21.290         | 67                |             |        |       |
| Tangential shrinkage              | Between Groups / između grupa    | 2.038          | 1                 | 2.038       | 3.014  | 0.087 |
| tangento utezanje                 | Within Groups / unutar grupa      | 44.634         | 66                | 0.676       |        |       |
|                                   | Total / ukupno                  | 46.672         | 67                |             |        |       |
| Volumetric shrinkage              | Between Groups / između grupa    | 4.244          | 1                 | 4.244       | 2.722  | 0.103 |
| volumno utezanje                  | Within Groups / unutar grupa      | 102.903        | 66                | 1.559       |        |       |
|                                   | Total / ukupno                  | 107.147        | 67                |             |        |       |
| Maximum MC                         | Between Groups / između grupa    | 233.0          | 1                 | 233.0       | 0.628  | 0.430 |
| maksimalni sadržaj vode           | 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 apsolutnom suhom stanju, nominalne gustoće i gustoće pri maksimalnom sadržaju vode, dvaju hibrida paulovnije
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 (1932 and 1934; Kelsey, 1963; Hann, 1969; Welch, 1932 and 1934; Kelsey, 1963; Hann, 1969; Skaar, 1988), the major cause of the variation in longitudinal shrinkage were reported by many authors when they reach larger diameters.

Table 4 Relationship between oven dry density and shrinkage of Paulownia hybrids 9051 and Shan Tong juvenile wood

| Relationship between oven dry density and shrinkage (9501) | R  | Equation / Jednadžba | F*  | p   |
|----------------------------------------------------------|----|----------------------|-----|-----|
| Longitudinal shrinkage / longitudinal utezanje           | 0.02 | 0.113 NS  | 0.916 |
| Radial shrinkage / radialno utezanje                   | 0.4635 | 8.751 *  | 0.006 |
| Tangential shrinkage / tangentno utezanje               | 0.3073 | 3.334 NS  | 0.077 |
| Volumetric shrinkage / volumno utezanje                 | 0.5014 | 10.745 * | 0.003 |

| Relationship between oven dry density and shrinkage (Shan Tong) | R  | Equation / Jednadžba | F*  | p   |
|---------------------------------------------------------------|----|----------------------|-----|-----|
| Longitudinal shrinkage / longitudinal utezanje               | 0.0980 | 0.311 NS  | 0.581 |
| Radial shrinkage / radialno utezanje                         | 0.3468 | 4.375 *  | 0.045 |
| Tangential shrinkage / tangentno utezanje                    | 0.3045 | 3.268 NS  | 0.080 |
| Volumetric shrinkage / volumno utezanje                      | 0.3183 | 3.609 NS  | 0.067 |

*significant at level = 0.05 / značajno pri < 0.05
NSnot significant / nije značajno

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 9051 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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