DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE • ZAGREB • VOLUMEN 67 • BROJ 3
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY • ZAGREB • VOLUME 67 • NUMBER 3

Fagara heitzii Aubrév. & Pellegr.

3/16

UDK 674.031.677.7 CODEN: DRINAT ISSN 0012-6772

UDK 630*8+674 Coden: Drinat ISSN 0012-6772

DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY

IZDAVAČ I UREDNIŠTVO
Publisher and Editor's Office
Šumarski fakultet Sveučilišta u Zagrebu
Faculty of Forestry, Zagreb University
10000 Zagreb, Svetošimunska 25
Hrvatska – Croatia
*Tel. (*385 1) 235 25 09*

SUIZDAVAČI
Co-Publishers
Exportdrvo d.d., Zagreb
Hrvatsko šumarsko društvo, Zagreb
Hrvatske šume d.o.o., Zagreb

OSNIVAČ
Founder
Institut za drvnoindustrijska istraživanja, Zagreb

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The journal is published quarterly.

OVAJ BROJ ČASOPISA POTPOMAŽE:

Sadržaj
Contents

NAKLADA (Circulation): *700 komada* · **ČASOPIS JE REFERIRAN U (Indexed in):** *CA search, CAB Abstracts, Compendex, DOAJ, Crossref, EBSCO, Forestry abstracts, Forest products abstracts, Geobase, Paperchem, SCI-Expanded, SCOPUS* · **PRILOGE** *treba slati na adresu Uredništva. Znanstveni i stručni članci se recenziraju. Rukopisi se ne vraćaju.* · **MANUSCRIPTS** *are to be submitted to the editor's office. Scientific and professional papers are reviewed. Manuscripts will not be returned.* · **KONTAKTI s uredništvom (Contacts with the Editor) e-mail:** *editordi@sumfak.hr* · **PRETPLATA (Subscription):** *godišnja pretplata (annual subscription) za sve pretplatnike 55 EUR. Pretplata u Hrvatskoj za sve pretplatnike iznosi 300 kn, a za đake, studente i umirovljenike 100 kn, plativo na žiro račun 2360000 – 1101340148 s naznakom "Drvna industrija"* · **ČASOPIS SUFINANCIRA** *Ministarstvo znanosti, obrazovanja i sporta Republike Hrvatske.* · **TISAK (Printed by)** *– DENONA d.o.o., Getaldićeva 1, Zagreb, tel. 01/2361777, fax. 01/2332753, E-mail: denona@denona.hr; URL: www.denona.hr* · **DESIGN** Aljoša Brajdić · **ČASOPIS JE DOSTUPAN NA INTERNETU:** *http://drvnaindustrija.sumfak.hr* · **NASLOVNICA** *Presjek drva* Fagara heitzii *Aubrév. & Pellegr., ksiloteka Zavoda za znanost o drvu, Šumarski fakultet Sveučilišta u Zagrebu*

DRVNA INDUSTRIJA · Vol. 67, 3 · str. 205-304 jesen 2016. · Zagreb
REDAKCIJA DOVRŠENA 2.09.2016.

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Calorific Value and Chemical Properties in Juvenile and Mature Wood of Thermally-Modified *Eucalyptus Grandis*

Kalorijska vrijednost i kemijska svojstva toplinski modificiranoga juvenilnog i zrelog drva eukaliptusa (*Eucalyptus grandis*)

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 30. 3. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*812.144; 630*813.4; 674.031.883.23*
doi:10.5552/drind.2016.1522

ABSTRACT • *During thermal modification, timber is exposed to temperatures approaching 200 ºC for several hours and wood properties change. This study was aimed at evaluating the calorific value and chemical properties of juvenile and mature wood of thermally modified Eucalyptus grandis. Boards were taken from 30-year-old E. grandis trees and thermally modified at 180ºC. Samples of the untreated and thermally modified wood were transformed into chips and then processed into sawdust for the energy and chemical characterization of juvenile and mature wood. The results show that the thermal modification causes: (1) significant increases of 3.7 % and 6.8 %, respectively, in the net calorific value of juvenile and mature wood; (2) significant increases of 24.8 % and 47.6 %, respectively, in the extractive content of juvenile and mature wood; (3) significant decreases of 4.2 % and 8.3 % in the respective holocellulose content; and (4) significant decreases in the galactose, xylose and glucose contents. It was demonstrated that the influence of thermal treatment was lower in juvenile wood than in mature wood.*

Key words: *biomass, energy, chemical properties, Eucalypts, thermally-modified wood*

SAŽETAK • *Tijekom postupaka toplinske modifikacije drvo se nekoliko sati izlaže temperaturama do 200 ºC, zbog čega se mijenjaju njegova svojstva. Cilj ove studije bio je vrednovati kalorijsku vrijednost i kemijska svojstva toplinski modificiranoga juvenilnog i zrelog drva eukaliptusa (Eucalyptus grandis). Piljenice su izrađene od tridesetogodišnjih stabala eukaliptusa i toplinski modificirane pri 180 ºC. Za istraživanje energijskih i kemijskih svojstava juvenilnoga i zrelog drva uzorci nemodificiranoga i toplinski modificiranog drva prerađeni su u iverje, a zatim u piljevinu. Rezultati su pokazali da toplinska modifikacija uzrokuje (1) značajno povećanje neto kalorijske vrijednosti juvenilnoga drva od 3,7 % i 6,8 % zrelog drva; (2) značajno povećanje ekstraktivnih tvari od 24,8 % u*

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juvenilnom drvu i 47,6 % u zrelom drvu; (3) značajno smanjenje sadržaja holoceluloze od 4,2 % u juvenilnom drvu i 8,3 % u zrelom drvu te (4) značajno smanjenje sadržaja galaktoze, ksiloze i glukoze. Dokazano je da je utjecaj toplinske modifikacije na energijska i kemijska svojstva juvenilnoga drva manji nego na svojstva zrelog drva.

Ključne riječi: *biomasa, energija, kemijska svojstva, eukaliptus, toplinski modificirano drvo*

1 INTRODUCTION
1. UVOD

During thermal modification, timber is exposed to temperatures approaching 200 ºC for several hours. Several heat treatments are used commercially in Europe. They differ in the temperature applied, the use of nitrogen or steam or oils as an inert fluid, and their application to wet or dry wood (Brito *et al.*, 2008; Calonego *et al.*, 2010, 2012; Esteves *et al.*, 2007; Wikberg and Maunu, 2004).

Studies showed an improvement of equilibrium moisture content and dimensional stability of 61.0 % and 90.0 % in *Eucalyptus globulus* wood after thermal modification at 190-210 ºC (Esteves *et al.*, 2007), and reductions of 21.5 % and 23.2 % in equilibrium moisture content and volumetric swelling in *E. grandis* wood when thermally-modified at 180 ºC (Calonego *et al.*, 2012). The same wood showed significant reductions of 15.7 % in the weight loss after exposure to *Pycnoporus sanguineus* fungi when thermally-modified at 180 ºC (Calonego *et al.*, 2010).

When the thermal treatment temperature is increased from 180 ºC to 220 ºC, an increase occurs in the number of specimens of *E. grandis* with fragile failures of 10.5 % to 100.0 % in compression to parallel to grain, and of 15.8 % to 100.0 % in static bending (Calonego *et al.*, 2012). Temperatures greater than 180 °C caused internal cracks in wood of thermally-modified *E. grandis* (Calonego and Severo, 2010). The thermal treatment of *Eucalyptus saligna* at 180 °C caused a decrease of up to 53.2 %, 62.8 %, 33.8 %, and 35.1 % in the arabinose, galactose, mannose, and xylose contents, respectively, whereas there was a proportional increase of up to 32.5 % in the lignin content of wood (Brito *et al.*, 2008).

Untreated *Pinus pinaster* wood and thermally modified wood at 260 ºC for 0.5 h, 1.0 h, 2.0 h and 4.0 h showed lignin contents of 28 %, 41 %, 51 %, 54 % and 84 %, respectively. The respective gross calorific values were 17932.1, 21076.4, 22164.9, 22181.7 and 25845.1 kJ/kg (Bourgois and Guyonnet, 1988).

Felfti *et al*. (2005) studied briquette of thermally modified wood between 220 ºC and 270 ºC during 0.5 to 1.5 h and concluded that the increase in the temperature and time of the thermal treatment caused degradation of hemicelluloses and improved the calorific value. The gross calorific value was 20020.0 kJ/kg for untreated wood and 21065.1 kJ/kg and 21209.1 kJ/kg, respectively, for thermally modified wood at 220 ºC for 1.5 h and 250 ºC for 0.5 h.

However, the wood is a heterogeneous material and its chemical and physical variations occur due to several factors, e.g. tree species, silviculture, and especially the wood anatomy. Juvenile wood can be defined as being close to the pith and technologically, it differs from mature wood on account of several properties such as: fiber length, density, stability of wood and chemical properties (Bao *et al*., 2001; Calonego *et al*., 2005a, 2014; Severo *et al*., 2012; Zobel and Van Buijtenen 1989).

Moreover, fine residues (wood shavings, sawdust and powder) of wood manufacturing and processing industries have a great potential for generating energy by combustion. According to Quirino *et al*. (2004), the gross calorific value of two hundred fifty-eight species of wood varies from 16039.6 to 22290.5 kJ/kg. Zanuncio *et al*. (2013) concluded that the gross calorific value of *Eucalyptus urophylla* wood varies between 19770.1 and 20017.1 kJ/kg. Calonego *et al*. (2005b) showed that the gross calorific value of *E. grandis* wood was 19897.8 kJ/kg.

Since there is no information about the effects of thermal treatment on calorific value of *E. grandis* wood, the aim of this study was to evaluate the calorific value and chemical properties of juvenile and mature wood of this species after thermal modification.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

This study utilized wood from 30-year-old *E. grandis* trees from the Forestry Institute of São Paulo located in Manduri, São Paulo, Brazil. Four trees were felled and sectioned into 2.9 m logs. The first log from each tree with diameters between 30 cm and 35 cm (measured at half height) were cut into flat saw boards. The boards that contained the pith were cut into 28-mm thick pieces. Subsequently, all the boards were dried up to 10.0 % moisture content in a dry kiln.

2.1 Thermal treatments of boards
2.1. Toplinska obrada piljenica

Four dried boards were planed to 24-mm thickness and cut into smaller pieces measuring 0.60 m in length. Regions with cracks and knots were discarded. One of these smaller pieces was kept in its original condition (untreated wood), and the other pieces were reserved for the thermal treatment (thermally modified wood).

The material was placed in an electric oven with a programmable controller and thermally modified in the Laboratory of Wood Drying and Preservation of UNESP, Botucatu, SP, in Brazil. The treatment started at an initial temperature of 100 over a period of 14 h and then was increased (1.34 ºC/minutes) up to 180 ºC and maintained over a period of 2.5 h according to the application of the patent developed by Severo and

Calonego (2011). After the end of the thermal treatment, wood pieces were allowed to cool naturally until they reached 30 ºC.

Subsequently, samples of the untreated and thermally modified woods were transformed into chips and then processed into sawdust in a slicer type Willey with 20 mesh sieve size (0.85mm) for the energy and chemical characterization of juvenile and mature wood. The juvenile and mature wood regions were defined according to Oliveira *et al*. (1997). The anatomical characterization of the wood used in this study showed that the juvenile wood is confined up to 80 mm from the pith.

2.2 Calorific value of wood
2.2. Kalorijska vrijednost drva

The untreated and thermally modified wood sawdust were transformed into pellets and placed in an oven at 103±2 ºC, and maintained in this condition until they reached 0 % moisture content.

The pellet was placed in a calorimeter PARR 1201 in the Laboratory of Applied Physics in the Department of Physics and Biophysics, IB - UNESP, Botucatu, SP, in Brazil. The gross calorific value was determined by bomb calorimeter method according to the standards presented in ABNT NBR-8633 (1984). After the combustion, the Equation 1 was used for determining the gross calorific value of the pellets.

$$GCV = \frac{(K \cdot W_W)}{W_P} \cdot \Delta t \qquad (1)$$

Where:
GCV - gross calorific value, kcal/kg;
W_W - weight of water used in the calorimeter, 2.5 kg;
W_P - oven-dry weight of pellet, kg;
Δt - temperature gradient before and after combustion, ºC;
K - calorimeter constant, 489.

The net calorific value was determined by gross calorific value and equilibrium moisture content of the wood according to the Equation 2 presented in Zanuncio *et al*. (2013).

$$NCV = GCV - (0.0114 \cdot EMC \cdot GCV) \qquad (2)$$

Where:
NCV - net calorific value, kcal/kg;
GCV - gross calorific value, kcal/kg;
EMC - equilibrium moisture content, %.

Subsequently, the gross and net calorific values determined in kcal/kg were mathematically transformed into kJ/kg.

2.3 Chemical properties of wood
2.3. Kemijska svojstva drva

The material used for chemical analysis was classified between 40 and 60 mesh (0.42 and 0.25 mm). The extractives content was determined by extraction sequences with ethanol/toluene 1/2 (v/v), ethanol and hot water (TAPPI T 264 cm-97, 1999). The acid-insoluble Klason lignin (TAPPI T 222 om-98, 1999), and holocellulose contents [holocellulose = 100 − (% Lignin + % Extractives Totals)] were determined in extractive-free wood.

The arabinose, galactose, xylose, mannose and glucose were analysed by High-Performance Anion-Exchange Chromatography with Pulsed Amperometric Detection (HPAE -PAD) in the filtrate obtained of the acid-insoluble Klason lignin. The analysis was carried out by using a chromatograph Thermo-Dionex, ICS-5000 with Pulsed Amperometric Detection, CarboPac PA 1 column and NaOH 0,5M as eluent at a flow rate of 1 mL/min (Sullivan, 1994).

For the evaluation of calorific value and chemical properties, a Kolmogorov-Smirnov's normality test was performed at 5 % significance. All variables had normal distribution. Subsequently, a parametric test (two-way ANOVA) was performed at 5 % significance taking into account the type of wood and the thermal treatment for the comparison of means of calorific value, extractive, lignin, holocellulose and sugar contents of wood. The Jandel SigmaStat version 2.0 was used for statistical analysis.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Calorific value of thermally modified wood
3.1. Kalorijska vrijednost toplinski modificiranog drva

The gross calorific values of juvenile and mature wood from untreated *E. grandis* were 19998.3 and 19355.6 kJ/kg (Table 1). These results are similar to those cited by Calonego *et al*. (2005b), Zanuncio *et al*. (2013), and Quirino *et al*. (2004).

Table 1 shows that the gross calorific value of *E. grandis* wood has not been significantly changed by thermal modification at 180 ºC, although the respective treatment promoted a decrease of up to 3.2 % in terms of physical property studied. Similar results were showed by Felfti *et al*. (2005), who concluded that the minimum condition that promotes significant improvements in a wood calorific value was 250 ºC.

Juvenile wood of untreated and thermally modified *E. grandis* wood, at air conditions (20 ºC and 74 % RH), presents equilibrium moisture content of 10.9 % and 9.1%, respectively. In mature wood, the respective moisture contents were 11.1 % and 8.4 %.

Table 1 shows that the thermal treatment at 180 ºC promoted significant reductions of 16.5 % and 24.3 % in the equilibrium moisture content of juvenile and mature woods. The influence of thermal treatment was lower on juvenile wood than on mature wood both in terms of calorific value and moisture content. Similar behavior was reported by Severo *et al*. (2012) and Calonego *et al*. (2014), who studied the changes of some properties of *E. grandis* and *P. elliotti* var. *elliottii* woods during thermal modification. According to the authors, the juvenile wood has an adverse effect on modification.

Due to smaller equilibrium moisture content in the thermally-modified wood of *E. Grandis,* more useful energy is generated through combustion, since the moisture present in certain materials uses part of the gross energy released. Thus the net calorific value is the better way to quantify the energy potential of wood. Table 1

Table 1 Equilibrium moisture content and calorific value of juvenile and mature wood from thermally modified *E. grandis*
Tablica 1. Ravnotežni sadržaj vode i kalorijska vrijednost toplinski modificiranoga juvenilnog i zrelog drva eukaliptusa

Wood *Drvo*	E.M.C. at air – 20 ºC and 74 % RH *EMC pri temperaturi zraka 20 ºC i vlažnosti od 74 %* %					Gross calorific value *Bruto kalorijska vrijednost* kJ/kg			Net calorific value *Neto kalorijska vrijednost* kJ/kg		
	N	U	N	TM	Red. or (Inc.) %	U	TM	(Inc.) %	U	TM	(Inc.) %
Juvenile *juvenilno*	4	10.9 [0.3]	4	9.1 [0.4]	16.5*	19998.3 [802.2]	20278.8 [803.5]	(1.4) NS	17520.5 [753.6]	18169.0 [720.6]	(3.7)*
Mature *zrelo*	4	11.1 [0.5]	4	8.4 [0.4]	24.3*	19355.6 [892.2]	19975.2 [732.3]	(3.2) NS	16911.3 [772.9]	18057.3 [686.6]	(6.8)*
Red. or (Inc.) %		(1.8) NS		7.7 *		3.2 NS	1.5 NS		3.5 NS	0.6 NS	

E.M.C. – Equilibrium moisture content / *ravnotežni sadržaj vode*, Red. – Reduction / *smanjenje*, Inc. – Increase / *povećanje*, N – Repeated number of samples / *broj uzoraka*, U – Untreated wood / *netretirano drvo*, TM – Thermally-modified wood / *toplinski modificirano drvo*, []– standard deviation / *standardna devijacija*, * – Significant difference by F test at 95 % probability / *signifikantna razlika prema F-testu i vjerojatnosti 95 %*, NS – Non-significant difference / *nesignifikantna razlika*.

shows that the thermal treatment at 180 ºC promoted significant increase of 3.7 % and 6.8 %, respectively, in the net calorific value of juvenile and mature woods.

3.2 Chemical properties of thermally modified wood
3.2. Kemijska svojstva toplinski modificiranog drva

The lignin, holocellulose, and extractive contents of juvenile wood from untreated *E. grandis* were 26.12 %, 73.69 %, and 2.06 %, respectively. In mature wood, these components were 28.27 %, 72.77 %, and 2.46 %. These results are presented in Table 2, and are similar to those cited by Bao *et al*. (2001), Brito *et al*. (2008), and Zobel and Van Buijtenen (1989).

Table 3 verifies that the galactose, xylose, and glucose contents in juvenile wood from untreated *E. grandis* were 0.32%, 16.35%, and 57.02%, respectively. In mature wood from untreated *E. grandis*, the respective contents were 0.55%, 14.18%, and 58.02%. These results are similar to those reported by Brito *et al*. (2008) for *E. grandis* wood.

The results of qualitative determination of sugars are also presented in Figure 1 and 2. The peak of

Table 2 Chemical compounds of juvenile and mature woods from thermally modified *E. grandis*
Tablica 2. Kemijska svojstva toplinski modificiranoga juvenilnog i zrelog drva eukaliptusa

Wood *Drvo*	Extractives content *Sadržaj ekstrativnih tvari* %					Insoluble lignin content *Sadržaj netopljivog lignina* %			Holoceluloses content *Sadržaj holoceluloze* %		
	N	U	N	TM	(Inc.) %	U	TM	(Inc.) %	U	TM	Red. %
Juvenile *juvenilno*	4	2.06 [0.21]	4	2.57 [0.59]	(24.8)*	26.12 [0.69]	26.12 [1.15]	0.0NS	73.69 [0.79]	70.61 [1.52]	4.2*
Mature *zrelo*	4	2.46 [0.48]	4	3.63 [0.74]	(47.6)*	28.27 [1.12]	30.41 [1.34]	(7.6) NS	72.77 [0.71]	66.71 [1.43]	8.3*
Red. or (Inc.) %		(19.4)*		(41.3) *		(8.2) *	(16.4)*		1.3 NS	5.5*	

Red. – Reduction / *smanjenje*, Inc. – Increase / *povećanje*, N - Repeated number of samples / *broj uzoraka*, U – Untreated wood / *netretirano drvo*, TM – Thermally-modified wood / *toplinski modificirano drvo*, []– standard deviation / *standardna devijacija*, * - Significant difference by F test at 95 % probability / *signifikantna razlika prema F-testu i vjerojatnosti 95 %*, NS – Non-significant difference / *nesignifikantna razlika*.

Table 3 Sugar content of juvenile and mature wood from thermally modified *E. grandis*
Tablica 3. Sadržaj šećera toplinski modificiranoga juvenilnog i zrelog drva eukaliptusa

Wood *Drvo*	Galactose content *Sadržaj galaktoze* %					Xylose content *Sadržaj ksiloze* %			Glucose content *Sadržaj glukoze* %		
	N	U	N	TM	Red. %	U	TM	Red. %	U	TM	(Inc.) %
Juvenile *juvenilno*	4	0.32 [0.10]	4	0.33 [0.07]	(3.1)NS	16.35 [0.71]	15.49 [0.51]	5.3*	57.02 [1.35]	54.80 [1.15]	3.9*
Mature *zrelo*	4	0.55 [0.06]	4	0.34 [0.11]	38.2*	14.18 [0.62]	12.21 [1.62]	13.9*	58.02 [0.79]	54.16 [1.11]	6.7*
Red. or (Inc.) %		(71.9)*		(3.0) NS		13.3 *	21.2 *		(1.8) NS	1.2 NS	

Red. – Reduction / *smanjenje*, Inc. – Increase / *povećanje*, N – Repeated number of samples / *broj uzoraka*, U – Untreated wood / *netretirano drvo*, TM – Thermally-modified wood / *toplinski modificirano drvo*, []– standard deviation / *standardna devijacija*, * – Significant difference by F test at 95 % probability / *signifikantna razlika prema F-testu i vjerojatnosti 95 %*, NS – Non-significant difference / *nesignifikantna razlika*.

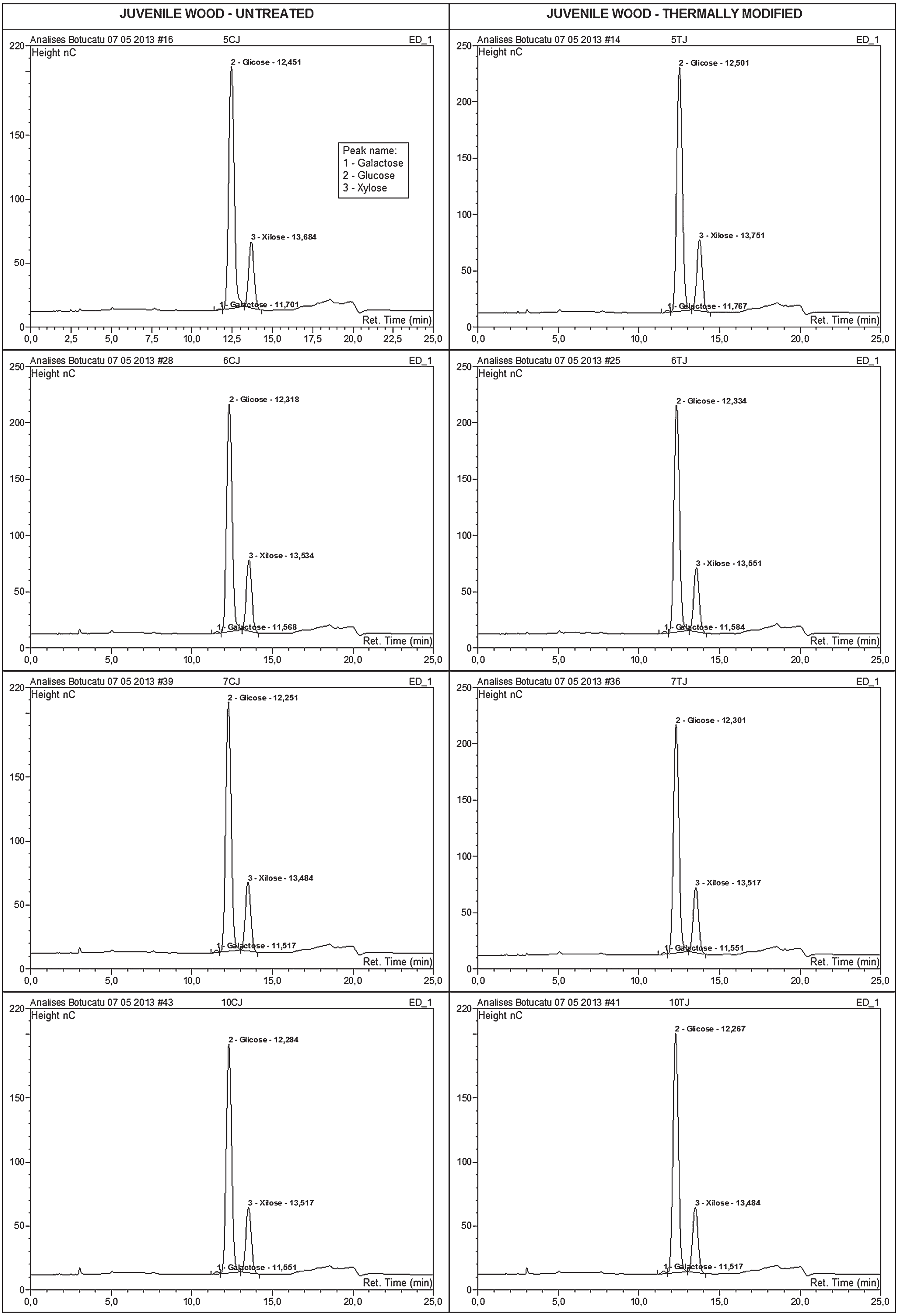

Figure 1 Chromatograms of extracts of juvenile wood from thermally modified *E. grandis*
Slika 1. Kromatogrami ekstraktivnih tvari u toplinski modificiranome juvenilnom drvu eukaliptusa

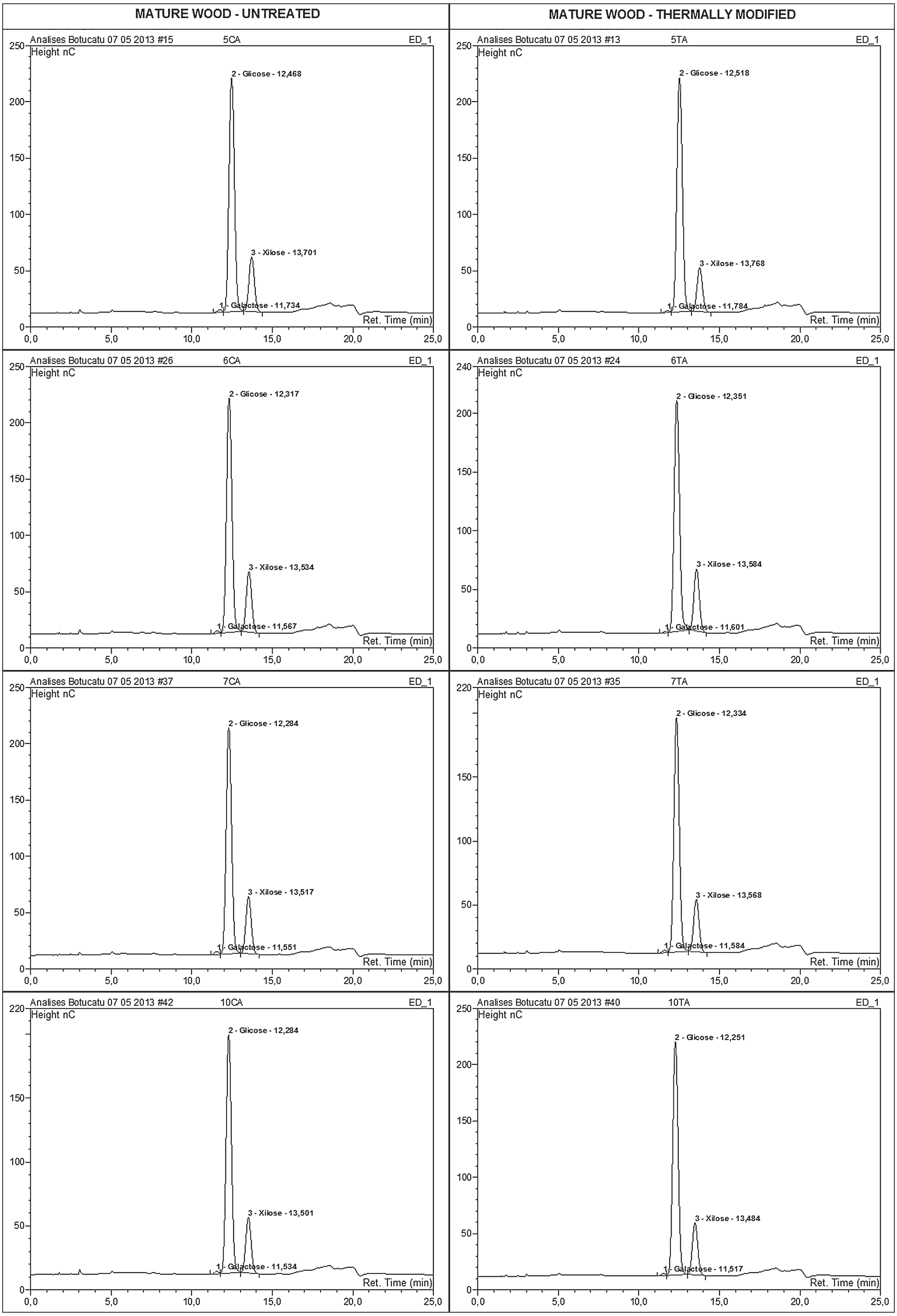

Figure 2 Chromatograms of extracts of mature wood from thermally modified *E. grandis*
Slika 2. Kromatogrami ekstraktivnih tvari u toplinski modificiranome zrelom drvu eukaliptusa

galactose, xylose and glucose by the chromatograms of extracts of untreated and thermally modified wood can be seen.

The effect of thermal treatment on the chemical properties of *E. grandis* wood is shown in detail in Table 2 and 3.

The current study demonstrates that the juvenile and mature wood from thermally modified *E. grandis* presented 2.57 % and 3.63 % in the respective extractive contents when compared with the values found for untreated wood, which were 2.06 % and 2.46 %. Mature wood, when thermally modified, showed a proportional increase of 7.6 % in the insoluble lignin content, whereas juvenile wood showed no change by thermal treatment. The mature wood, when thermally modified, showed greater significant reduction (8.3 %) in holocellulose content than juvenile wood (4.2 %).

The thermal treatment of mature wood of *E. grandis* at 180 °C caused a decrease of 38.2 %, 13.9 %, and 6.7 % in the galactose, xylose, and glucose contents. The influence of thermal treatment in juvenile wood was lower than in mature wood. Similar changes were reported by Bourgois and Guyonnet (1988), Brito *et al*. (2008), Severo *et al*. (2012), Bächle *et al*. (2010) and Wikberg and Maunu (2004), who studied the variations in the chemical properties of other kinds of wood during the thermal modification.

The changes in chemical properties of thermally modified *E. grandis* wood can explain the increase in the calorific value. Similar behavior was reported by Bourgois and Guyonnet (1988), who concluded that the thermal treatment in *Pinus pinaster* wood at 260 ºC during 0.5 to 4 h caused an increase between 46.4 % and 200 % in the lignin contents, and between 17.5 % and 44.1 % in the gross calorific value. These results are similar to those reported by Felfti *et al*. (2005) who concluded that the increase in the temperature and the time of the thermal treatment causes degradation of hemicelluloses and increase the calorific value of wood.

4 CONCLUSIONS
4. ZAKLJUČAK

This study shows that thermal modification of *Eucalyptus grandis* wood increases its net calorific value up to 6.8 %. Regarding chemical properties, significant increase was detected in the extractive content of juvenile and mature wood and reduction in the holoceluloses and sugar contents, when it was submitted to the thermal modification at 180 ºC. Finally, the influence of thermal treatment in juvenile wood was lower than in mature wood.

Acknowledgments – Zahvala

The authors thank the Research Assistance Foundation from São Paulo (FAPESP) and the Coordinator for the Improvement of Higher Level Personnel (CAPES), Brazil, for financial support through grant numbers 05/59074-7 and PNPD-02405/09-1.

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Cutting Power during Milling of Thermally Modified Pine Wood

Snaga rezanja pri glodanju toplinski modificiranog drva

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 18. 6. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*823.121; 630*847.2; 674.031.475.442*
doi:10.5552/drind.2016.1527

ABSTRACT • *The paper presents experimental testing results of cutting power of thermally modified wood of Scots pine (Pinus sylvestris L.) during lengthwise milling. The process of heat treatment was performed in the atmosphere of superheated steam, at temperatures of 130, 160, 190 and 220 °C, maintaining an identical heating time of 4 h for all modification variants. Cutting power was determined during milling of the radial surface of modified and non-modified samples. It was calculated as the difference of power used by a milling machine during wood machining and at idling. Based on the results of measurements, it was found that, in the case of modified wood, cutting power decreases with an increase in modification temperature (the dependence being linear) and increases with an increase in the working engagement. At temperatures exceeding 160 °C, the power required for milling of modified wood is lower than cutting power for non-modified wood. The experiment indicated a significant reduction of cutting power with an increase in wood modification temperature. It was also found that an increase in the working engagement results in an increase of cutting power both in thermally modified and non-modified wood.*

Key words: *woodworking, thermal modification, cutting, lengthwise milling, power consumption, softwood, Pinus sylvestris L.*

SAŽETAK • *U radu su prikazani rezultati eksperimentalnih istraživanja snage rezanja toplinski modificiranog drva običnog bora (Pinus sylvestris L.) tijekom njegove obrade glodanjem. Proces toplinske obrade borovine proveden je u atmosferi pregrijane pare, pri temperaturi od 130, 160, 190 i 220 °C, uz jednako vrijeme grijanja od četiri sata za sve varijante modifikacije. Snaga rezanja određena je pri glodanju radijalne površine modificiranih i nemodificiranih uzoraka, a izračunana je kao razlika snage izmjerene tijekom rada stroja pri glodanju uzoraka i tijekom praznog hoda stroja.*

Na temelju rezultata mjerenja utvrđeno je da se snaga rezanja pri obradi modificiranog drva smanjuje s porastom temperature modifikacije (ovisnost je linearna), a povećava se s povećanjem visine dodatka za obradu (visine glodanja). Snaga potrebna za glodanje drva modificiranoga na temperaturama višim od 160 °C manja je od snage rezanja za obradu nemodificiranog drva. Eksperiment je pokazao znatno smanjenje snage rezanja s povećanjem temperature modifikacije drva. Također je utvrđeno da je povećanje visine dodatka za obradu rezultiralo povećanjem snage rezanja, kako pri obradi toplinski modificiranoga, tako i pri obradi nemodificiranog drva.

Ključne riječi: *obrada drva, toplinska modifikacija, rezanje, protusmjerno glodanje, potrošnja energije, meko drvo, Pinus sylvestris L.*

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1 INTRODUCTION
1. UVOD

Wood subjected to thermal treatment has been increasingly used in Europe and worldwide. One of the many types of thermal modification of wood is ThermoWood® technology. Due to many advantageous properties of ThermoWood, its production is increasing, at present accounting for the greatest share in the total production of thermally modified wood in Europe, while most frequently modified softwood species are pine and spruce (Ala-Viikari, 2007; Boonstra *et al*., 2007).

During the thermal modification process, many significant changes take place in the chemical structure of wood, affecting its properties. High-temperature treatment causes degradation of chemical cell wall components (cellulose, hemicellulose, lignins). Heating of wood initially reduces its weight as a result of losses of free and hygroscopic water and release of volatile minor components. A further increase in temperature results in changes in the structure of polymer cell wall components, mainly carbohydrates (Hill, 2006; Doczekalska, 2010). The basic structural components of wood are degraded, while cellulose and lignin are broken down at a slower rate and at higher temperatures than hemicelluloses. Moreover, extractives are also degraded and they are released during the modification process (Hill, 2006; Borysiuk and Mamiński, 2007; Doczekalska, 2010). Thermal modification of wood results in reduced contents of low-polymer carbohydrates components, depolymerisation of cellulose and a reduction of its crystallinity. Positive effects of these changes include e.g. reduced hygroscopicity and changes in wood colour to darker, resembling that of exotic species (Nakao *et al*., 1983; Fangel and Wegener, 1984; Jämsä *et al*., 2000; ThermoWood® Handbook, 2003). Reduced wood density in thermal treatment is caused by the degradation of its components, mainly hemicellulose, to volatile substances, released during wood modification (Bekhta and Niemz, 2003; Pétrissans *et al*., 2003).

Thermally modified wood, in comparison to non--modified wood, is characterised by greater natural durability – resistance to biotic and abiotic factors, enhanced dimensional stability and hardness. For this reason, it is used as a suitable material for the production of floors, stairs, ceilings, paneling, elements of building facades, while it is also successfully used in humid facilities such as saunas and bathrooms (Borysiuk and Mamiński, 2007). Thermal modification also causes an increase in Young's modulus, brittleness and susceptibility to cracking (González-Peña and Hale, 2007; Boonstra, 2008; Orłowski and Wierzbowski, 2010), as well as reduced specific cutting resistance and specific work of fracture (Orłowski and Grześkiewicz, 2009; Orłowski and Wierzbowski, 2010), tensile strength and bending strength. Changes of mechanical properties of thermally modified wood, especially impact strength. depend on the parameters of the modification process (Barcík and Gašparík, 2014). The effect of thermal treatment of wood is also reflected in differences in particle size of splinter produced during the cutting process. Thermally modified sawdust is finer and dimensionally less homogeneous than native wood (Dzurenda *et al*. 2010; Dzurenda and Orłowski, 2011; Barcík and Gašparík, 2014).

In technological processes of mechanical conversion, thermally modified wood is subjected to identical cutting operations, e.g. sawing, planing, milling and sanding as non-modified wood. However, in contrast to the physico-mechanical and chemical properties extensively described in literature on the subject, there is a marked shortage of experimental data concerning technological properties of thermally modified wood. Apart from the general information that this type of wood is subjected to machining similarly as non-modified wood, and that due to its greater cleavability excessive loads imposed by feed mechanisms may not be applied, there is no information e.g. on power consumption at its machining or the effect of machining on the quality of worked wood surface. In view of the reported higher hardness, brittleness, susceptibility to cracking and increased Young's modulus in comparison to non-modified wood, at simultaneously reduced density and tensile, shear yield stresses and bending strength, the question concerning energy consumption in machining of thermally modified wood seems justified.

The aim of this study was to determine cutting power of thermally modified wood of Scots pine (*Pinus sylvestris* L.) during lengthwise milling. This species is commonly used in the Polish wood industry, also in the production of thermally modified wood. The process of thermal modification was conducted under laboratory conditions with the following treatment parameters: constant modification time of 4 h and varied temperature (130, 160, 190, 220 °C).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Wood
2.1. Drvo

Experiments were conducted on sapwood of Scots pine (*Pinus sylvestris* L.) from the central part of Wielkopolska (Great Poland) region in Poland. The material was collected from the centre plank of 63 mm in thickness, cut above breast height from the butt end of a tree aged approx. 100 years. Density of the wood used in the tests, determined at an 8 % moisture content, was 530 kg·m^{-3}, the width of annual rings was 2.3 mm, and the share of late wood was 31.6 %.

From the defect-free sapwood zone, characterised by the linear course of annual rings at the radial surface of the plank and the parallel course of fibres in relation to its axis, identified on the tangential plane, tangentially oriented slats were cut at a length of approx. 1000 mm, which were then planed to the transverse dimension of 20×50 mm and cut into sections of 250 mm in length. In this way pairs of twin samples were produced.

In the course of the measurements, mean equilibrium moisture content of modified wood samples at 130, 160, 190 and 220 °C was 5.5, 5.1, 4.5 and 3.5 %, while mean moisture content of non-modified samples for temperatures of 130 and 160 °C was 5.0 %, and for 190 and 220 °C it was 4.0 %. After thermal modification at 190 and 220 °C, wood density was reduced to 525 and 500 kg·m^{-3}.

2.2 Thermal modification of wood
2.2. Toplinska modifikacija drva

In this study, the most frequently used method of wood modification in the atmosphere of superheated steam was applied. Wood modification was performed under laboratory conditions in the facilities consisting of a modification chamber, a steam generator, thermocouples and a set of devices to measure and record modification temperatures.

The modification process was conducted as follows: samples were heated until a temperature of 110 °C was reached over their entire volume and this temperature was maintained for 2 h, until an approx. 1 % moisture content was obtained. Then, the temperature was increased until a pre-set value (130, 160, 190, 220 °C) was reached and it was kept constant for 4 h, i.e. the duration of the heating process. From the moment the temperature of 130 °C was obtained throughout the sample volume, the modification was run in the atmosphere of superheated steam. After completing wood heating at a constant temperature, the heat generator was switched off and after wood temperature decreased to 130 °C, the steam inflow was shut and the samples were left in the chamber until the temperature of wood dropped to ambient temperature.

During the modification process, thermocouples were used to control the temperature of wood and air in the chamber. Thermocouples measuring wood temperature were placed in the middle of the height and width of the control sample, and air temperature was measured using the thermocouple placed over the set of slats. Temperature was read automatically at every 5 min and the data was recorded in the computer program memory.

The course of the modification process is presented in the form of graphic records of changes in temperature in the function of time based on the modification at a temperature of 220 °C (Fig. 1).

2.3 Measurements of cutting power
2.3. Mjerenje snage rezanja

In order to determine the effect of thermal modification on cutting properties of wood, it was decided to measure cutting power during milling. From the point of view of machining kinematics, milling with router does not differ from rotational planing. Milling and rotational planing, as well as sawing, are the most common methods of wood machining.

Cutting power was determined during lengthwise milling of the radial surface of modified and control samples. In order to maintain comparable experimental conditions, the moisture content of the control samples was adjusted prior to the test to moisture content corresponding to the equilibrium moisture content of modified wood. Milling operations were performed using an NC FLA 16 upper-spindle milling machine by OBRUSN (Fig. 2a, b). Constant machining parameters were as follows: rotational speed of the machine spindle of 18000 min^{-1}, feed speed of 1 m·min^{-1}, tool diameter of 16 mm. The used tool was an end mill with one cutting knife, with a tool blade of cemented carbide HW (producer: TIGRA GmbH, trade name T02SMG – group of application K01) with a wedge angle of 55°. The rake angle was 20° and the clearance angle was 15°. The working engagement was a variable parameter (height of the machined layer a_e), i.e. 0.5, 1 and 2 mm. For each of these machining variants, 10 replications were performed. Power was measured using an N13 meter of 3-phase current by LUMEL (Fig. 2c). Data on power consumption was transferred digitally using an RS-485

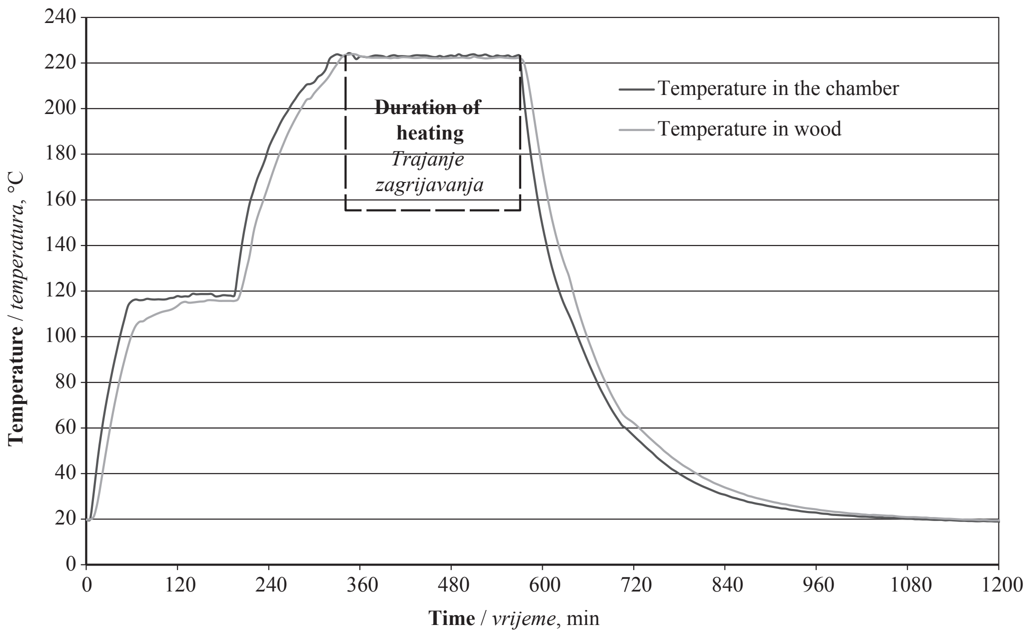

Figure 1 The course of thermal wood modification (temp. 220 °C, time 4 h)
Slika 1. Tijek toplinske modifikacije drva (temperatura 220 °C, vrijeme 4 h)

a) b) c)

Figure 2 The set of apparatus used to measure cutting power at milling: a) mechanical part of upper-spindle milling machine; b) numerical control of machine; c) meter of 3-phase current
Slika 2. Mjerni lanac upotrijebljen za mjerenje snage rezanja pri glodanju: a) mehanički dio nadstolne glodalice; b) numerička kontrola stroja; c) uređaj za mjerenje električne snage

integrated connector and recorded in the memory of a personal computer. This personal computer was part of a set of apparatus measuring and recording cutting power, which also facilitated visualisation of changes in power in the function of machining time. During the measurements of cutting power, the sampling frequency was 8 Hz. Power demand of the machine tool was determined for the performance of an idling working cycle and the total power used by the machine tool at milling. The cutting power of wood was assumed to be active power consumed during milling, calculated as the difference between total power and idling power.

Figure 3 presents a scheme of plain milling with conventional cutting. The machining operation was performed in the lengthwise-perpendicular system, at the parallel feed direction and the direction of the cutting edge of the blade perpendicular to grain.

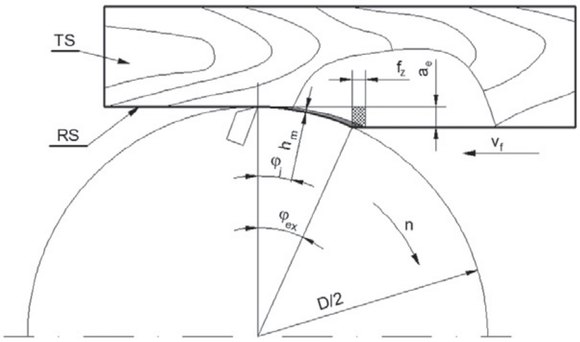

Figure 3 A scheme of plain milling with conventional cutting, where: *D* – tool diameter, f_z – feed per tooth, a_e – working engagement, v_f – feed speed, *n* – rotational speed, h_m – average uncut chip thickness, φ – angular cutting edge position, *RS* – radial surface, *TS* – tangential surface
Slika 3. Shema jednostavnoga glodanja konvencionalnim rezanjem: *D* – promjer alata, f_z – posmak po zubu, a_e – visina dodatka za obradu, v_f – posmična brzina, *n* – frekvencija vrtnje, h_m – srednja debljina strugotine, φ – kut zahvata oštrice, *RS* – radijalna površina, *TS* – tangencijalna površina

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Numerical data listed in Table 1 are mean values from 10 replications of the milling process of the radial surface of samples. Results were analysed statistically, determining the measure of location – the arithmetic mean ($\bar{x}$), standard error (*S.E*) and measures of scatter – standard deviation (*S.D.*) and the coefficient of variation (*v*). These data show that irrespective of the working engagement and the temperature of wood modification, the coefficients of variation, both for modified and non-modified wood, fell within a narrow range of values from approx. 2 to 7 %. Standard error and standard deviation in relation to the mean value of the analysed measure ($\bar{x}$) also assumed low values. Analysis of presented statistical data indicates low variability of results. Mean values of the investigated measure were used in order to illustrate the dependence between the cutting power and the temperature of modification and working engagement.

The graphic presentation of measurements of cutting power in the function of time shows relationships between cutting power of non-modified wood and thermally modified wood for the working engagement of 2 mm (Figs. 4 and 5).

Cutting power of wood modified at 220 °C is markedly lower (mean 22 %) than that of analogous non-modified wood. In contrast, thermal treatment of wood at 130 °C did not reduce cutting power of modified wood in comparison to non-modified wood.

The dependence of cutting power of thermally modified wood on modification temperature is presented in Fig. 6. An increase in modification temperature causes a decrease in cutting power irrespective of the working engagement. These dependencies within the analysed range of temperatures are well described by linear functions ($0.77<R^2<0.98$). The reduction of cutting power is proportional to the increase in wood modification temperature and its volume increases with an increase in the working engagement. In the case of a 0.5-mm layer, its cutting power within the range of modification temperature of 130-220 °C decreased by 14 %, while for working engagement of 1 and 2 mm, it is more than 2-fold higher, amounting to 30 % and 34 %.

Table 1 Cutting power of thermally modified wood
Tablica 1. Snaga rezanja toplinski modificiranog drva

Temperature *Temperatura* °C	**Cutting power** / *Snaga rezanja* $\bar{x}$, W ± S.E., W ± S.D., W *v*, %					
	Modified wood / *Modificirano drvo*			Non-modified wood / *Nemodificirano drvo*		
	Working engagement a_e, mm / *Dodatak za obradu* a_e *, mm*					
	0.5	1.0	2.0	0.5	1.0	2.0
130	33.94 0.07 1.14 3.36	60.97 0.18 2.86 4.70	95.71 0.39 6.44 6.73	35.97 0.09 1.36 3.79	63.15 0.08 1.33 2.11	96.73 0.19 3.04 3.14
160	34.64 0.10 1.48 4.26	56.39 0.10 1.63 2.89	80.45 0.33 4.81 5.98	38.58 0.06 0.94 2.44	63.63 0.25 3.84 6.03	105.04 0.32 4.96 4.72
190	32.40 0.10 1.47 4.53	50.78 0.18 2.91 5.74	69.56 0.17 2.68 3.86	38.85 0.08 1.33 3.42	63.48 0.21 3.29 5.18	93.04 0.40 6.43 6.91
220	29.29 0.12 1.99 6.79	42.89 0.10 1.56 3.65	62.98 0.16 2.71 4.31	34.59 0.08 1.28 3.70	53.18 0.11 1.83 3.44	80.39 0.33 5.38 6.66

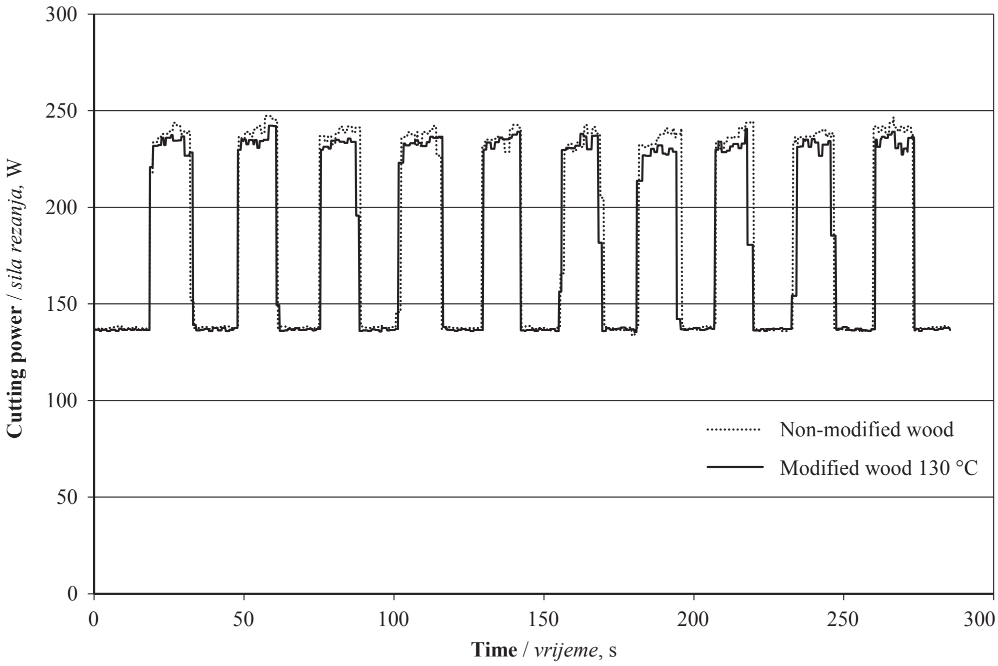

Figure 4 The course of measurements of cutting power for twin samples of non-modified wood and wood modified at 130 ºC for the working engagement of 2 mm
Slika 4. Rezultati mjerenja snage rezanja pri glodanju nemodificiranog drva i drva modificiranog pri temperaturi 130 ºC uz dodatak za obradu visine 2 mm

The cutting power also increases with an increase of the working engagement. This dependence confirms a relationship between these parameters, well-known in machining processes (Dmochowski, 1981; Rousek and Kopecký, 2005; Csanády and Magoss, 2011). The greater the working engagement, the greater the wood volume that has to be changed to chips, i.e. the greater machining work has to be performed in a unit of time, while maintaining the other machining parameters constant, such as e.g. feed rate, back engagement, rotational speed of the tool and the number of cutting blades.

With an increase in the working engagement, a greater increase in cutting power was recorded in the case of lower modification temperatures. Within the analysed range of the working engagement (0.5 – 2.0 mm), the greatest increase in cutting power of modified wood was observed at 130 °C, amounting to 180 %, while at 160 °C, it was 130 %, with the smallest increase recorded at 190 and 220 °C, respectively, for which it amounted to 115 %.

Although in the case of thermally modified wood, an increase in the working engagement is accompanied

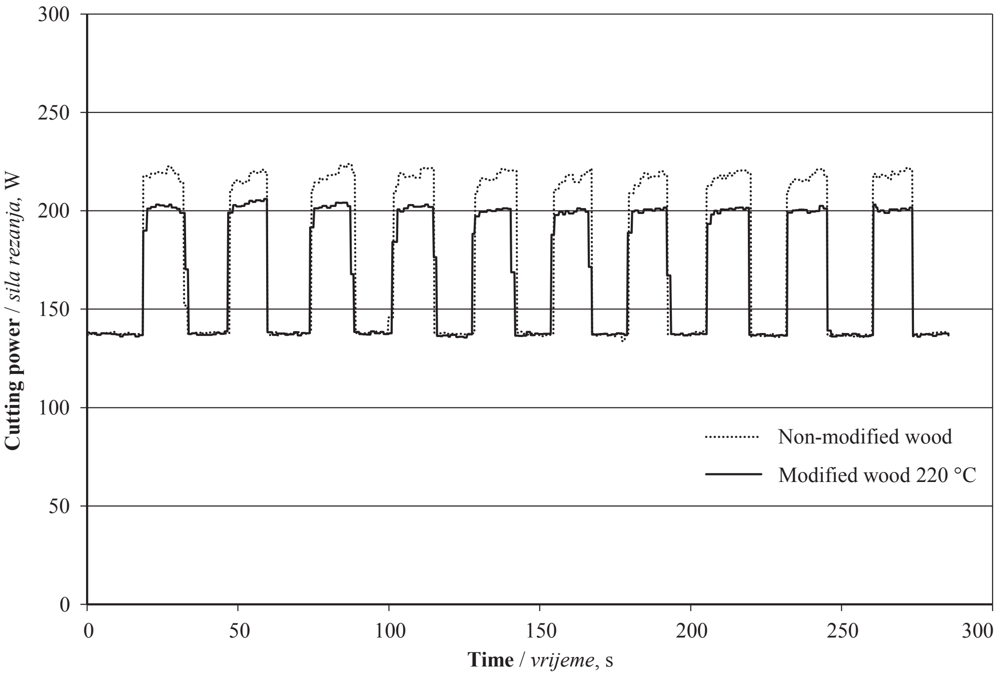

Figure 5 The course of measurements of cutting power for twin samples of non-modified wood and wood modified at 220 ºC for the working engagement of 2 mm
Slika 5. Rezultati mjerenja snage rezanja pri glodanju nemodificiranog drva i drva modificiranog pri temperaturi 220 ºC uz dodatak za obradu visine 2 mm

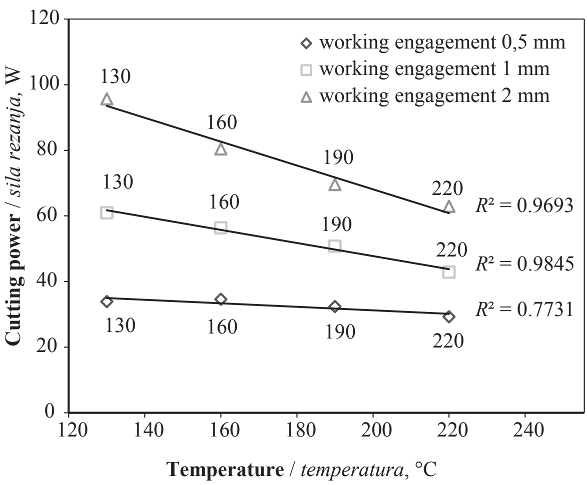

Figure 6 Cutting power of thermally modified wood depending on modification temperature
Slika 6. Snaga rezanja toplinski modificiranog drva u ovisnosti o temperaturi modifikacije

by an increase in cutting power, it decreases with an increase in modification temperature. In terms of the location of the cutting edge and the direction of the cutting motion in relation to the direction of the grain, lengthwise milling is lengthwise-transverse machining. In such a case, an increase in the working engagement causes an increase in the share of machining across the grain, i.e. an increase in cutting force and power. However, the reduced increase in cutting power in the case of thermally modified wood following an increase in the working engagement with the growing modification temperature indicates lower cutting forces, which may result from changes in cell wall ultrastructure and increased brittleness of thermally modified wood.

Reduction of cutting force as well as cutting power following an increase in the working engagement may result only from a decrease in mechanical strength properties of wood. Piernik (2014), in her analyses concerning the effect of thermal modification of wood on its mechanical properties, showed that the impact value of Scots pine wood modified at 220 °C is an equivalent of only 40 % impact value of wood modified at 130 °C. She also stated that an increase in modification temperature from 130 to 220 °C also causes a considerable reduction of Young's modulus in the radial direction by 27 % and in the tangential direction by 46 %. Results of numerous studies indicate changes in the structure of thermally modified wood, in turn leading to changes in its physical and mechanical properties. Depolymerisation of cellulose and a reduction of the degree of its crystallinity, as well as decreased contents of carbohydrate components in cell walls of wood were shown e.g. by Bhuiyan *et al*. (2000) and Yildiz and Gümüşkaya (2007). Also Hill (2006) and Doczekalska (2010), who investigating physico-mechanical properties of thermally modified wood and reported degradation of basic structural wood components, i.e. cellulose, lignin and hemicellulose, as well as degradation of extractives. Bekhta and Niemz (2003) and Pétrissans *et al*. (2003) showed that in the process of thermal modification, wood density decreases and in softwood resins and volatile substances are partly removed.

Values of cutting power at milling of twin samples of non-modified wood and wood thermally modified at different temperatures, depending on working engagement, are presented in Figs. 7a-d.

Cutting power of wood modified at 130 °C practically does not differ from that of non-modified

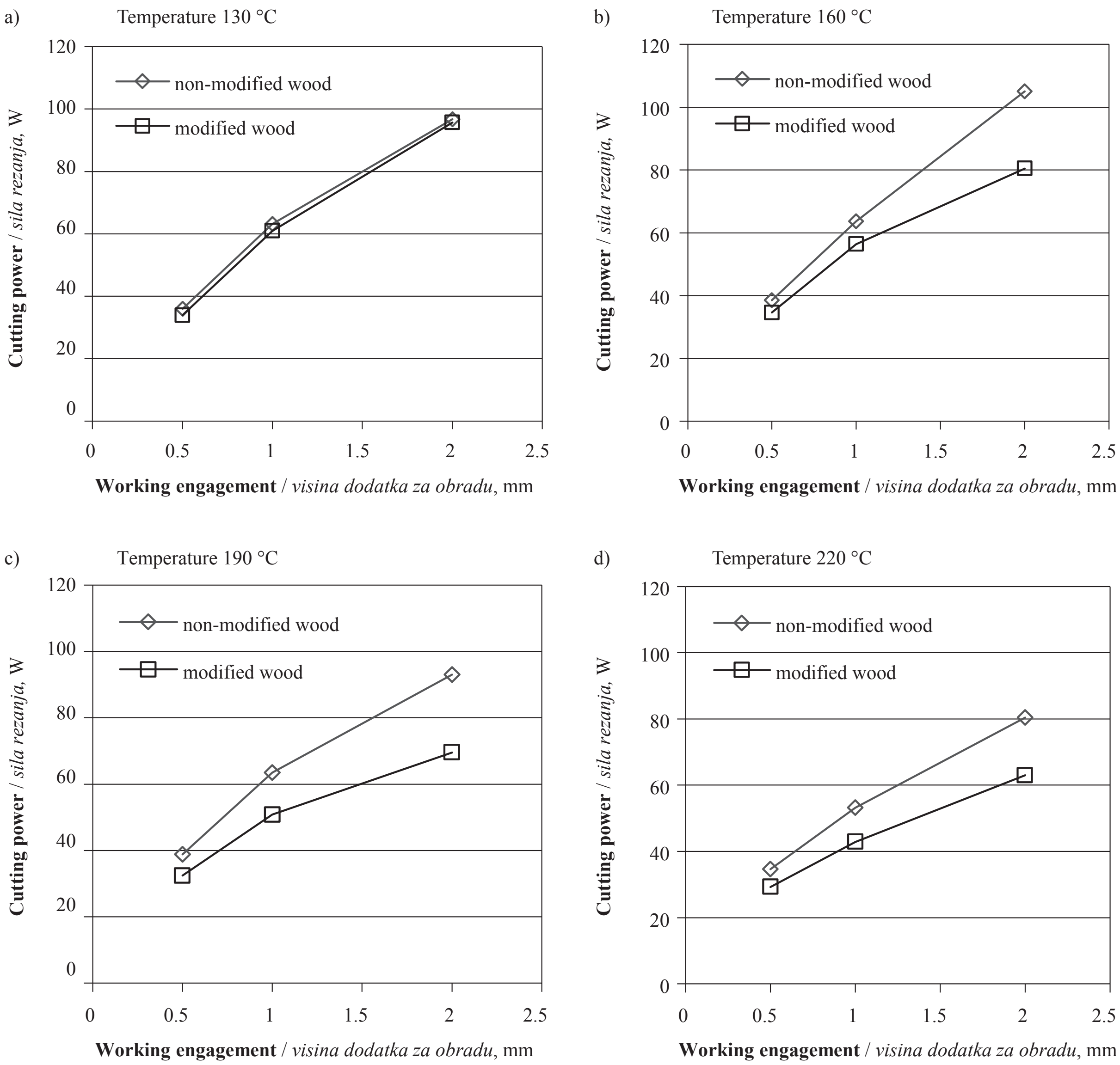

Figure 7 Cutting power of thermally modified and non-modified wood depending on working engagement for individual variants of modification temperature
Slika 7. Snaga rezanja toplinski modificiranoga i nemodificiranog drva u ovisnosti o visini dodatka za obradu za svaku varijantu temperature modifikacije drva

wood. At higher temperatures applied in the course of thermal treatment, a decrease in cutting power may be observed at milling of modified wood in comparison to non-modified wood. This reduction of energy requirement increases with the increase in the working engagement. For the working engagement of 0.5 mm and modification temperature of 160, 190 and 220 °C it is a mean of 14 %, while it increases to 23 % at the 2-mm working engagement. For identical working engagement, in the case of wood thermally modified at different temperatures in comparison to non-modified wood, lower values of cutting power may be explained by changes in properties of modified wood. The mechanism of wood machining is an interaction between wood and the applied tool. It is determined by physical and mechanical properties of wood, geometry of the cutting edge and machining parameters. In the conducted experiment, the tool, its rotational speed and feed rate were constant factors. In contrast, the working engagement and the temperature of wood modification were variable parameters. The negative effect of modification on cutting power of wood starting at the temperature of 160 °C is consistent with our knowledge on the effect of modification on mechanical properties of wood. González-Peña and Hale (2007) and Boonstra (2008) stated that an increase in modification temperature above 150 °C results in reduction of tensile strength along the grain and bending strength, as well as an increase in hardness and fracture toughness. Causes for the variation in cutting power during milling in identical working engagement in non-modified and modified wood may thus be associated with changes in the ultrastructure of wood subjected to thermal treatment.

4 CONCLUSIONS
4 ZAKLJUČAK

Cutting power during milling of thermally modified wood:

– is lower than that of non-modified wood; the effect of thermal wood treatment on cutting power is manife-

sted starting from the modification temperature of 160 °C and it increases with an increase in the working engagement,
– decreases with an increase in modification temperature,
– increases with an increase in the working engagement; the higher the temperature of wood modification, the lesser the increase in cutting power.

Mechanical and physical properties of thermally treated wood (especially higher brittleness), reduced cutting performance, because chips are easier to break and crumble.

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Surface Roughness and Wettability Variation: The effect of Cutting Distance during Milling of Pinus Radiata Wood

Promjene hrapavosti i svojstva kvašenja površine: utjecaj duljine rezanja tijekom blanjanja borovine

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 4. 9. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*812.732; 630*812.22; 630*847.; 674.031.475.49*
doi:10.5552/drind.2016.1531

ABSTRACT • *The variation of the machined surface properties is usually described in terms of changes in cutting parameters. However, the effect of the cutting distance should be considered, as it further shows the influence of the cutting tool wear. In order to assess the effect of the cutting distance on roughness and wettability of Pinus radiata wood surfaces, three conditions of feed speed and cutting speed were applied on cutting distance of 0 to 10000 meters. This study describes the effect of machining parameters on the behavior of roughness and wettability through the cutting distance, and the interaction of both surface properties is also discussed. The variation of surface roughness in function of the cutting distance is not directly related to variations in the surface wettability. It was, therefore, concluded that is was not reliable to consider only the surface roughness to explain the wetting behavior of a heterogeneous surface such as wood.*

Key words: *cutting distance, roughness, wettability, contact angle, wood, milling*

SAŽETAK • *Varijacije svojstava obrađene površine drva obično se opisuju kao posljedica promjene parametara obrade. Međutim, treba uzeti u obzir i učinak duljine rezanja jer to dodatno pokazuje utjecaj istrošenosti reznog alata. Kako bi se procijenio učinak duljine rezanja na hrapavost i svojstvo kvašenja površine drva bora (Pinus radiate), pri blanjanju na duljini od 0 do 10 000 metara primijenjene su tri različite posmične brzine i brzine rezanja. U radu se opisuje utjecaj parametara obrade na hrapavost i svojstvo kvašenja obrađene površine u ovisnosti o duljini rezanja, a objašnjena je i interakcija tih dvaju svojstava obrađene površine. Varijacije hrapavosti površine u ovisnosti o duljini rezanja nisu izravno povezane s varijacijama svojstva kvašenja površine. Zaključeno je da za određivanje svojstva kvašenja heterogene površine materijala kao što je drvo nije pouzdano uzimati u obzir samo hrapavost njegove površine.*

Ključne riječi: *duljina rezanja, hrapavost, svojstvo kvašenja, kontaktni kut, drvo, blanjanje*

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1 INTRODUCTION
1. UVOD

The characterization of wood cutting surfaces is very important as it normally interacts with adhesives, paints and varnishes. Roughness and wettability are surface properties that are normally used to assess surface quality. The characterization of surface quality depends on many influencing factors and can be related both to wood properties and machining conditions (Magoss, 2008). Dundar *et al*., (2008) and Magoos (2008) found that an increase in cutting speed decreased the surface roughness. On the other hand, by the increasing of the feed speed, the surface roughness is increased (Keturakis and Juodeikienė, 2007; Hernandez and Cool, 2008). Walinder (2000) explained that the intrinsic wood surface structure combined with the irregular surface structure resulting from different machining processes might cause variation in wood wettability. Hernandez and Cool (2008) found that an increment in feed speed affected the wetting of a surface. The authors considered that better wetting was associated with higher surface roughness. In a comparison of different types of wood surface machining, planed, sanded and disc sawn surfaces, Santoni and Pizzo (2011) found that the high roughness, produced in the sanding process made more wettable the sanding surfaces. Cool and Hernandez (2011) also measured better wettability on rough surfaces compared to smoother ones.

Nevertheless, the effect of those cutting parameters on surface properties is not constant due to the wear on the cutting tool by the effect of the cutting distance. This cutting distance was considered for limited cutting distances or the wear was reproduced artificially. The wood milling tools undergo wear during the cutting process, the mass of the tools decreases and the geometrical parameters change (Keturakis and Lisauskas, 2010). Surface quality is particularly sensitive to the changes in wear profile geometry (Sheikh and McKenzie, 1997). Itaya and Tsuchiya (2003) cited by Aknouche *et al*. (2009) concluded that the direct consequence of the cutting edge wear is the gradual loss of its ability to cut the machined material. These conditions also result in a poor wood surface quality. Keturakis and Juodeikienė (2007) modelled artificially the cutting edges of the knives and found that a decrease on tool edge blunt radius and feed rate during milling decreases the surface roughness of birch wood. Gilewicz *et al*. (2010), evaluated the wear by the effect of the cutting distance until 6000 meter on the surface properties and found almost a linear increase of R_z together with the tool wear. This study is intended to provide information on the variation of surface properties depending on the cutting distance in order to support decisions as to when to renew the cutting tool.

Therefore, the main objective of this study was to describe the behavior of roughness and wettability on *Pinus radiate* wood surfaces in function of the cutting distance during its machining.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

In this study, *Pinus radiata* D. Don samples, see table 1, with a mean EMC of 10.9 % (NCh176/1) and a mean density of 470 kg·m^{-3} (NCh176/2) according to Chilean standard, were machined using a single-spindle shaper (milling) machine with variable cutting speed and feed, with three hydro centered mounting cutter-heads of 6 knives HS6-5-2 (High Speed Steel type M2) with 26° clearance angle and 15° of rake angle each.

The machining takes into account a tool wear at a cutting distance of 0 to 10000 meters (linear cutting meters of material to be cut), with specific wear conditions, see Table 1.

Also in order to control and measure the tool wear, the cutting edge recession was measured with the help of a magnifying glass and software. Each 2000 meters of cutting distance, the machining conditions were adjusted, see Table 1, to assess the surface quality through the roughness and wettability surface properties. The mean peak-to-valley height (R_z) parameter, in accordance with ISO 4287 (1997) standard, was used to measure the roughness surface using a Mitutoyo SJ-201 apparatus. On the other hand, wettability was measured by the principle of contact angle using a DSA25 Krüss device.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 2, below, shows the variation of average surface roughness in function of the cutting distance associated with the machining parameters. Independent of the

Table 1 Experimental conditions
Tablica 1. Uvjeti eksperimentalnih mjerenja

Factors *Činitelji*	**Wood** *Drvo*	**Tool Wear** *Trošenje alata*	**Surface quality measuring** *Mjerenje kvalitete površine*
Density / *gustoća*	470 kg·m^{-3}		
Equilibrium Moisture content (EMC) *ravnotežni sadržaj vode (EMC)*	10.9 %		
Tool diameter / *promjer alata*		192 mm	
Rake angle / *prsni kut*		15°	15°
Feed speed, v_f / *posmična brzina,* v_f		26 m·min^{-1}	22, 30, 38 m·min^{-1}
Cutting speed, v_c / *brzina rezanja,* v_c		50 m/s	44, 50, 56 m/s
Cutting distance, *L* / *duljina rezanja, L*		0 to 10000 meters	each 2000 meters

Table 2 Variation of the average roughness R_z (μm) during *Pinus radiata* wood machining
Tablica 2. Varijacije srednje vrijednosti hrapavosti R_z (μm) tijekom obrade borovine

Feed speed v_f *Posmična brzina, v_f* m·min^{-1}	**Cutting speed v_c** *Brzina rezanja, v_c* m·s^{-1}	**Cutting distance, m** / *Duljina rezanja,* m					
		0	2000	4000	6000	8000	10000
22	44	21.0	20.3	26.5	27.8	27.3	25.2
	50	21.9	20.5	25.5	27.0	25.9	24.3
	56	19.9	19.3	23.8	23.9	25.5	23.9
30	44	22.4	20.7	26.8	29.5	32.2	26.9
	50	20.5	21.2	25.6	26.7	28.4	24.7
	56	18.6	18.6	24.0	25.6	26.5	24.2
38	44	20.7	19.8	26.9	25.7	25.1	26.2
	50	20.5	19.6	26.3	27.4	28.6	28.4
	56	20.7	19.4	27.3	28.7	25.5	25.4

machining conditions, the average roughness decreases from its initial level at 0 meters until 2000 meters and then increases again until the cutting distance of 8000 meters; then it shows a gentle tendency to diminish.

When the roughness is compared in function of the cutting speed, roughness tends to diminish as the cutting speed v_c increases. On the other hand, when the comparison is related to feed speed, there is a slight increase of the roughness as feed speed v_f increases. These trends become more consistent when the comparison is made among conditions of v_f (22 to 38 m·min^{-1}) and as the cutting distance increases. Table 3 shows the average contact angle in function of the cutting distance and machining conditions. In general, it does not show a clear trend through the cutting distance, or with the cutting speed. However, when comparison is made based on the cutting distance of 0 meter and 10000 meter, the contact angle changes depending on the feed speed. In case of feed speed of 22 and 38 m·min^{-1}, the surface wetting tends to decrease with the cutting distance, i.e. higher contact angle at 10000 meters than 0 meters.

The statistical analysis, ANOVA, see Table 4, shows that the cutting distance (*L*) is the most significant factor for roughness (R_z). It is followed in importance by the cutting speed (v_c), and only then by the feed speed (v_f). In the case of wettability (contact angle), the most significant factor of variance is the feed speed (v_f) followed by the cutting distance (*L*) and the cutting speed (v_c) as the least important.

Table 3 Variation of average contact angle θ (°) during *Pinus radiata* wood machining
Tablica 3. Varijacije srednjega kontaktnog kuta kvašenja površine θ (°) tijekom obrade borovine

Feed speed v_f *Posmična brzina, v_f* m·min^{-1}	**Cutting speed v_c** *Brzina rezanja, v_c* m·s^{-1}	**Cutting distance, m** / *Duljina rezanja,* m					
		0	2000	4000	6000	8000	10000
22	44	31.8	50.6	37.9	90.1	60.3	61.5
	50	30.2	47.9	25.5	90.1	48.6	61.9
	56	31.9	47.7	32.3	85.0	55.1	55.2
30	44	28.6	21.2	19.8	46.7	22.4	20.6
	50	29.2	21.3	25.5	23.2	28.3	15.7
	56	35.1	25.1	24.9	26.7	24.8	18.5
38	44	34.3	32.5	36.5	31.0	35.4	46.4
	50	33.6	25.4	39.8	19.0	34.8	29.8
	56	28.9	20.9	26.6	20.3	29.3	40.9

Table 4 ANOVA of surface properties in function of cutting conditions and distance
Tablica 4. ANOVA analiza svojstava obrađene površine u ovisnosti o parametrima obrade i duljini rezanja

Roughness *Hrapavost*	***Df***	**Sum *Sq***	**Mean *Sq***	***F* value**	**Pr (>*F*)**
L	5	8153.45	1630.69	110.22	0.0000
v_c	2	503.30	251.65	17.01	0.0000
v_f	2	126.28	63.14	4.27	0.0143
Residuals	960	14203.16	14.79		
Contact angle *Kontaktni kut*					
L	5	31494.08	6298.82	31.22	0.0000
v_c	2	2467.21	1233.60	6.11	0.0023
v_f	2	137211.76	68605.88	340.02	0.0000
Residuals	960	194103.55	201.77		

Table 5 Pearson correlation matrix between studied factors
Tablica 5. Pearsonova korelacijska matrica između istraživanih utjecajnih činitelja

	L	v_c	v_f	R_z	θ
L	1.00	0.00	0.00	0.46	0.17
v_c		1.00	0.00	-0.14	-0.07
v_f			1.00	0.06	-0.44
R_z				1.00	0.00
θ					1.00

Moreover, Pearson correlation shows similar tendencies. R_z behavior is most related to the effect of the cutting distances (L) followed by the cutting velocity (v_c) and only then by the feed speed (v_f). In the case of contact angle θ, the most related factor is the feed speed (v_f) followed by the cutting distance and only then by the cutting velocity, see Table 5.

Based on the factor significance, the behavior of surface properties, roughness and wettability (contact angle), are presented below in function of the cutting distance. The figures 1 to 4 represent the values as (+ main, — median, ┬ ┴ min – max and ° outliers).

Figure 1 shows the general behavior of surface roughness parameter R_z in function of the cutting distance (L). As can be seen, the R_z values decrease from 0 meter to 2000 meters, and then increase until 8000 meters, to decrease again when the cutting distance of 10000 meters has been completed. The above is consistent with a Duncan test that identifies three different groups of roughness through the cutting distance (L), 0 to 2000, 4000 to 8000, and 10000 meters, at a significance level of 0.05 %. Second in importance is the influence of the cutting speed (v_c), Figure 2 shows the well known effect of the cutting speed on roughness; it decreases as the cutting speed increases.

This effect on roughness appears consistent throughout the cutting distance. Nevertheless, the values of roughness for the same machining conditions change as the cutting distance accumulates. For example, up to the cutting speed of 44 m/s, at the cutting distance of 0 meter, the R_z is slightly greater than 25 μm, but after the cutting distance of 8000 meters, the same machining conditions no longer generate the same level of roughness; it changes up to 25 μm.

The effect of cutting distance (L) and feed speed (v_f) on surface wettability (contact angle) of *Pinus radiate* wood throughout the cutting distance are shown in Figure 3 and 4. If the whole experiment design is considered, see Figure 3, it can be seen that the median and the average contact angle decrease until the minimum level when the cutting distance has reached 4000 meters, and then begin to rise steadily from 6000 meters on.

However, when the feed speed is plotted through the cutting distance, see Figure 4, its significance on wetting is evident.

Figure 4 shows how the contact angle evolves three different paths as the cutting distance increases. It could be said that the feed speed of 30 m·min^{-1} produced the most wettable surface, while the feed speed of 22 m·min^{-1} produced less wettable surface.

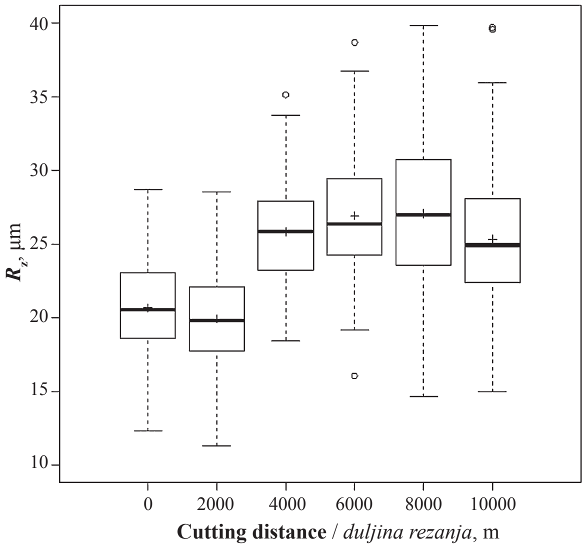

Figure 1 Surface roughness parameter R_z in function of cutting distance considering the whole experiment
Slika 1. Parametar hrapavosti površine R_z u ovisnosti o duljini rezanja tijekom cijelog eksperimenta

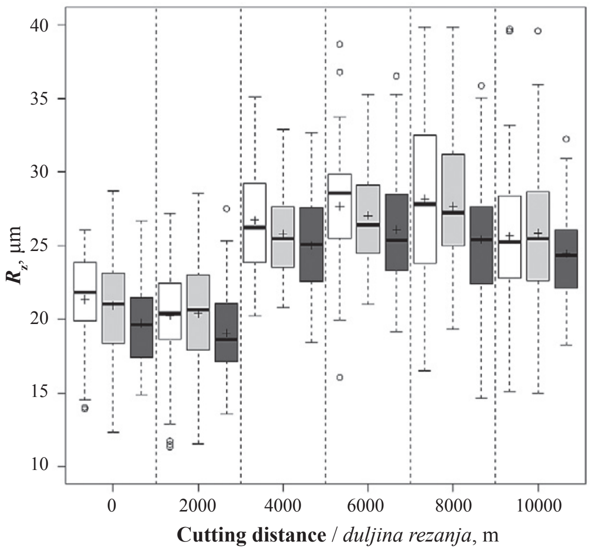

Figure 2 Surface roughness parameter R_z in function of cutting distance and cutting speed v_c (white 44 m/s, grey 50 m/s and black 56 m/s) considering the whole experiment
Slika 2. Parametar hrapavosti površine R_z u ovisnosti o duljini i brzini rezanja v_c (bijela 44 m/s, siva 50 m/s, crna 56 m/s) tijekom cijelog eksperimenta

Regarding the wear of the cutting tool, Figure 5 shows a comparison of cutting edges at the cutting distance of 0 meters and a dull condition of the knives after 10000 meters. The total average accumulated wear was of 3.5 μm. Both the Rake Face and the Clearance Face showed modifications to its original geometry. As shown in Figure 5, the most variable region is the so called land wear located on the Clearance Face. Future studies should focus on measuring this region through the cutting distance.

In this study, the behavior of roughness and wetting is described through the cutting distance. As it is well known, wettability is a thermodynamic response

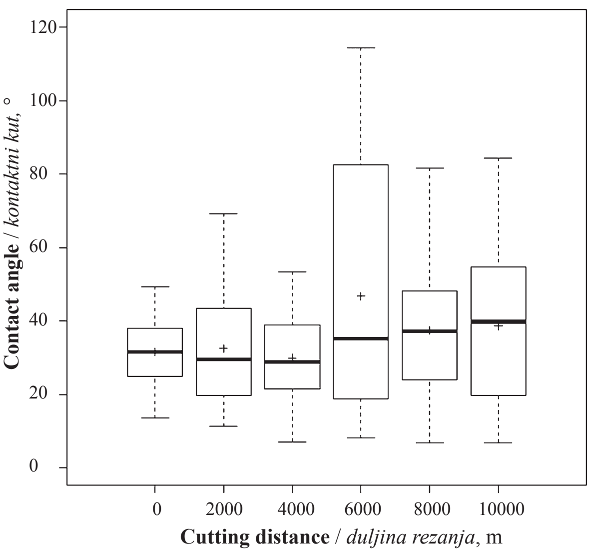

Figure 3 Contact angle θ in function of cutting distance considering the whole experiment
Slika 3. Kontaktni kut kvašenja površine θ u ovisnosti o duljini rezanja tijekom cijelog eksperimenta

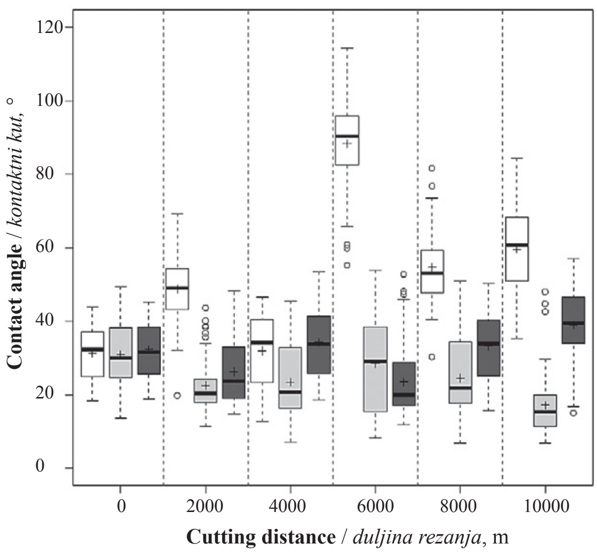

Figure 4 Contact angle θ in function of cutting distance and feed speed (white 22 m/min, grey 30 m/min and black 36 m/min) considering the whole experiment
Slika 4. Kontaktni kut kvašenja površine θ u ovisnosti o duljini rezanja i posmičnoj brzini v_f (bijela 22 m/min, siva 30 m/min, crna 36 m/min) tijekom cijelog eksperimenta

to physical and chemical properties of wood surfaces (Tshabalala, 2005). Apparently, chemical properties would be playing a more important role than physical properties, and their influence on wettability of a wood surface would be related in part to the wear of the cutting tool as a result of the cutting distance. This assumption is based on the null correlation found among roughness and wettability in this study. Hansson *et al*. (2011) indicate that surface roughness failed to correctly predict the contact angle on a heterogeneous surface with chemical or topological heterogeneities covered by the droplet. Frybort *et al*. (2014) explain that variability in wettability of a surface is largely determined by surface chemistry, besides other factors such as e.g. surface roughness, and conclude that differences in polarity between freshly cut cell walls and native inner lumen surfaces correlate with chemical heterogeneity. Apparently, the wear of the cutting tool, related to the cutting distance, produced a variation in the exposure of the chemical components of the wood ultrastructure and determined the thermodynamic behavior of the machined surface.

4 CONCLUSION
4. ZAKLJUČAK

The monitoring of the surface properties through the cutting distance has allowed a correlation to be

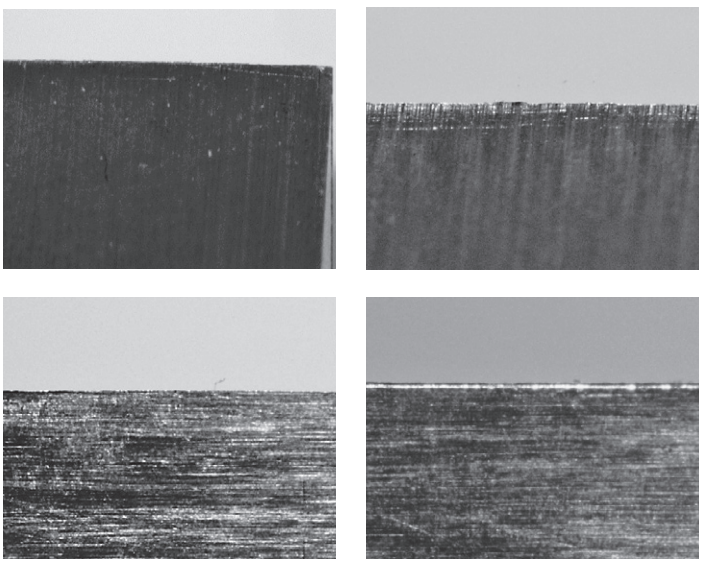

Figure 5 Cutting edge wear samples: cutting distance of 0 (left) to 10000 meters (right) Clearance Face (above) and Rake Face (below)
Slika 5. Primjeri trošenja oštrice alata: duljina rezanja 0 m (lijevo) i duljina rezanja 10 000 m (desno), leđna strana oštrice (gore) i prednja strana oštrice (dolje)

made between the wear of a cutting tool and the wettability of a machined surface. It is not reliable to explain the wettability of machined surfaces considering only the surface roughness on a heterogeneous surface such as wood. It is necessary to continue this study of the effect of the cutting distance with assessing changes in the surface chemistry and its relation with the thermodynamics of machined wood surfaces.

Acknowledgments – Zahvala

The authors would like to thank the Research and Development (DID) and the Faculty of Forest Science and Natural Resources Austral University of Chile, as well as, to the National Commission for Scientific and Technological Research CONICYT particularly the FONDECYT program which financed the development of this research through the project FONDECYT No. 1120347

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Čimbenici koji utječu na rastresitost usitnjenog materijala nastalog blanjanjem drva

Influencing Factors on Looseness of Chipped Material Generated during Wood Planing

Izvorni znanstveni rad • Original scientific paper
Prispjelo – received: 21. 10. 2015.
Prihvaćeno – accepted: 5. 5. 2016.
*UDK: 630*812.22; 630*839.811*
doi:10.5552/drind.2016.1537

SAŽETAK • *Poznavanje faktora rastresitosti i nasipne gustoće usitnjenog materijala nastaloga u procesu mehaničke obrade drva važno je radi optimalnog izbora sredstava za rukovanje, transportiranje i skladištenje, ali i radi trajnosti i kvalitete usitnjenog drva kao sirovine za izradu drvnih proizvoda od usitnjenog drva. Faktor rastresitosti usitnjenoga drvnog materijala definiran je kao omjer volumena usitnjenog materijala i cjelovitog drva od kojega je nastao. U radu je analiziran utjecaj posmične brzine, prednjeg kuta rezne oštrice i vrste drva na faktor rastresitosti usitnjene blanjevine. Odabrani su uzorci jelovine, hrastovine, parene bukovine i termički modificirane bukovine (pri temperaturi od 212 °C) dobiveni blanjanjem pri četiri posmične brzine (v_{p1} = 6; v_{p2} = 12; v_{p3} = 18 i v_{p4} = 24 m/min) i tri prednja kuta oštrice (γ_1 = 15°; γ_2 = 20° i γ_3 = 25°). Povećanje posmične brzine utjecalo je na smanjenje faktora rastresitosti samo za uzorke bukovine i jelovine. Utjecaj prednjeg kuta oštrice pri blanjanju različitih vrsta drva nije jednoznačan. Debljina strugotine nije se pokazala najvažnijim činiteljem koji utječe na faktor rastresitosti nego je to smjer rezanja u odnosu prema smjeru vlakanaca drva te oblik nastale čestice i njezina lomljivost. Najveći faktor rastresitosti dobiven je za blanjevinu jelovine pri najmanjoj posmičnoj brzini (f_r = 28,42), a najmanji faktor rastresitosti zamijećen je za blanjevinu termički modificirane bukovine (f_r = 2,62). Dobiveni rezultati za faktor rastresitosti blanjevine višestruko su veći od navoda u literaturi.*

Ključne riječi: *usitnjeno drvo, faktor rastresitosti, nasipna gustoća, posmična brzina, blanjanje*

ABSTRACT • *It is necessary to know the looseness factor and bulk density of chipped wood generated in the mechanical wood processing to make the optimal choice of equipment for handling, transportation and storage, and also to determine the durability and quality of chipped wood as raw material. The looseness factor of chipped wood is defined as the ratio of volume of chipped wood and volume of solid wood. This paper presents the analysis of the effect of feed speed, rake angle and wood species on the looseness factor of chips generated in planing solid wood. Selected samples of chipped pine-wood, oak-wood, steamed and thermally modified beech-wood (at temperature of 212 °C) were generated in planing at four different feed speeds (v_{p1}= 6; v_{p2}=12; v_{p3}=18 i v_{p4}=24 m/min) and three rake angles (γ_1 = 15°; γ_2 = 20° i γ_3 = 25°). The increase of feed speed only affects the reduction of the looseness factor for beech-wood and fir-wood. The impact of the rake angle during planing of researched wood species is not entirely clear. The presumed significant influence of cutting depth on the looseness factor was not established but significant influence was found of the cutting direction relative to the wood grain direction, the particles shape and their ability to fragmentation. The maximum looseness factor was obtained for chipped*

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wood generated during planing of fir-wood at minimum feed speed (f_r=28.42) and the lowest in planing thermally modified beech-wood (f_r=2.62). All obtained looseness factors were several times higher than those quoted in the literature.

Key words: *chipped wood, looseness factor, bulk density, feed speed, planing*

1. UVOD
1 INTRODUCTION

U posljednje su vrijeme šumska biomasa, kao i drvna biomasa iz drvoprerađivačke industrije, postali vrlo važan obnovljivi izvor energije jer su ekološki prihvatljiviji od fosilnih goriva. Uglavnom se upotrebljavaju u energanama za zagrijavanje pogona, dobivanje toplinske energije za sušenje drvnog materijala u sušionicama, za proizvodnju drvnih briketa i peleta te, u novije vrijeme, za proizvodnju električne energije u kogeneracijskim postrojenjima. Biomasa se usitnjava iveračima te transportira i skladišti u rasutom stanju. Pri tome se, osim o ekonomičnosti procesa rukovanja i transportiranja usitnjenog materijala, vodi briga i o očuvanju njegove kvalitete. Vrlo je korisno poznavati svojstva usitnjenog drva važna za transport i skladištenje (kao što su nasipna gustoća i faktor rastresitosti). Usitnjeno drvo pripada skupini sipkih materijala. Prema definiciji (Sever, 1988.; Madjarević, 1969.), sipki je materijal tvar koja se može presipavati, lopatati, hrptati i sl. a da to bitno ne smanjuje njezinu uporabnu vrijednost.

Permeabilnost usitnjenog materijala utječe na njegovu trajnost i očuvanje kvalitete ovisno o granulometrijskom sastavu, poroznosti, sadržaju vode u drvu i nasipnoj gustoći materijala. Poznato je da povećanje sadržaja vode u drvu za 10 % drastično smanjuje permeabilnost usitnjenog materijala te da je permeabilnost veća za krupnije čestice odnosno za usitnjeni materijal manje nasipne gustoće (Shang i dr., 1999.).

Pri projektiranju kapaciteta transportnih sredstava, izboru uređaja za odvajanje čestica (ciklona, filtara i dr.) te pri proračunu opterećenja i tlaka na stijene bunkera i dr. treba poznavati nasipnu gustoću usitnjenog materijala (Sever, 1988.).

Faktor rastresitosti jedno je od važnih svojstava sipkog materijala, a označava omjer volumena usitnjenog materijala i cjelovitog drva od kojega nastaje. Nasipna gustoća i faktor rastresitosti ovise o svojstvima drva, sadržaju vode u njemu, o vrsti mehaničke obrade drva (blanjanje, piljenje, glodanje, brušenje i dr.) te o parametrima procesa rezanja. Nasipna gustoća usitnjenog materijala povećava se sa smanjenjem veličine čestica (Beljo Lučić i dr., 2005.). Nasipna gustoća i faktor rastresitosti ovise o granulometrijskom sastavu usitnjenog materijala, na koji pak utječu brojni parametri procesa rezanja – vrsta drva, smjer rezanja s obzirom na smjer vlakanaca, posmična brzina, brzina rezanja, geometrija alata i dr. Prema Palmqvistu i Gustafssonu (1999.), smanjenjem debljine strugotine i sadržaja vode u drvu povećava se udio sitnih čestica usitnjenog materijala pri blanjanju različitih vrsta drva. Treba izbjegavati debljinu strugotine manju od 0,1 mm jer se zbog drastično većega jediničnog otpora rezanja prebrzo zatupljuje rezna oštrica i nastaju vrlo sitne drvne čestice sklone lebdenju u okolnom zraku.

Prema teoriji rezanja, debljina strugotine proporcionalna je posmičnoj brzini i obrnuto proporcionalna brzini rezanja. Iz dosadašnjih granulometrijskih analiza usitnjenog materijala nastaloga pri otvorenom rezu (blanjanje, obodno glodanje i brušenje) poznato je da povećanje posmične brzine pozitivno utječe na stvaranje većeg broja krupnijih čestica i manjeg broja sitnih čestica, manjih od 0,1 mm (Kopecky and Rousek, 2007.; Beljo Lučić i dr., 2007a). Međutim, rezultati drugih istraživanja pokazuju suprotno (Hemmilä i dr., 2002.): pri glodanju nižim brzinama nastao je usitnjeni materijal s manje sitnijih čestica. Također se pokazalo da smanjenje posmične brzine rezultira smanjenjem udjela sitnijih čestica u usitnjenome materijalu, kao i to da utjecaj posmične brzine na granulometrijski sastav nije jasan. Istraživanja Varge i dr. (2004.) pokazala su da s povećanjem posmične brzine i brzine glodanja u usitnjenom materijalu nastaje više sitnijih čestica.

Složenost problematike očituje se u brojnosti čimbenika koji utječu na usitnjavanje drva.

Rezultati granulometrijske analize usitnjenog materijala nastaloga pri zatvorenom rezu (piljenje) pokazali su da povećanje posmične brzine ne rezultira uvijek nastankom većeg broja krupnijih čestica u smjesi te da smjer rezanja u odnosu prema smjeru vlakanaca i obliku nastale čestice imaju veći utjecaj na granulometrijski sastav negoli debljina strugotine. Promjenom položaja radnog stola pri piljenju kružnom pilom mijenja se smjer rezanja u odnosu prema vlakancima pa tako nastaju čestice različitog oblika – kraće i deblje čestice pri rezanju okomito na vlakanca ili dulje i tanje čestice pri rezanju uzduž vlakanaca (Beljo Lučić i dr., 2007b). Neposredno nakon nastanka čestice u zatvorenom rezu dolazi do dodatnog usitnjavanja ovisno o obliku čestice.

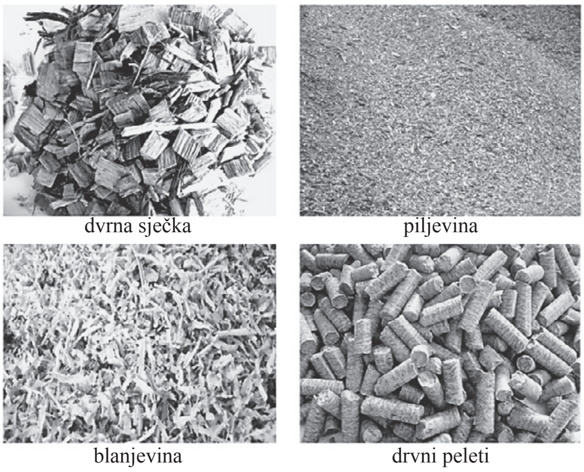
Istraživanjem utjecaja smjera brušenja na usitnjavanje čestica smrekovine i borovine pokazalo se da bruševina značajno manje nasipne gustoće nastaje pri brušenju u smjeru vlakanaca negoli poprečno na vlakanca (Očkajová i dr., 2008.; Dolny i Rogoziński, 2011.). Pritom je građa drva uzrok nastanka čestica vlaknastoga (omjer duljina /širina $\mu > 3$) ili izometričnog oblika ($\mu < 3$), ovisno o geometriji rezanja i smjeru rezanja s obzirom na vlakanca.

Utjecajni čimbenik katkad može biti i oblik rezne oštrice. Naime, istraživanje Očkajove i dr. (2006.) pokazalo je da pri piljenju smrekovine, bukovine i merantija listom sa stlačenim zubima nastaju krupnije čestice usitnjenog materijala te da je u smjesi dvostruko manje čestica sitnijih od 1 mm nego pri piljenju listom pile s asimetričnim trobridnim razvraćenim zubima.

U tablici 1. dane su vrijednosti faktora rastresitosti različitoga usitnjenog materijala iz dosadašnje lite-

Tablica 1. Faktor rastresitosti sipkog materijala (Sever, 1988.)
Table 1 Looseness factor of chipped material (Sever, 1988)

Vrsta sipkog materijala *Type of chipped material*	**Faktor rastresitosti** (f_r) *Looseness factor* (f_r)
iverje s piljevinom *chips with sawdust*	2,65
iverje / *chips*	3
piljevina / *sawdust*	3,2
blanjevina / *shavings*	4,6



Slika 1. Vrste sipkoga drvnog materijala
Figure 1 Type of chipped wood material

rature (Sever, 1988.), a na slici 1. prikazane su neke vrste sipkoga drvnog materijala u drvoprerađivačkoj industriji.

Posljedica povećanja volumena usitnjenog drva jest smanjenje njegove nasipne gustoće s obzirom na gustoću cjelovitog drva. Nasipna gustoća (ρ) definira se kao masa jedinice volumena nasutog materijala (kg/dm^3; kg/m^3 i dr.). Određuje se uz pomoć mjerne posude poznatog volumena (1 – 3 dm^3). Materijal može biti slobodno nasut (ρ) ili stlačen (ρ_s). Omjer tih dviju gustoća $\psi = \rho_s/\rho$ daje stupanj stlačenja (Madjarević, 1969.). Ovisno o stupnju stlačenja (zbijenosti) te granulometrijskom sastavu i sadržaju vode u drvu stlačivanjem je moguće postići neznatno povećanje nasipne gustoće. Time se omogućuje povećanje nasipne gustoće suhoga zrnatog materijala za 5 do 10 %, dok je stlačivanjem vlažnog materijala moguće povećanje nasipne gustoće za 30 do 50 %.

S obzirom na nasipnu gustoću, razlikuju se ovi sipki materijali: laki, nasipne gustoće do 0,6 t/m^3 (drvna piljevina, koks); srednje teški, nasipne gustoće od 0,6 do 1,1 t/m^3 (kameni ugljen, šljaka) i vrlo teški, nasipne gustoće veće od 2 t/m^3 (rude) (Sever, 1988.).

Usitnjeni materijali nastali na tračnoj pili, brusilici i bušilici pripadaju skupini materijala veće nasipne gustoće. U skupini materijala manje nasipne gustoće nalaze se materijali nastali obradom na kružnoj pili i blanjalici (Beljo Lučić i dr., 2005.).

Odnos između nasipne gustoće piljevine (označene indeksom 1) i drugih vrsta drvnih ostataka jednakog sadržaja vode za blanjevinu iznosi 0,69; za blanjevinu i iverje 1,1; za iverje 1,05, a za iverje i piljevinu 1,2 (Sever, 1988.).

Tablica 2. Nasipna gustoća usitnjenog materijala za različite vrste drva i različit sadržaj vode u njemu (Madjarević, 1969.)
Table 2 Bulk density of chipped material for different wood species and moisture content (Madjarević, 1969)

Sadržaj vode u drvu, % *Moisture content*, %	**Nasipna gustoća**, kg/m^3 *Bulk density*, kg/m^3		
	Jelovina *fir-wood*	Bukovina *beech-wood*	hrastovina *oak-wood*
10	140	206	225
25	152	220	240
50	180	259	283
75	210	305	330
100	240	346	420

U tablici 2. navedeni su podaci iz literature (Madjarević, 1969.) za nasipne gustoće usitnjenog materijala istraživanih vrsta drva različitog sadržaja vode.

U dosadašnjim istraživanjima faktor rastresitosti usitnjenoga drvnog materijala nije temeljito analiziran niti o tome postoje opširniji podaci u literaturi. Rezultati ovog istraživanja pridonijet će upoznavanju faktora rastresitosti i nasipne gustoće usitnjenog materijala dobivenog od triju vrsta drva pri različitim uvjetima blanjanja. Cilj rada bio je ustanoviti imaju li posmična brzina, prednji kut oštrice i vrsta drva značajan utjecaj na faktor rastresitosti usitnjenog materijala nastaloga pri blanjanju drva.

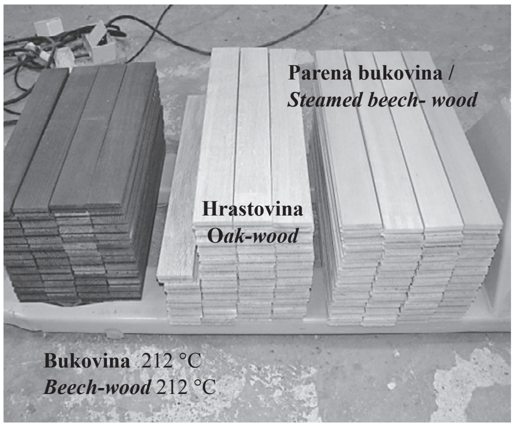
2. MATERIJALI I METODE
2 MATERIALS AND METHODS

Odabrani su uzorci radijalnog smjera vlakanaca (blistače) triju vrsta drva – jelovine, hrastovine i bukovine (parena bukovina i termički modificirana bukovina pri temperaturi 212 °C; dalje u tablicama i grafovima: bukovina 212 °C).

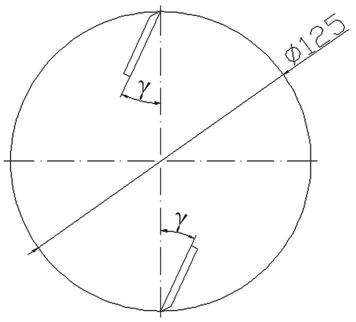
Uzorci dimenzija 600 x 70 x 21 mm blanjani su na viševretenoj blanjalici (WEINIG Powermat 400, 2006.). Obrađivana je samo jedna, donja, strana uzorka uz visinu blanjanja Δh = 2 mm i promjenu posmičnih brzina kako slijedi: v_{p1} = 6; v_{p2} = 12; v_{p3} = 18 i v_{p4} = 24 m/min. Broj okretaja radne glave iznosio je 6000 min^{-1}. Blanjanje je provedeno konvencionalnom glavom za blanjanje s dva noža kojima su mijenjani prednji kutovi oštrice kako slijedi: γ_1 = 15°; γ_2 = 20° i γ_3 = 25° (sl. 3.).

Za crtanje srednje debljine strugotine, duljine luka zahvata, posmaka po zubu i bočne površine strugotine primijenjen je program AutoCAD 2007 (sl. 4.). Vrijednosti izmjerene na taj način (tabl. 4.) provjerene su računskim postupkom i ne razlikuju se značajno od izračunanih vrijednosti. Slika 4. prikazuje glavu s nožem u zahvatu i mjerene veličine značajne za faktor rastresitosti i nasipnu gustoću usitnjenog materijala.

Nakon blanjanja svakoga od 48 uzoraka blanjevina je prikupljena u PVC vrećicu kako vanjska temperatura i vlaga ne bi utjecale na suhi materijal. Volumen rastresitog materijala određen je uz pomoć menzure od 2000 ml u koju je nasipavan s visine od 100 mm kroz lijevak.



Slika 2. Uzorci odabranih vrsta drva
Figure 2 Samples of selected wood species



Slika 3. Radna glava s nožem prednjeg kuta oštrice γ
Figure 3 Cutting tool with rake angle γ

Iz poznatih dimenzija uzorka i visine blanjanja uz pomoć izraza (1) izračunan je volumen kompaktnog drva (V_k):

$$V_k = L \cdot B \cdot \Delta h \tag{1}$$

gdje je:
L – duljina uzorka, mm
B – širina uzorka, mm
Δh – dodatak za obradu, mm.

Faktor rastresitosti usitnjenog materijala (f_r) izračunan je kao omjer volumena usitnjenog materijala i volumena kompaktnog drva:

$$f_r = \frac{V_r}{V_k} \tag{2}$$

gdje je:
V_r – volumen usitnjenog materijala, dm^3
V_k – volumen kompaktnog drva, dm^3.

Faktor rastresitosti određen je i iz omjera gustoće kompaktnog drva i nasipne gustoće usitnjenog materijala:

$$f_r = \frac{\rho_k}{\rho_r} \tag{3}$$

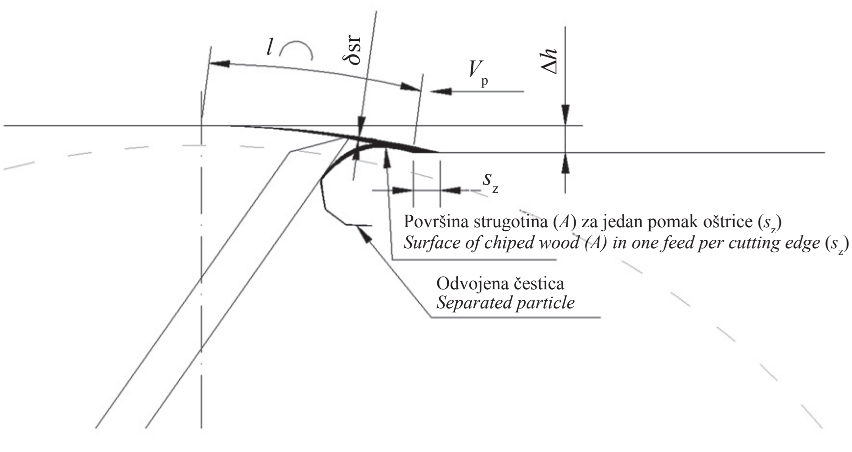
gdje je:
ρ_k – gustoća kompaktnog drva, kg/m^3
ρ_r – nasipna gustoća usitnjenog materijala, kg/m^3.

Nasipna gustoća usitnjenog materijala (ρ_r) određena je vaganjem menzure poznatog volumena (800 ml) prije i nakon nasipavanja usitnjenog materijala uz pet ponavljanja. Iz razlike tih dviju masa dobivena je masa usitnjenog materijala, a nasipna je gustoća izračunana prema izrazu (4):

$$\rho_r = \frac{m}{V} \tag{4}$$

gdje je:
m – masa usitnjenog materijala, kg
V – volumen usitnjenog materijala (V = 800 ml; dm^3).

Gustoća u apsolutno suhom stanju određena je gravimetrijskom metodom, a gustoća pri izmjerenom sadržaju vode dobivena je iz izraza (5), koji vrijedi



Slika 4. Veličine geometrije reza
Figure 4 Geometrical values of cut

samo za područje od 0 do 25 % sadržaja vode u drvu. Sadržaj vode uzoraka izmjeren je klasičnim igličnim vlagomjerom GANN, model HT 85T (GANN, 2006.), prema normi EN 13183-2:2008, a gustoća pri određenom sadržaju vode izračunana je prema izrazu:

$$\rho_w = \rho_0 \cdot \frac{1+w}{1+0{,}84 \cdot \rho_0 \cdot w} \tag{5}$$

gdje je:
ρ_w – gustoća pri određenom sadržaju vode, g/cm^3
ρ_0 – gustoća u apsolutno suhom stanju, g/cm^3
w – sadržaj vode, %.

Statistička razlika između faktora rastresitosti uzoraka dobivenih pri različitim uvjetima blanjanja testirana je Studentovim *t*-testom. U slučaju nehomogenosti varijanci poslužila je neparametarska analiza Mann-Whitneyjevim *u*-testom (McClave i Dietrich, 1988.). Statističke analize rađene su primjenom statističkog programa STATISTICA 6.0.

3. REZULTATI I DISKUSIJA
3 RESULTS AND DISCUSSION

U tablici 3. prikazane su vrijednosti sadržaja vode i gustoće uzoraka drva pri navedenom sadržaju vode te gustoće drva u apsolutno suhom stanju za različite vrste drva.

U tablici 4. navedene su izmjerene vrijednosti posmaka po nožu, srednje debljine strugotine, duljine luka zahvata i bočne površine strugotine za različite posmične brzine (v_p).

U tablicu 5. uvrštene su vrijednosti faktora rastresitosti f_r dobivene iz omjera volumena usitnjenog materijala (V_r) i kompaktnog drva (V_k) za različite posmične brzine i prednje kutove oštrice.

Prema teoriji rezanja moglo bi se očekivati da će s povećanjem posmične brzine nastati usitnjeni materijal s većim česticama i manjom nasipnom gustoćom odnosno s većim faktorom rastresitosti. Ipak, rezultati istraživanja pokazali su kako se za većinu uzoraka s povećanjem posmične brzine nasipna gustoća povećala odnosno faktor rastresitosti blanjevine smanjio (tabl. 5. i 6.). I ovim je istraživanjem potvrđen manji utjecaj posmične brzine odnosno debljine strugotine na usitnjenost materijala, a značajnim čimbenikom pokazao se smjer rezanja s obzirom na smjer vlakanaca (Beljo Lučić i dr., 2007b). Pri istosmjernom rezanju veća je vjerojatnost pojave sitnijih frakcija čestica.

U usporedbi s podacima iz literature (Madjarević, 1969.), dobivene su nasipne gustoće (tabl. 6.) i do pet puta manje za jelovinu te do tri puta manje za hrastovinu, ovisno o uvjetima nastanka usitnjenog materijala.

U tablici 7. dane su vrijednosti faktora rastresitosti usitnjenog materijala dobivenoga iz omjera gustoće

Tablica 3. Sadržaj vode i gustoća uzoraka
Table 3 Moisture content and density of samples

Vrsta drva *Wood species*	**Sadržaj vode, %** *Moisture content*, %	**Gustoća, kg/m³** *Density*, kg/m³	**Gustoća u aps. suhom stanju, kg/m³** *Density in dry condition*, kg/m³
jelovina / *fir-wood*	18,27	481,24	434
hrastovina / *oak-wood*	9,31	682,08	656
parena bukovina *steamed beech-wood*	9,18	689,64	664
bukovina 212 °C *beech-wood 212 °C*	4,47	676,81	639

Tablica 4. Vrijednosti geometrije reza određene uz pomoć programa AutoCAD za različite posmične brzine odnosno posmake po zubu
Table 4 Values of cutting geometry obtained using AutoCAD for different feed speeds and feed rates

Posmična brzina *Feed speed*	**Posmak po zubu** *Feed rate*	**Duljina luka zahvata** *Length of cut*	**Debljina strugotine** *Chip thickness*	**Bočna površina strugotine** *Side surface of chip*
m/min	mm	mm	mm	mm²
6	0,5	16,31	0,063	0,999
12	1	16,85	0,13	1,999
18	1,5	17,35	0,19	2,998
24	2	17,85	0,24	3,995

Tablica 5. Faktor rastresitosti (V_r/V_k) za različite vrste drva pri odabranoj posmičnoj brzini (v_p) i prednjem kutu oštrice (γ)
Table 5 Looseness factor (V_r/V_k) for different wood species at selected feed speed (v_p) and rake angle (γ)

Vrsta drva *Wood species*	**Prednji kut 15°** *Rake angle 15°*				**Prednji kut 20°** *Rake angle 20°*				**Prednji kut 25°** *Rake angle 25°*			
	$v_{p,}$ m/min				$v_{p,}$ m/min				$v_{p,}$ m/min			
	6	12	18	24	6	12	18	24	6	12	18	24
	Faktor rastresitosti, f_r (V_r/V_k) / *Looseness factor*, f_r (V_r/V_k)											
jelovina / *fir-wood*	28	22	16	99	18	15	11	11	22	15	12	10
hrastovina / *oak-wood*	9	6	6	5	7	6	5	4	5	5	5	8
parena bukovina / *steamed beech-wood*	16	12	10	8	18	11	9	8	15	10	9	11
bukovina 212 °C / *beech-wood 212°C*	4	3	4	3	3	3	3	4	3	4	3	4

Tablica 6. Srednja vrijednost nasipne gustoće (ρ_r) za različite vrste drva pri odabranoj posmičnoj brzini (v_p) i prednjem kutu oštrice (γ)
Table 6 Arithmetic mean values of bulk density (ρ_r) for different wood species at selected feed speed (v_p) and rake angle (γ)

Vrsta drva *Wood species*	**Prednji kut 15°** *Rake angle 15°*				**Prednji kut 20°** *Rake angle 20°*				**Prednji kut 25°** *Rake angle 25°*			
	v_p m/min				v_p m/min				v_p m/min			
	6	12	18	24	6	12	18	24	6	12	18	24
	Srednja vrijednost nasipne gustoće, ρ_r, kg/m³ /*Arithmetic mean values of bulk density, ρ_r*, kg/m³											
jelovina / *fir-wood*	31,01	48,24	50,09	55,89	29,87	41,86	59,48	63,51	25,97	42,93	45,9	53,55
hrastovina *oak-wood*	66,00	122,37	128,45	166,48	98,88	127,21	159,63	173,57	141,69	146,47	183,36	189,55
parena bukovina *steamed beech-wood*	41,22	62,38	79,24	98,36	44,96	73,14	92,04	99,93	58,97	82,8	95,87	88,91
bukovina 212 °C *beech-wood 212°C*	112,33	144,87	160,16	191,73	159,69	160,03	189,98	185,26	167,49	168,74	185,23	192,49

kompaktnog drva i nasipne gustoće usitnjenog materijala. Faktori rastresitosti dobiveni na taj način približno su jednaki onima koji su izračunani kao omjer volumena usitnjenog materijala i volumena kompaktnog drva. Međutim, ovisno o vrsti drva, faktori rastresitosti za blanjevinu višestruko su veći od vrijednosti u postojećoj literaturi (Sever, 1988.), u kojoj je to samo 4,6.

3.1. Utjecaj posmične brzine na faktor rastresitosti
3.1 Influence of feed speed on looseness factor

Na slikama 5., 6. i 7. za svaki od odabranih prednjih kutova oštrice dijagramom je prikazan utjecaj posmične brzine na promjenu prosječne vrijednosti faktora rastresitosti dobivenih iz omjera volumena usitnjenog materijala i volumena kompaktnog drva (V_r/V_k).

Kako prikazuju dijagrami, vidljive su značajne promjene faktora rastresitosti usitnjenog materijala jelovine i bukovine za raspon posmične brzine između 6 i 24 m/min. Najveće smanjenje faktora rastresitosti za sve prednje kutove oštrice i uz povećanje posmične brzine zabilježeno je pri obradi parene bukovine, dok promjena nije zabilježena za uzorke hrastovine ni za termički modificiranu bukovinu.

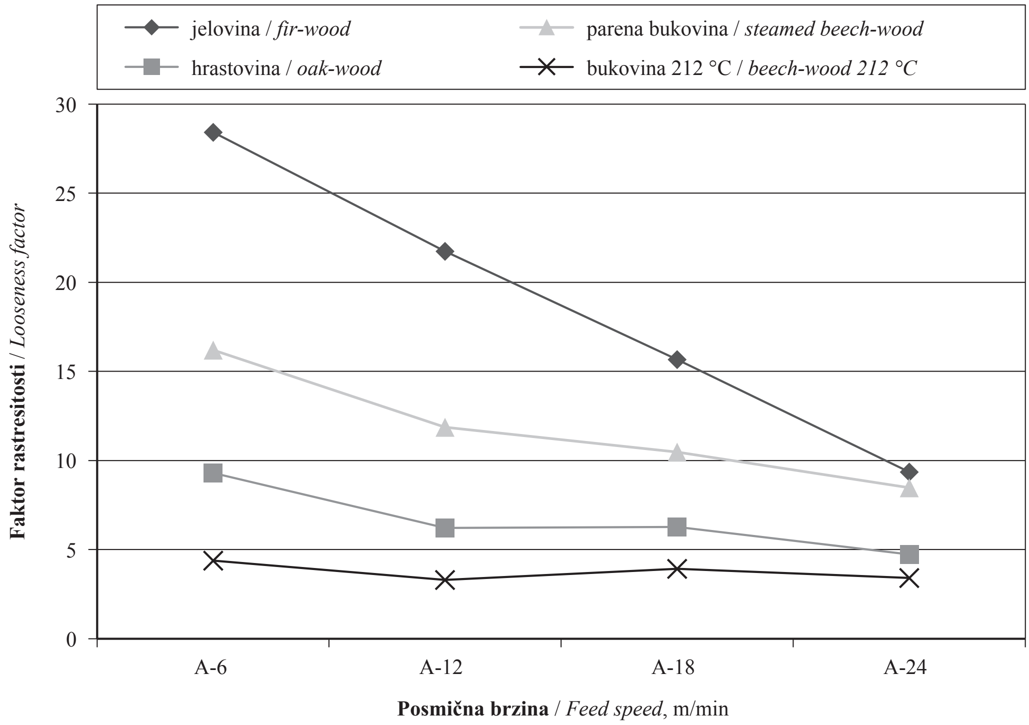
Usporedbom srednjih vrijednosti faktora rastresitosti prikazanih na slikama 9., 10. i 11. za uzorke jelovine postoji statistički značajna razlika za sve skupine uzoraka (p = 0). Ta razlika nije dokazana za uzorke nastale pri piljenju posmičnom brzinom od 12 i 18 m/min pri najmanjem prednjem kutu oštrice γ_1 (p = 0,38) te za uzorke nastale piljenjem uz posmičnu brzinu 12 i 18 m/min i najveći prednji kut oštrice γ_3 (p = 0,12). Također nije utvrđena statistički značajna razlika između faktora rastresitosti za termički modificirane uzorke nastale pri posmičnoj brzini od 6 i 12 m/min za prednji kut oštrice γ_2 (p = 0,88) i posmičnu brzinu 18 i 24 m/min (p = 0,07). Isto vrijedi (p = 0,18) za uzorke nastale blanjanjem uz posmičnu brzinu 6 i 12 m/min i prednji kut oštrice γ_3.

3.2. Utjecaj prednjeg kuta oštrice na faktor rastresitosti
3.2 Influence of rake angle on looseness factor

Statistički su testovi pokazali da ne postoji signifikantna razlika između faktora rastresitosti blanjevine nastale obradom jelovine pri najmanjoj posmičnoj brzini za kutove γ_1 i γ_2 (p = 0,24). Isto se može reći i za blanjevinu nastalu pri posmičnoj brzini od 12 m/min s prednjim kutom oštrice γ_2 i γ_3 (p = 0,41). Blanjevina jelovine nastala pri posmičnoj brzini od 18 m/min ima isti faktor rastresitosti pri obradi drva uz najmanji γ_1 i najveći γ_3 prednji kut oštrice (p = 0,09). Pri blanjanju uzoraka hrastovine za sve skupine uzoraka postoji statistički značajna razlika u faktoru rastresitosti s obzirom na prednji kut oštrice (p = 0). Za uzorke blanjevine parene bukovine utvrđena je statistički značajna razlika između faktora rastresitosti svih skupina uzoraka s obzirom na prednji kut oštrice (p = 0). To ne vrijedi za uzorke nastale blanjanjem kad je oštrica imala

Tablica 7. Faktor rastresitosti (ρ_k/ρ_r) za različite vrste drva pri odabranoj posmičnoj brzini (v_p) i prednjem kutu oštrice (γ)
Table 7 Looseness factor (ρ_k/ρ_r) for different wood species at selected feed speed (v_p) and rake angle (γ)

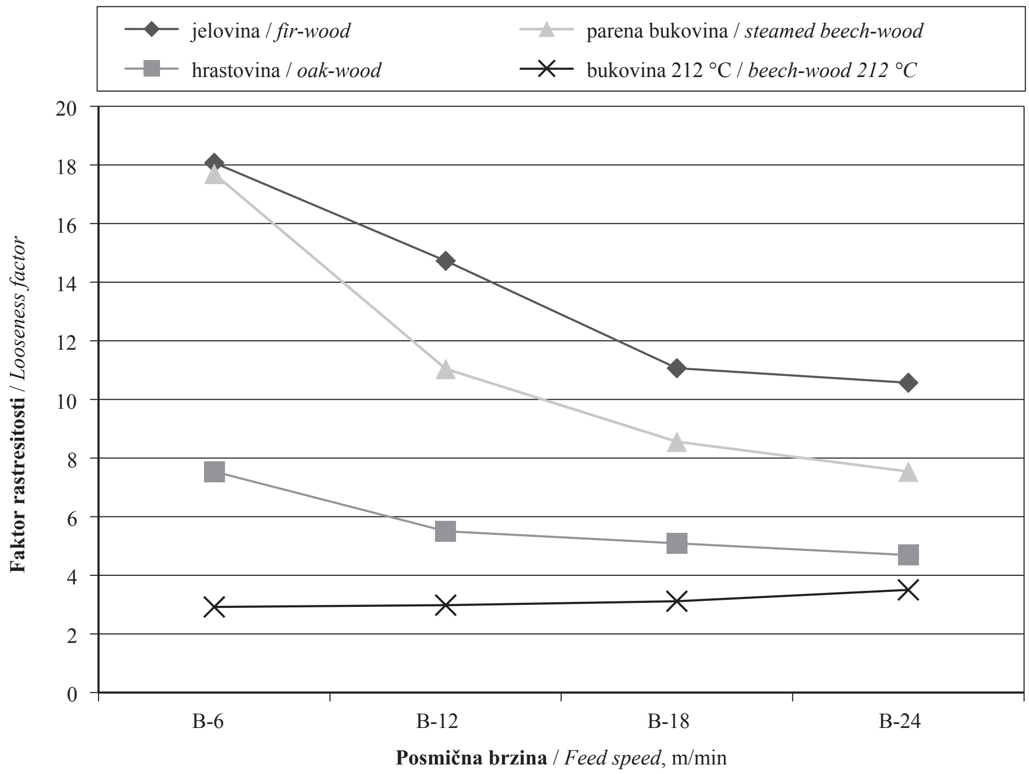
Vrsta drva *Wood species*	**Prednji kut 15°** *Rake angle 15°*				**Prednji kut 20°** *Rake angle 20°*				**Prednji kut 25°** *Rake angle 25°*			
	v_p, m/min				v_p, m/min				v_p, m/min			
	6	12	18	24	6	12	18	24	6	12	18	24
	Faktor rastresitosti, f_r (ρ_k/ρ_r) / *Looseness factor*, f_r (ρ_k/ρ_r)											
jelovina / *fir-wood*	15,52	9,98	9,61	8,61	16,11	11,50	8,09	7,58	18,53	11,21	10,49	8,99
hrastovina / *oak-wood*	10,33	5,57	5,31	4,10	6,90	5,36	4,27	3,93	4,81	4,66	3,72	3,60
parena bukovina / *steamed beech-wood*	16,73	11,06	8,70	7,01	15,34	9,43	7,49	6,90	11,70	8,33	7,19	7,76
bukovina 212 °C *beech-wood 212°C*	6,03	4,67	4,23	3,53	4,24	4,23	3,56	3,65	4,04	4,01	3,65	3,52



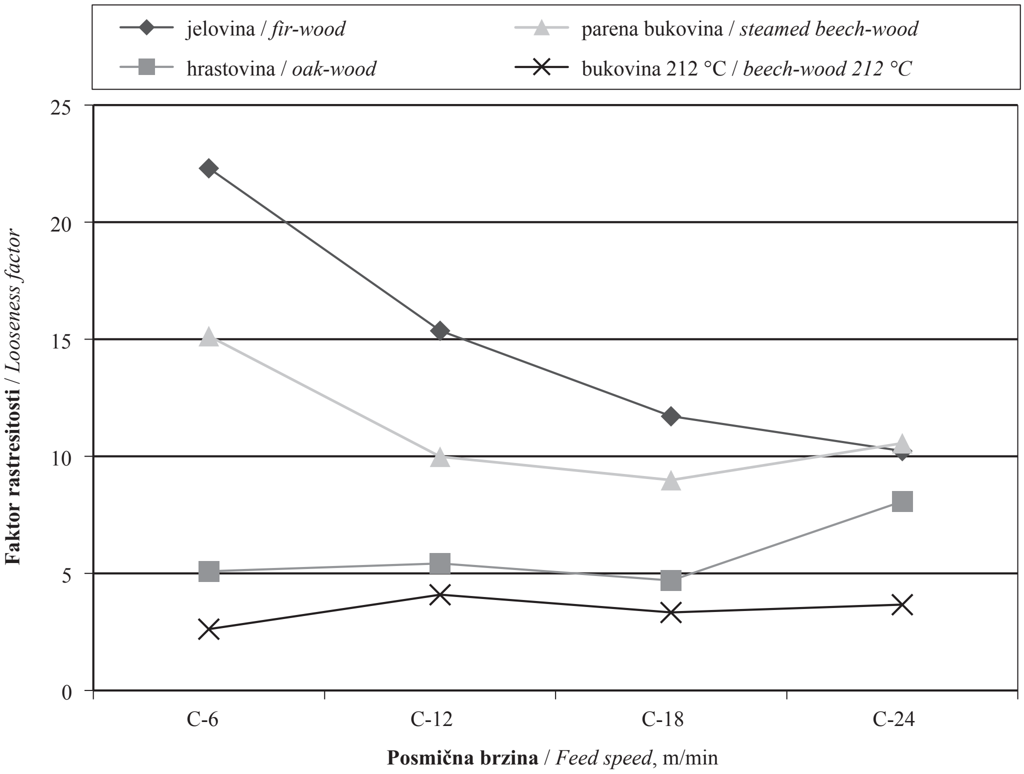
Slika 5. Faktor rastresitosti (V_r/V_k) za prednji kut oštrice γ_1 = 15° (A)
Figure 5 Looseness factor (V_r/V_k) at rake angle γ_1 = 15° (A)

prednji kut γ_1 i γ_2, pa je faktor rastresitosti bio jednak (p = 0,37) pri posmičnoj brzini od 24/min. Nema statistički značajne razlike ni među faktorima rastresitosti uzoraka blanjevine termički modificirane bukovine nastale pri posmičnoj brzini od 24 m/min pri najmanjem prednjem kutu oštrice γ_1 i onih dobivenih pri najvećem γ_3 prednjem kutu oštrice (p = 0,62). Za sve ostale skupine uzoraka termički modificirane bukovine postoji statistički značajna razlika među faktorima rastresitosti (p = 0). Usporedba srednjih vrijednosti faktora rastresitosti za sve skupine uzoraka prikazana je na slikama 9., 10. i 11.

Granulometrijska analiza prijašnjih istraživanja na istim uzorcima pokazala je da pri blanjanju termički modificirane bukovine, ako se blanja alatom koji ima veći prednji kut, i pri malim posmičnim brzinama nastaje



Slika 6. Faktor rastresitosti (V_r/V_k) za prednji kut oštrice γ_2 = 20° (B)
Figure 6 Looseness factor (V_r/V_k) at rake angle γ_2 = 20° (B)

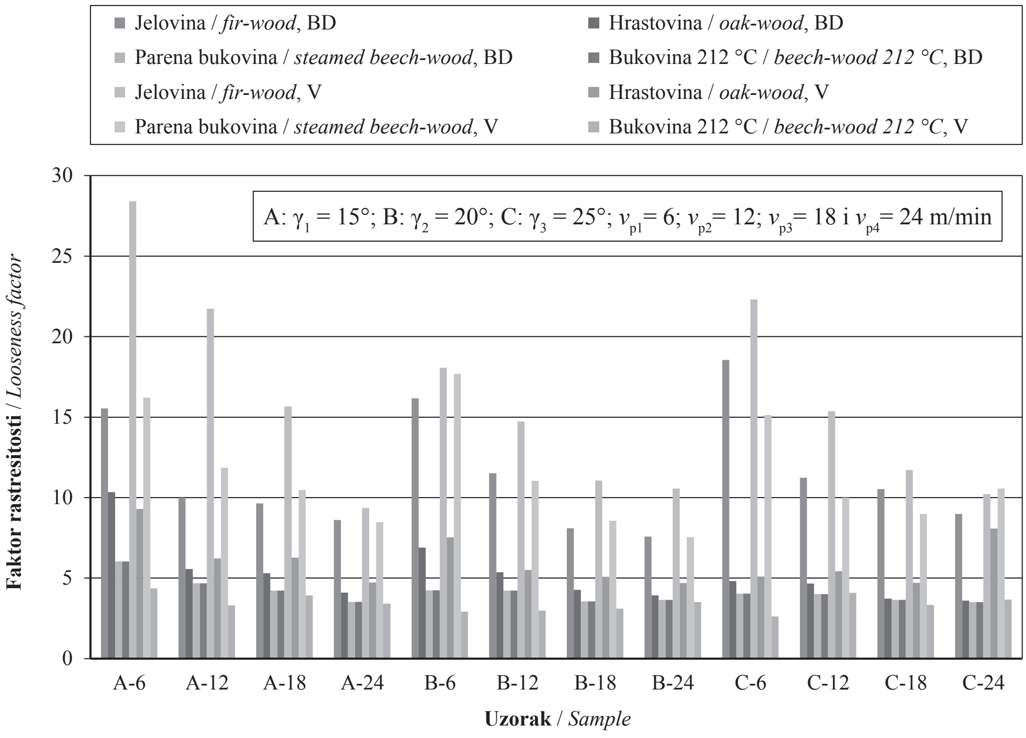


Slika 7. Faktor rastresitosti (V_r/V_k) za prednji kut oštrice γ_3 = 25°(C)
Figure 7 Looseness factor (V_r/V_k) at rake angle γ_3 = 25° (C)

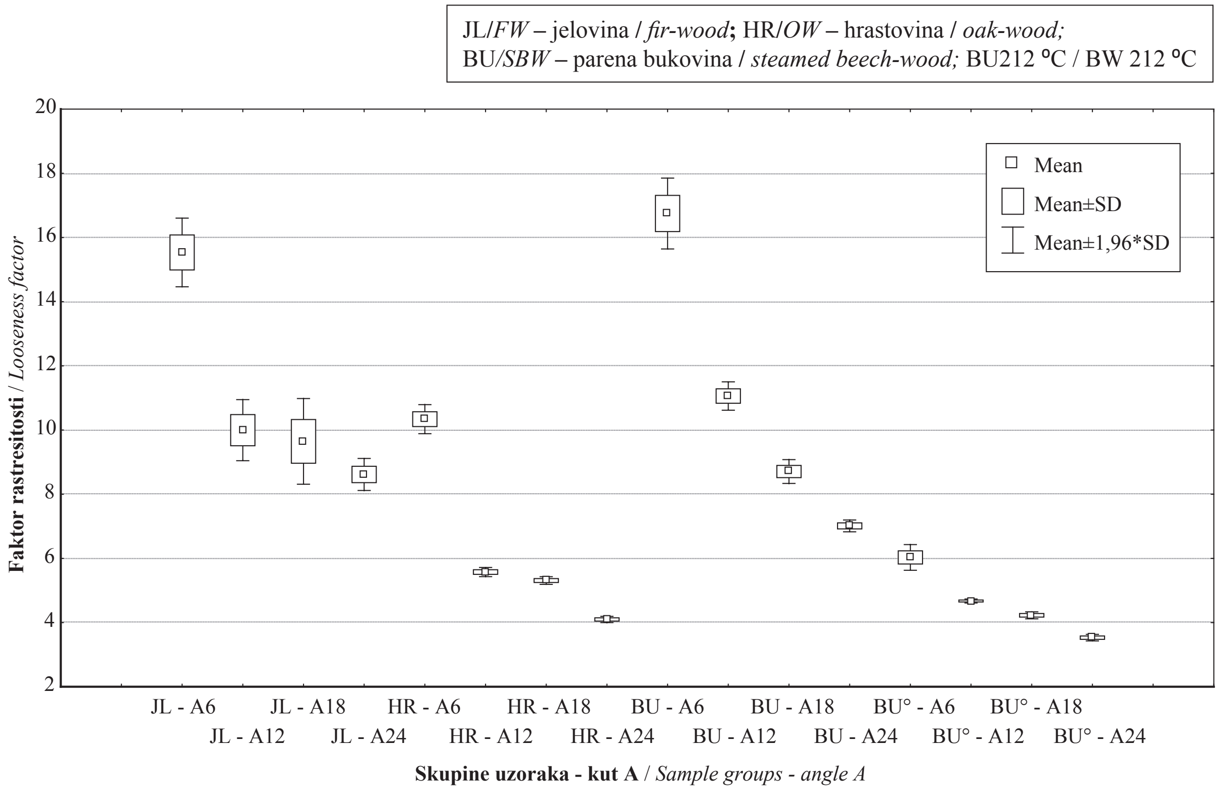
više sitnijih čestica. Za uzorke parene bukovine pri velikim je posmičnim brzinama rezultat povećanja prednjeg kuta blanjanja suprotan, to jest nastaju krupnije čestice (Beljo Lučić i dr., 2009.). Istraživanja Palmqvista i Gustafssona (1999.) također nisu pokazala nedvojben utjecaj prsnog kuta oštrice (0 – 30º) na usitnjavanje materijala pri blanjanju borovine, bukovine i MDF-a.

3.3. Utjecaj vrste drva na faktor rastresitosti
3.3 Influence of wood species on looseness factor

Usporedba faktora rastresitosti blanjevine odabranih vrsta drva, posmičnih brzina i prednjih kutova prikazana je na slici 8., a statistička usporedba srednjih vrijednosti predočena je slikama 9., 10. i 11. Najveća razlika faktora rastresitosti usitnjenog materijala uočena je iz-



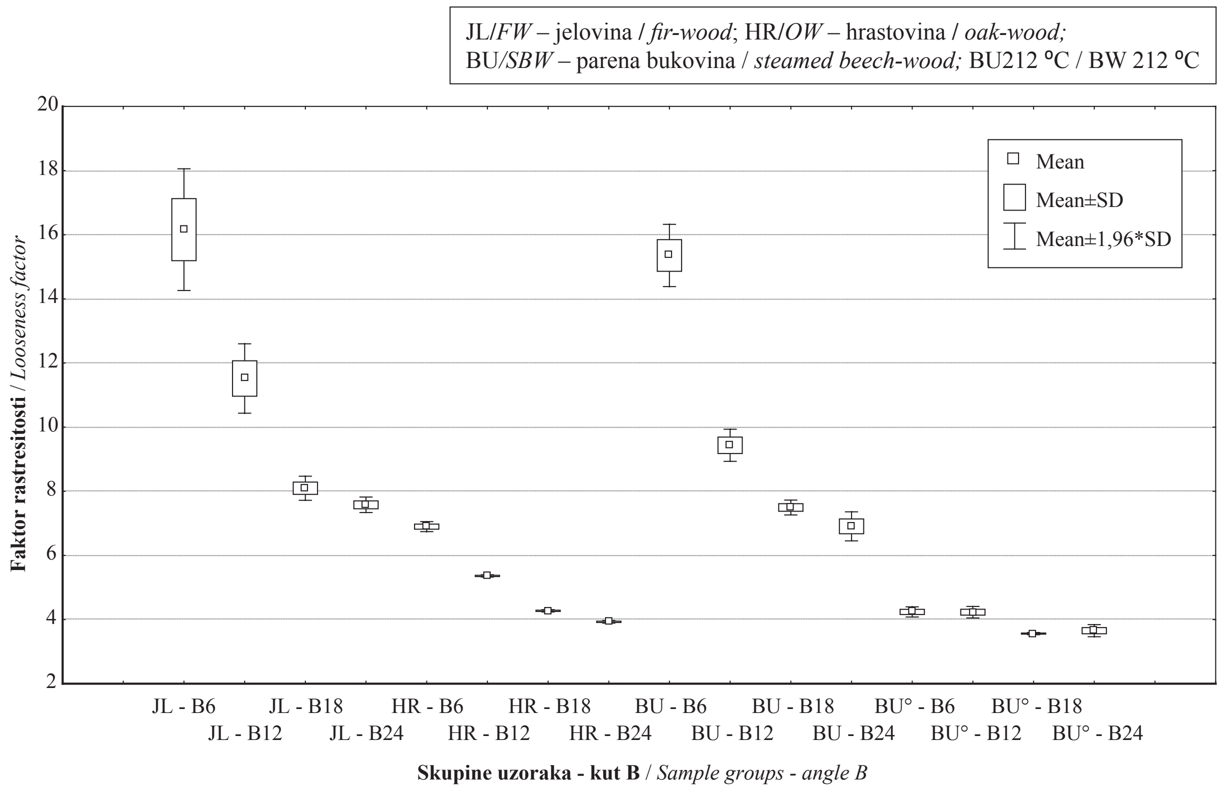
Slika 8. Usporedba faktora rastresitosti (ρ_k/ρ_r i V_r/V_k) svih uzoraka
Figure 8 Comparison of looseness factor (ρ_k/ρ_r i V_r/V_k) of all samples



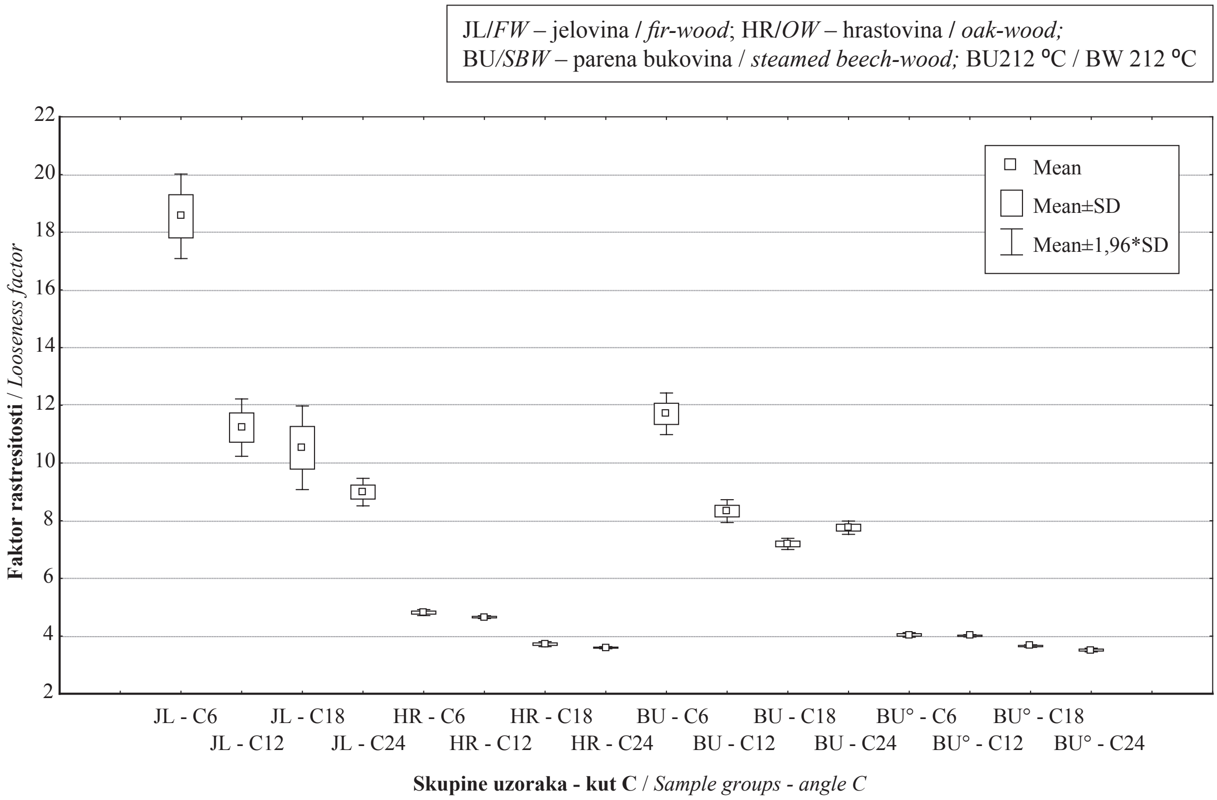
Slika 9. Usporedba faktora rastresitosti (ρ_k/ρ_r) za ispitivane vrsta drva – kut A
Figure 9 Comparison of looseness factor (ρ_k/ρ_r) of all wood species – angle A

među jelovine i termički modificirane bukovine. Jelovina ima faktor rastresitosti 3 do 10 puta veći od faktora rastresitosti termički modificirane bukovine (tabl. 5.).

Faktor rastresitosti blanjevine pri jednakom prednjem kutu oštrice značajno se razlikuje za sve parove uzoraka osim za uzorke parene bukovine i jelovine ($p_{\gamma2}$ = 0,14) nastale pri posmičnoj brzini od 6 m/min. Također se statistički značajno razlikuju faktori rastresitosti za sve parove uzoraka dobivenih pri jednakoj posmičnoj brzini. U svim uvjetima blanjanja



Slika 10. Usporedba faktora rastresitosti (ρ_k/ρ_r) za ispitivane vrsta drva – kut B
Figure 10 Comparison of looseness factor (ρ_k/ρ_r) of all wood species – angle B



Slika 11. Usporedba faktora rastresitosti (ρ_k/ρ_r) za ispitivane vrsta drva – kut C
Figure 11 Comparison of looseness factor (ρ_k / ρ_r) of all wood species – angle C

značajno su se jače usitnile drvne čestice nastale obradom termički modificirane bukovine u usporedbi s ostalim vrstama drva. Takvi su rezultati posljedica smanjene čvrstoće cijepanja i povećane krtosti termički modificiranog drva (Feist i Sell, 1987.; Sailer i Rapp, 2000.; Rapp i Sailer, 2001.; Rep i Pohleven, 2001.; Sinn i dr., 2002.). Nešto se manje usitnjavaju čestice nastale obradom hrastovine, a najmanje čestice nastale obradom jelovine.

Nasipna gustoća usitnjenog materijala nastaloga pri blanjanju termički modificirane bukovine dva je do tri puta veća od nasipne gustoće blanjevine parene bukovine, a faktor rastresitosti manji joj je i do četiri puta. Razlog za to je izostanak karakterističnih spiralnih čestica pri obradi termički obrađene bukovine (212 °C) manjim posmičnim brzinama, i to zbog krtosti materijala, što su pokazali i rezultati granulometrijske analize istih uzoraka (Beljo Lučić i dr., 2009.).

Uzimajući u obzir sve uzorke bez obzira na posmičnu brzinu i prednji kut oštrice, usporedbom faktora rastresitosti za ispitivane vrsta drva (sl. 9., 10. i 11.) zamijećen je značajan utjecaj vrste drva na faktor rastresitosti usitnjenog materijala. Iz dijagrama je vidljiva značajna razlika između podataka za sve vrste drva. Za sve prednje kutove oštrice faktor rastresitosti jelovine i parene bukovine odnosno hrastovine i termički modificirane bukovine bio je gotovo jednak, no ipak različit za sve skupine uzoraka.

I istraživanja Palmqvista i Gustafssona (1999.) pokazala su da pri blanjanju borovine, bukovine i MDF ploča pri jednakim debljinama strugotine znatan utjecaj na usitnjavanje materijala ima vrsta drva.

4. ZAKLJUČAK
4 CONCLUSION

Poznavanje utjecaja parametara obrade drva na faktor rastresitosti dobivenoga usitnjenog materijala korisno je za odabir uvjeta blanjanja radi postizanja željene usitnjenosti tako nastaloga drvnog materijala. Analizom zahtjeva vezanih za usitnjeni drvni materijal (sa stajališta rukovanja njime, njegova transportiranja i skladištenja, trajnosti i kvalitete te udjela potencijalno lebdećih čestica) dolazi se do zaključka da je poželjnija blanjevina većeg faktora rastresitosti. Međutim, za takav je materijal potrebno više prostora za skladištenje, ali ga je lakše transportirati, manje su emisije lebdećih čestica u radni prostor, a takav materijal ima i bolju permeabilnost.

Sve veća produktivnost strojeva za obradu drva temelji se na velikim brzinama rezanja i velikim posmičnim brzinama. U ovom je istraživanju pokazano da pri obradi jelovine i parene bukovine povećanje posmične brzine pri konstantnoj brzini rezanja utječe na smanjenje faktora rastresitosti dobivenoga usitnjenog materijala. Pri blanjanju termički modificirane bukovine prednji kut oštrice i posmična brzina nemaju utjecaja na faktor rastresitosti usitnjenog materijala, ali je pri blanjanju termički obrađene bukovine koncentracija lebdećih čestica znatno veća nego pri blanjanju ostalih istraživanih vrsta drva.

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An Exploratory Assessment of FSC Chain of Custody Certification Benefits in Croatian Wood Industry

Određivanje koristi od certifikacije FSC lanca sljedivosti u hrvatskoj drvnoj industriji

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 24. 11. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*79*
doi:10.5552/drind.2016.1540

ABSTRACT • *Croatian State Forest Enterprise covers more than seventy five percent of forest area in the Republic of Croatia and it is the biggest supplier of Croatian wood industry companies. From the year of national forests FSC certification (2002) onwards, the number of issued FSC CoC certificates has exceeded two hundred. The increase of issued FSC certificates confirms that CoC certification has become a very important segment of the Croatian wood industry. In this research, the survey among Croatian FSC CoC certificate holders has been conducted. The aim of the research was to determine the reasons of implementing FSC CoC certification, benefits of certification and problems arising out of implementation. The research has shown that the respondents were forced to implement FSC CoC by the request from their customers. Furthermore, respondents stated that the most important benefit from FSC CoC implementation was to keep the existing customers and for the largest part of respondents the main problem in FSC CoC implementation was related to high certification costs. Regarding the financial benefits of FSC CoC certification for respondents, the results showed small, but significant positive correlation between certification duration and efficiency of total equity, as well as between certification duration and return on assets.*

Key words: *forest certification schemes, the Republic of Croatia, wood industry, benefits of certification, FSC®, CoC*

SAŽETAK • *Hrvatske šume d.o.o. pokrivaju više od 75 % šumskog područja Republike Hrvatske i najveći su dobavljač sirovine za hrvatsku drvnu industriju. Od godine FSC certifikacije državnih šuma (2002.) do danas broj izdanih FSC CoC certifikata veći je od dvije stotine. Povećanje broja izdanih certifikata potvrđuje da je CoC certifikacija postala vrlo važna sastavnica poslovanja hrvatske drvne industrije. U sklopu ovog istraživanja provedena je anketa među hrvatskim nositeljima FSC CoC certifikata, a cilj istraživanja bio je odrediti razloge implementacije FSC CoC certifikacije, koristi od certifikacije i probleme koji nastaju pri implementaciji tog certifikata.*

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Rezultati su pokazali da je implementacija FSC CoC certifikacije u ispitanika najčešće potaknuta zahtjevima njihovih kupaca. Nadalje, najčešće isticana korist od FSC CoC implementacije jest zadržavanje postojećih kupaca, a za najveći dio ispitanika glavni su problem FSC CoC implementacije visoki troškovi tog postupka. S obzirom na financijske koristi od FSC CoC certifikacije za ispitanike, rezultati su pokazali malu, ali pozitivnu korelaciju između trajanja certifikacije i ekonomičnosti cjelokupnog poslovanja, kao i između trajanja certifikacije i njezina utjecaja na povrat imovine.

Ključne riječi: *certifikacijske sheme šuma, Republika Hrvatska, drvna industrija, koristi od certifikacije, FSC®, CoC*

1 INTRODUCTION
1. UVOD

Forest certification has been growing steadily in the last twenty years. After the Earth summit held in 1992 at Rio de Janeiro, Brazil, United Nations Conference on Environment and Development (UNCED) and the first global agreement concerning sustainability of forest management called the Statement of Forest Principles, forest certification began to develop more rapidly (Perera and Vlosky, 2006). In the next few years, as a reaction to the summit, the following forest certification schemes were established: FSC – Forest Stewardship Council (in 1993); SFI – Sustainable Forestry Initiative (in 1995); CSA – Canadian Sustainability Association – Sustainable Forestry Management System (in 1996); PEFC – Programme for the Endorsement of Forest Certification (in 1999) (Ozinga, 2004). Today, the two largest international forest certification schemes in Europe and in the world are Forest Stewardship Council (FSC) and Programme for the Endorsement Forest Certification schemes (PEFC). There are two types of certificates: certificate for forest management (FM) and certificate for chain of custody (CoC). Currently, 272 million hectares of forest area are under the PEFC certification scheme (PEFC, 2015b) and 188 million hectares under the FSC certification scheme (FSC, 2016), which is more than 11 % of the total global forest area (according to Forest Products Annual Market Review 2014-2015 the total global forest area is 4.033 billion hectares). Regarding CoC certificates, 30137 companies are the FSC CoC certificate holders (FSC, 2016) and 10744 companies are the PEFC CoC certificate holders (PEFC, 2015b). CoC certification is applicable to all organizations that trade, process or manufacture wood based and non-timber forest products. The FSC CoC certification is applicable to all CoC operations: trading, processing or manufacturing wood based and non-timber forest products from virgin and/or reclaimed materials including the primary industry sector (harvesting, pre-processing) or, in the case of recycled materials, reclamation sites, the secondary sector (primary and secondary manufacturing), and the tertiary sector (trading, wholesale, retail, print services) (FSC-STD-40-004 V2-1, 2011). Certified forest area has grown from 18 million ha in 2000 to over 430 million ha in 2014, and it has increased by more than twenty times (FAO, 2015). Almost 90 % of global certificated area is in Northern Hemisphere (Fernholtz *et al.,* 2015). According to UNECE/FAO's Forests Products Annual Market Review (2015), the number of CoC certificates of the two major certification schemes – FSC and PEFC, is steadily increasing. As forests cover almost one third of the earth's land surface, it is necessary to ensure sustainable forest management if global sustainable development is to come true (Paluš and Kaputa, 2009). The market is more and more oriented towards quality of products (Pirc Barčić and Motik, 2013), environmental projects, demands for a restructuration of wood industry in accordance with environmental needs (Lipušček *et al.,* 2010; Oblak and Jošt, 2011). The world's largest furniture retailer – IKEA has been a member of FSC since 1993 and IKEA's long-term goal is to source all wood from forests certified as responsibly managed (IKEA, 2015).

Croatian State Forest Enterprise (Hrvatske šume d.o.o.) covers more than 75 % of forest area in the Republic of Croatia (Hrvatske šume, 2015) and it is the biggest supplier of Croatian wood industry companies. Since 2002, Croatian State Forest Enterprise has been a FSC certificate holder. Therefore, Croatian wood industry sector companies got the chance to enter into the chain of custody. Constant growth of the number of FSC CoC certificates indicates that the Croatian wood industry has followed certification market trends. From the year of certification of national forests, the number of FSC CoC certificates has exceeded two hundred certificates (FSC, 2015). Only four PEFC CoC certificates are issued in the Republic of Croatia and those companies are engaged in trading with or belong to paper industry (PEFCa, 2015).

2 LITERATURE REVIEW
2. PREGLED LITERATURE

Since forest products certification market has grown rapidly, the need has emerged of understanding benefits, reasons and problems of certification as an important direction of research. Forest certification has brought many positive changes in forest management (Moore *et al.*, 2012). According to Rickenbach and Overdevest (2006), there are three views/perspectives of forest certification: market-based view; signal view and learning organization view. The first perspective sees certification effectiveness in direct market benefits – price premiums and market share. Signal view holds that certification operates as a signal that the company applies high ecological standards to all stakeholders – buyers, governmental and non-governmental organizations. The third view sees certification as a tool for improving forest practices and production through learning.

Numerous studies have attempted to determine whether the certification brings any benefit and why certificate holders decided to implement chain of custody standards (Rickenbach and Overdevest, 2006; Vlosky *et al.*, 2009; Bowers *et al.*, 2012; Narasimhan *et al.,* 2015). Vlosky *et al.* (2009) investigated changes in perception of wood-product manufacturers about certification in US from 2002 to 2008. Understanding of CoC certification has significantly increased from 2002 to 2008. Business owner commitment to environment is the highest ranked reason for getting involved in certification by US certificate holders. Rickenbach and Overdevest (2006) came to quite similar results, showing that FSC certificate holders from US have made their decision to become certified to provide cue/signal to all external stakeholders that they apply higher level standards in forest practice. From the above studies, it can be seen that environmental awareness is very important for US certificate holders. Recent research results showed that intangible benefits of CoC certification – support to sustainable forestry and responsibility goals were also the highest ranked reasons among Chinese and Vietnamese FSC CoC certificate holders (Bowers *et al*., 2012). Price premium and market-based benefits from certification were among the lowest ranked reasons (Rickenbach and Overdevest, 2006; Bowers *et al*., 2012). On the other hand, Montague's study (2010) has shown that many companies pursue certification because of their customers and in order to achieve market advantage. Vidal *et al.* (2003) stated that the benefits associated with CoC certification may be long term and indirect. Nowadays, customers are willing to pay higher prices for certificated products (Kozak *et al.,* 2004; Hoang *et al.,* 2015). Therefore, FSC certification provides economic benefits in the form of higher prices (Newsom, 2008). The reasons CoC certification has not been adopted among Malaysian furniture manufacturers are as follows: lack of price premiums, limited market potential and high costs (Ratnasingam, 2009). Narasimhan *et al.* (2015) researched the impact of FSC certification on company's performance depending on company's position in the supply chain. They confirmed that the FSC certification brings more market benefits (measured via sales growth) to downstream companies – those closer to the end customer.

Chain of custody certification has become very important for wood industry of the Republic of Croatia. As no systematic researches have been conducted in this area, need has emerged to make research among chain of custody certificate holders of the Republic of Croatia. The objective of this study is presented through the following research questions:

(1) What are the main reasons for the implementation of FSC certification?
(2) What are the benefits of FSC certification?
(3) What are the main problems in implementing FSC certification?
(4) Does FSC certification bring financial benefits?

3 METHODS
3. METODE

For collecting data about FSC CoC certification, a survey method was used (Dillman, 2000). The survey was carried out among companies from the Republic of Croatia that hold FSC certificate. These companies were, therefore, placed in FSC Certificate Holder database (www.info.fsc.org). Companies certified under FSC certification scheme were chosen because almost all certificates are FSC (99 %). Later in the text, the term certification is referred to FSC CoC certification. In order to gather data from FSC certificate holders, Google Docs online questionnaire has been designed. The questionnaire was sent to all FSC certificate holders of the Republic of Croatia via a link embedded within an e-mail. The questionnaire consisted of two parts with a total of nineteen questions. The first part of the questionnaire contained general questions about the company. The second part referred to FSC certification, reasons for the implementation of FSC certification, gained benefits of certification, problems with the implementation of FSC certification and other questions concerning FSC certification. The survey with a cover letter was sent to 221 FSC certificate holder from the Republic of Croatia and resulted with 23.5 % response rate. Financial reports (income statement and balance sheet for 2014), needed for calculating profitability ratios, were obtained from the Registry of Financial Reports (RGFI, 2015). The research was conducted during June and July of 2015. Data were analysed using descriptive statistics, χ^2-test and Pearson correlation by the use of STATISTICA 12 for MS Windows software (Dell Inc., 2015).

4 RESULTS
4. REZULTATI

4.1 Profile of respondents
4.1. Profil ispitanika

General characteristics of companies that participated in this research are shown in Table 1. The largest proportion of respondents are limited liability companies (65.4 %) and, according to the number of employees, they are micro and small companies (56.0 %).

The majority of respondents (96.2 %) sell their products outside the Republic of Croatia, mostly to the countries of the European Union (85 %). Italy, Germany, Austria and Slovenia were the most frequently stated (65 %) as the target market countries.

More than half of the surveyed FSC certificate holders (56.3 %) are engaged in wood processing and only 6.3 % are furniture manufacturing companies (Table 1). Table 2 presents certified product groups by FSC product classification (FSC-STD-40-004a V2-0, 2011). It can be seen from Table 2 that FSC certificate holders from the Republic of Croatia are mostly certified for primary wooden products. The largest number of companies are certified for sawn wood (W5 = 72.9 %) and wood in chips or particles (W3 = 64.6 %).

4.2 Reasons, benefits and problems of certification
4.2. Razlozi, dobiti i problemi certifikacije

One of the goals of research questions was to establish the main reasons of implementation of FSC certification (Table 3). The most important reason for in-

Table 1 Profile of respondents
Tablica 1. Profil ispitanika

Characteristics / *Obilježja*	**Description** / *Opis*	**Percent** *Postotak*
Legal form *pravni oblik*	company limited by shares / *dioničko društvo - d.d.*	11.5 %
	limited liability company / *društvo s ograničenom odgovornošću - d.o.o.*	65.4 %
	craft / *obrt*	23.1 %
Number of employees *broj zaposlenika*	less than 10 / *do 10*	20.0 %
	from 11 to 50 / *od 11 do 50*	36.0 %
	from 51 to 100 / *od 51 do 100*	22.0 %
	from 101 to 150 / *od 101 do 150*	10.0 %
	more than 151 / *više od 151*	12.0 %
Basic activity *osnovna djelatnost*	wood processing / *prerada drva*	56.3 %
	furniture manufacturing / *proizvodnja namještaja*	6.3 %
	trade / *trgovina*	20.8 %
	production of paper / *proizvodnja papira*	2.1 %
	printing / *tiskarska industrija*	2.1 %
	other / *ostalo*	12.5 %

troducing FSC certification is that it was requested by their customers (92.3 %). This was followed by market demand (63.5 %), which means that a large number of companies surrounding the respondents had provided certification, so they decided to implement certification in order to stay competitive. More than half of respondents indicated the image of the company (51.9 %) and environmental awareness of FSC CoC certificate holders (42.3 %) as the reasons for the implementation of FSC certification. These results show that FSC certificate holders have made the decision regarding FSC certification mostly on request from their customers. They have not recognized FSC certificate as an instrument of promotion, and only 19.2 % of respondents indicated that the reason for FSC implementation was company's promotion. Only 50 % of respondents uses FSC trademarks for promotional purposes. Results indicate that for Croatian FSC certificate holders, implementation of FSC certificate is just one of the ways to survive in the market. In the last three years, there were no governmental subsidies for the implementation of FSC certification. The last subsidy program of the Government of the Republic of Croatia for certification of products was issued in 2013. None of the respondents noted the governmental subsidies as the reason for FSC implementation.

Benefits of implementation of FSC certification were also examined (Table 4). Keeping the existing customers is the main benefit of FSC certification for the largest number of respondents (80.8 %). As other benefits of FSC certification, respondents stated obtaining new customers (59.6 %), increase of competitiveness (50.0 %), increase of export (34.6 %) and increase of company's image (32.7 %). Increase of profit and increase of sales were the lowest ranked benefits of FSC certification. Low ranking of financial benefits are in correspondence with the results of Rickenbach and Overdevest (2006). Only 11.5 % of

Table 2 Certified products by product groups ($N = 52$)
Tablica 2. Proizvodne skupine certificiranih proizvoda ($N = 52$)

Product groups / *Proizvodne skupine*	**Number of answers** *Broj odgovora*	**Percent of answers** *Postotak odgovora*
W1 – Rough wood / *oblo drvo*	27	56.3 %
W2 – Wood charcoal / *drvni ugljen*	1	2.1 %
W3 – Wood in chips or particles / *usitnjeno drvo*	31	64.6 %
W5 – Sawn wood (sawn, chipped, sliced or peeled) / *piljena građa*	35	72.9 %
W6 – Products from planing mill / *blanjano drvo*	1	2.1 %
W7 – Veneer / *furnir*	7	14.6 %
W8 – Wood panels / *drvne ploče*	7	14.6 %
W9 – Engineered wood products / *konstrukcijsko drvo*	8	16.7 %
W10 – Wood package / *drvna ambalaža*	6	12.5 %
W11 – Wood for construction / *drvo u graditeljstvu*	14	29.2 %
W12 – Indoor furniture / *namještaj za interijer*	10	20.8 %
W13 – Outdoor furniture and gardening / *namještaj za eksterijer i vrtni namještaj*	3	6.3 %
W15 – Recreational goods / *rekreacijski proizvodi*	3	6.3 %
W18 – Other manufactured wood products / *ostali proizvodi od drva*	2	4.2 %
W19 – Other wood products n.e.c. / *ostali neklasificirani drvni proizvodi*	1	2.1 %
P – Pulp and paper products / *pulpa i proizvodi od papira*	6	12.5 %

Table 3 Reasons of implementation of FSC certification ($N = 52$)
Tablica 3. Razlozi uvođenja FSC certifikata ($N = 52$)

Reasons / *Razlozi*	**Number of answers** *Broj odgovora*	**Percent of answers** *Postotak odgovora*
Customer's requests *zahtjev kupca*	48	92.3 %
Market demand *potreba tržišta*	33	63.5 %
Company image *imidž poduzeća*	27	51.9 %
Environmental awareness *ekološka osviještenost*	22	42.3 %
Promotion / *promocija*	10	19.2 %
Governmental subsidies *državni poticaji*	0	0.0 %

respondents stated that they did not achieve any benefit from the implementation of FSC certification, but it may be just a matter of their personal perception. If they do not see an increase in sales and income, then they can think that there is no benefit from certification implementation. On the other hand, if they had not implemented FSC certificate, they would probably lose market share, considering that the FSC CoC certification was mainly implemented at their customer request.

High certification costs (71.2 %) was the highest ranked problem in the implementation of FSC certification. Extensive documentation was the second ranked problem in the implementation of FSC certification (36.5 %). Revealing of confidential information, lack of understanding of suppliers, frequent changes of standards and resistance of employees were the least ranked problems in the implementation of FSC certification.

Table 4 Benefits of implementation of FSC certification ($N = 52$)
Tablica 4. Dobiti od uvođenja FSC certifikata ($N = 52$)

Benefits / *Dobiti*	**Number of answers** *Broj odgovora*	**Percent of answers** *Postotak odgovora*
Keeping existing customers *zadržavanje postojećih kupaca*	42	80.8 %
Obtaining new customers *pridobivanje novih kupaca*	31	59.6 %
Increase of competitiveness *povećanje konkurentnosti*	26	50.0 %
Increase of export *povećanje izvoza*	18	34.6 %
Increase of company's image *poboljšanje imidža*	17	32.7 %
Increase of profit *povećanje dobiti*	10	19.2 %
Increase of sales *povećanje prodaje*	8	15.4 %
None / *nije ih bilo*	6	11.5 %

Table 5 The main problems in implementation of FSC certification ($N = 52$)
Tablica 5. Glavni problemi uvođenja FSC certifikata ($N = 52$)

Problems / *Problemi*	**Number of answers** *Broj odgovora*	**Percent of answers** *Postotak odgovora*
High costs of certification *visoki troškovi certifikacije*	37	71.2 %
Extensive documentation *opsežna dokumentacija*	19	36.5 %
Revealing of confidential information / *zadiranje u povjerljive podatke*	7	13.5 %
Suppliers' lack of understanding *nerazumijevanje dobavljača*	7	13.5 %
Frequent changes of standards *česte promjene standarda*	4	7.7 %
Resistance of employees *otpor zaposlenika*	3	5.8 %

4.3 The impact of FSC certification on financial performance
4.3. Utjecaj FSC certifikacije na financijsku uspješnost

During 2014, over a quarter of respondents (27 %) achieved annual income higher than 6571 thousand Euros and 31 % of respondents achieved the income between 1314 and 6571 thousand Euros. In 2014, only 2 % of respondents had the annual income lower than 131 thousand Euros.

Only 6.4 % of respondents stated that they have zero income share of certified products. This means that 93.6 % of respondents have been selling FSC certificated products. For most of them, the share of certificated products in total income was between 80 and 100 %. This research has shown that the share of certified products in total income of 72.3 % of FSC certificate holders from the Republic of Croatia was more than 20 % during 2014. The majority of respondents were those who had the income above 1314 thousand Euros (58 %) and had the income share of certified products above 80 % (34 % of respondents). χ^2-test is used to establish whether the share of certified products in total income and total income are independent. In 2014, according to χ^2-test results, ($\chi^2 = 34.15$; $df = 20$; $p = 0.03$), the share of certified products and total income were dependent.

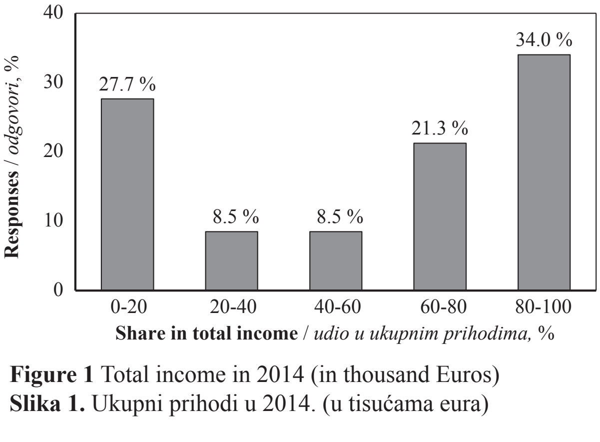

Figure 1 Total income in 2014 (in thousand Euros)
Slika 1. Ukupni prihodi u 2014. (u tisućama eura)

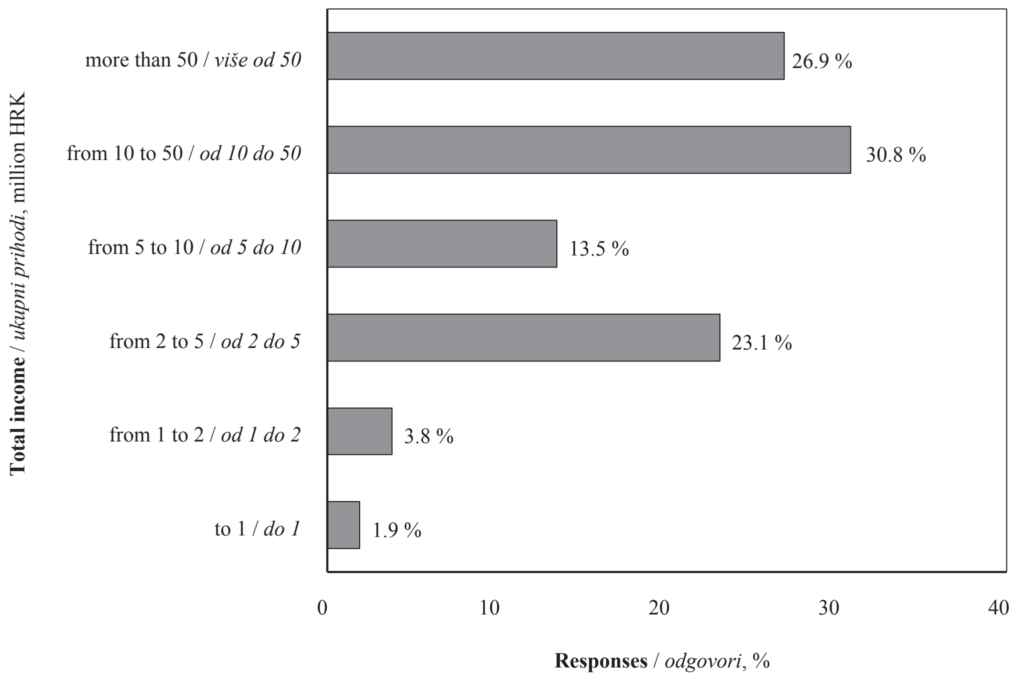

Figure 2 Total income share of certified products in 2014
Slika 2. Udio prihoda od certificiranih proizvoda u 2014.

Respondents were also asked some additional questions regarding financial benefits of FSC certification and certified suppliers. Approximately one third of respondents (34.6 %) stated that profit increased and 21.2 % of respondents have raised their prices due to FSC certification. Most respondents (75 %) preferred certificated suppliers and 25 % of respondents had problems in finding certified suppliers. The majority of respondents admitted that FSC certification has met their expectations. This is confirmed by the positive answer of maintaining FSC certification among 96 % of respondents. Quite interesting results have been gained among the respondents who stated that they did not have any benefits from FSC certification. Although they did not benefit from the implementation of FSC certification, they unexpectedly declared that would keep the FSC certificate.

Correlation analysis of employee number, income share of certified products, certification duration, and efficiency of total equity (EU) and financial performance profitability ratios (ROA – Return on Assets, ROE – Return on Equity and ROS – Return on Sales) is shown in Table 6. Small positive significant correlations between certification duration and efficiency of total equity and return on assets were established. No significant correlations were established between employee number and profitability ratios. Additionally, no significant correlations between the income share of certified products and profitability ratios were established. Results from correlation matrix suggest that certificate holders from the Republic of Croatia are certificated on customer's request. They have not achieved any additional financial benefit, except keeping customers. Although they failed to achieve additional

Table 6 Correlation matrix
Tablica 6. Matrica korelacija

		ENo	ICP	CD	EU	ROA	ROE	ROS
		r	*r*	*r*	*r*	*r*	*r*	*r*
ENo	*r*	1	0.050	0.255	0.191	-0.107	-0.132	0.002
ICP	*r*		1	0.275	-0.033	0.144	-0.055	0.269
CD	*r*			1	0.331*	0.286*	-0.092	0.189
EU	*r*				1	0.322*	0.266	0.213
ROA	*r*					1	0.161	0.806**
ROE	*r*						1	-0.058
ROS	*r*							1

ENo – Employees number / *broj zaposlenika*; ICP – percentage of income from certified products / *udio prihoda od certificiranih proizvoda*; CD – certification duration in years / *trajanje certifikacije u godinama*; EU – Efficiency of total equity / *ukupna ekonomičnost poslovanja;* ROA – Return on assets */ povrat aktive ;* ROE – Return on equity */ povrat kapitala;* ROS – Return on sales */ povrat prodaje; r* – Pearson correlation / *Pearsonova korelacija*.
* Correlation is significant at the 0.05 level. / *Korelacija je značajna na razini 0,05.*
** Correlation is significant at the 0.01 level. / *Korelacija je značajna na razini 0,01.*

profit due to certification, they plan to maintain FSC certificate in order to survive in the market.

5 DISCUSSION AND CONCLUSION
5. RASPRAVA I ZAKLJUČAK

Are wood processing companies implementing certification because of their environmental awareness? According to the results of this study, huge expansion of FSC CoC certification in the last decade was customer driven – certification process was initiated by customers. The majority of certificate holders sell their products on EU market (96 %) and numerous sustainable development initiatives among EU member countries have emerged in a form of chain of custody certification. The most frequently stated reason for the introduction of FSC certification is the customer's request (92.3 %). This certificate is just one of the ways to survive on the market and companies do not see FSC certificate as an instrument of promotion, since the promotion was the second lowest reason for introducing certification. Only 50 % of respondents uses FSC trademarks for promotional purposes.

For the largest number of respondents (80.8 %) the main benefit of FSC certification is to keep the existing customers. This result is in accordance with their customer driven certification. As other FSC certification benefits, respondents stated other market based benefits – obtaining new customers, increase of competitiveness, increase of export and increase of the company image. For the largest number of respondents, the main problem in the implementation of FSC certification was related to high certification costs (71.2 %).

Although optional, FSC certification for wood industry companies of the Republic of Croatia is not a matter of choice, rather a necessity. Importance of FSC certification can be seen from the fact that 93.6 % of respondents were selling FSC certificated products, almost thirty five respondents (34.6 %) increased profit due to certification, more than half of respondents have more than 60 % share of certified products in total income and 21.2 % raised prices due to FSC certification. The majority of respondents admitted that FSC certification has met their expectations. This is confirmed by the positive answer of respondents (96 %) who were willing to maintain FSC certification. Quite interesting results that confirm the importance of FSC certification were obtained among respondents who stated that they did not have any benefits from FSC certification (11.5 %). Although they pointed out that did not have benefits from the implementation of FSC certification, they also unexpectedly declared that they would keep FSC certificate.

Even though the results of correlation analysis did not show significant influence of FSC certification on all financial performance indicators, the impact of FSC certification on financial performance cannot be neglected. Small significant positive correlations between certification duration and efficiency of total equity and return on assets were established. Although FSC certificate holders did not substantially profit due to certification, FSC certification has enabled them to be competitive, and they had to maintain FSC certificate in order to survive on the market. Results of this study suggest that FSC certification is a precondition for competitiveness for Croatian wood industry companies. These findings are consistent with the findings of Narasimhan *et al.* (2015), who confirmed that upstream firms (companies at the beginning of supply chain), to which Croatian wood processing companies mostly belong, face coercive pressure from their business customers, and thus might choose to certify even if the benefits of certification are not apparent. Although financial benefits have not been proven significantly, the share of certified products in total revenue is quite significant. Importance of FSC certification for Croatian FSC certificate holders can be presented through the share of certified products in total revenue.

Overall, our findings encourage the implementation of FSC certification. The FSC certification can serve as a signal to customers that the company implements standards which ensure traceability of materials, applies high environmental principles and that it is not included in the trade of illegally harvested timber. However, FSC certification scheme is optional. Many wood processing and furniture manufacturing companies from the Republic of Croatia have implemented FSC standards and this could make it easier for them to provide compliance with mandatory European Union regulations, such as EU Timber Regulation (EUTR 995/2010).

This study is a contribution to the research area of benefits of FSC CoC certification, because besides using subjective benefit measures based on respondent's evaluation, objective measures based on financial reports were also used. Although this study is a significant contribution to the area of chain of custody certification, it is not without limitations. Limitation of this study could be the timeframe of financial performance indicators, so in future research financial performance could be measured over a period of time. Additionally, comparison of financial performance of FSC certificate holders of wood industry and other industries (e.g. printing) could be made.

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Investigation of Isatis Tinctoria and Isatis Buschiana Stalks as Raw Materials for Pulp and Paper Production

Istraživanje mogućnosti upotrebe stabljika biljki *Isatis tinctoria* i *Isatis buschiana* kao sirovine za proizvodnju celuloze i papira

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 7. 12. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*861.069*
doi:10.5552/drind.2016.1542

ABSTRACT • *Isatis tinctoria and Isatis buschiana were evaluated as raw materials for pulp and paper production. Chemical composition and morphological aspects of Isatis stalks were determined. Lignin contents of I. tinctoria and I. buschiana were 23.9 % and 19.9 %, respectively. α-cellulose ratio was found to be 48.5 % in I. tinctoria and 32.9 % in I. buschiana. Fiber length, fiber diameter, lumen diameter and cell wall thickness were measured and the obtained data was used to calculate felting rate, elasticity coefficient, rigidity coefficient, runkel index and F factor. Handsheets were produced from Isatis stalks, and physical and optical properties were determined. Breaking length, tear index and burst index values were higher for the beaten pulp than for unbeaten pulp, while brightness and whiteness values were higher in unbeaten pulp.*

Key words: *I. tinctoria, I. buschiana, chemical composition, pulp, paper*

SAŽETAK • *U radu su istražene mogućnosti upotrebe stabljike biljaka Isatis tinctoria i Isatis buschiana kao sirovine za proizvodnju celuloze i papira. Određeni su kemijski sastav i morfološka svojstva stabljike. Sadržaj lignina u stabljici I. tinctoria bio je 23,9 %, a u stabljici I. buschiana 19,9 %. U stabljici I. tinctoria utvrđen je udjel α-celuloze od 48,5 %, a u stabljici I. buschiana taj je postotak iznosio 32,9 %. Izmjereni su duljina i promjer vlakanaca, promjer pore i debljina stanične stijenke, a dobiveni su podaci iskorišteni za izračunavanje brzine filcanja, koeficijenta elastičnosti, koeficijenta krutosti, Runkelova indeksa i F-faktora. Od stabljika biljaka Isatis tinctoria i Isatis buschiana proizvedeni su listovi papira kojima su zatim određena fizikalna i optička svojstva. Utvrđeno je da je veće vrijednosti duljine lomljenja, indeksa cijepanja i indeksa pucanja imao papir od mljevene celuloze nego papir od nemljevene celuloze, dok je papir od nemljevene celuloze imao veće vrijednosti sjajnosti i bjeline.*

Ključne riječi: *I. tinctoria, I. buschiana, kemijski sastav, celuloza, papir*

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1 INTRODUCTION
1. UVOD

The growth of paper consumption leads to the increase of the demand for fibrous material in pulp and paper industry (Daud and Law, 2010). Due to decreases in forests and increasing environmental awareness, seeking alternative non-wood raw metarials for papermaking has been the subject of scientific interest (Kaldor, 1992). Non-wood plant fibers, such as bagasse, wheat and rice straws, bamboo and kenaf are being used in the manufacture of pulp and paper (Ashori *et al*., 2006). Search for new non-wood raw materials will lead to discover alternatives to wood-based raw materials. Cotton (*Gossypium hirsutum*) stalks (Gencer et al., 2001; Tutus et al., 2010a), *Crambe orientalis* and *C. tataria* (Tutus *et al*., 2010b), and tea (*Camellia sinensis*) wastes (Tutus *et al*., 2015) were evaluated for their chemical composition and fiber characteristics.

I. tinctoria L. (*Brassicaceae*) or woad is a biennial or perennial herb growing up to 120 cm in height (Stoker *et al*., 1998a; Guarino *et al*., 2000). The flowers are small and yellow in color, and the leaves are hastate with minute auricles (Guarino *et al*., 2000). *I. tictoria* is one of the sources of the blue dye indigo (Maugard *et al*., 2001) and was cultivated in the Mediterranean countries for centuries to produce indigo (Fréchard *et al*., 2001; Stoker *et al*., 1998b). Besides dyeing properties, phytochemical, biological and pharmacological investigations have been carried out on *I. tinctoria* due to its medicinal properties. Antibacterial, antifungal, antiviral and cytoinhibitory activities were screened from *Isatis* extracts and constituents were selected (Hamburger *et al*., 2002). *I. buschiana* is also a biennial or perennial plant species, the flowering time is in May-July and the fruits can be observed in June-August (Davis, 1965). The herb can grow up to 98 cm in height (Comlekcioglu *et al*., 2014). In contrast to *I. tinctoria*, blue coloring dye could not be obtained from *I. buschiana* (Comlekcioglu *et al*., 2015).

The aim of this study was to determine the chemical and morphological properties of *I. tinctoria* and *I. buschiana* stalks. Kraft-AQ pulping method of *Isatis* stalks was also investigated to evaluate the potential use of *Isatis* in pulp production. To the best of our knowledge, this is the first report evaluating the *I. tinctoria* and *I. buschiana* as a raw material for paper production. *Isatis* stalks waste obtained from indigo production is a sustainable fiber source since the waste is not used for another purpose. This waste should be used in the paper industry in order to provide income for indigo producers.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 The plant materials
2.1. Biljni materijal

I. tinctoria was grown in Kahramanmaras/Turkey in 2013 using the seeds provided from the previous study (Comlekcioglu *et al*., 2014) and stalks were obtained from the breeded *I. tinctoria* after 7 months. *I. buschiana* was collected from native flora in 2013 and identified using Flora of Turkey and East Aegean Islands (Davis, 1965).

2.2 Morphological properties of fibers
2.2. Morfološka svojstva vlakanaca

The fiber lengths and widths, lumen diameters, and cell wall thicknesses, as the morphological properties of raw materials, were measured with a microscope. To measure the fiber morphologic properties of the specimens (0.5 mm thick and 2 cm long, parallel to the fiber), the chloride method was performed (Wise and Karl, 1962). In this method, specimens were immersed into chloride solution until they were defibered. Fiber dimension variables were measured using Olympus BX51 microscope with 10X ocular lens provided with a measuring scale. Fiber width and lumen diameter were measured with a magnification of 40X object lens and the fiber length was measured with a magnification of 10X object lens. Mean values were calculated from the measurement of 100 fibers in each plant. The felting rate, elasticity coefficient, rigidity coefficient, runkel index and F factor were calculated by using the equations below (Tutus *et al*., 2010b):

Felting rate = Fiber length / Fiber diameter

Elasticity coefficient (%) = Lumen diameter / Fiber diameter×100

Rigidity coefficient (%) = Cell wall thickness / Fiber diameter ×100

Runkel index = Cell wall thickness ×2 / Lumen Diameter

F ratio (%) = Fiber length / Cell wall thickness ×100

2.3 Chemical properties of *Isatis* stalks
2.3. Kemijska svojstva stabljika biljaka *Isatis*

Isatis stalks were prepared according to TAPPI T 264 cm–07 for chemical analysis. *Isatis* stalks were analyzed for moisture, lignin, α-cellulose, ash, ethanol-toluen-acetone solubility, cold and hot water solubility and 1 % NaOH solubility in accordance with the applicable standards: TAPPI T 264 om–88, TAPPI T 222 om–88, TAPPI T 203 os–71, TAPPI T 211 om–85, ASTM D1107 - 96, TAPPI T 207 om–88, TAPPI T 207 om–88, respectively. Holocellulose and cellulose contents of *Isatis* stalks were determined according to Wise's chloride method (Wise and Karl, 1962) and Kurscher-Hoffer method (Browning, 1967), respectively. The raw material samples, 5 g of oven-dried weight, were placed into a 500 mL Erlenmeyer flask, to which 200 mL of deionized water (having a temperature of 90 ºC) was then added, followed by 10 mL of acetic acid and 2.5 g of 80 % (w/w) $NaClO_2$. An optional 25 mL Erlenmeyer flask was inverted in the neck of the reaction flask. The flask was kept in a water bath at 90 ºC for 60 min, at which time 10 mL of acetic acid and 2.5 g of 80 % (w/w) $NaClO_2$ were added with shaking. The 60 min cycle was repeated for up to 6 cycles. At the end, the flask was stoppered and cooled with cold water to stop the reaction. The reaction mixture was then filtered using a tared fritted disk glass thimble, washed with cold water and acetone, and dried at 105 ºC until the crucible weight was constant, and the holocellulose content was calculated. The cellulose was obtained by refluxing wood meal three times for 1 h with a 1:4 (v/v) mixture of nitric acid and ethanol. Three replicates were done for each experiment, and mean values were used.

2.4 Pulping and handsheets
2.4. Priprema celuloze i listova papira

Air dried *Isatis* stalks were cleaned and cut into pieces about 6-8 cm long. To determine the optimum pulping conditions, 4 cooking experiments were carried out on *Isatis* stalks, using kraft-anthraquinone (AQ) processes. Pulping conditions are given in Table 1. Pulping experiments were performed in 15-L electrically heated laboratory rotary digester. At the end of pulping, the pulp was washed, disintegrated in a pulp mixer and screened on a 0.15 mm slotted plate. The pulp yield was determined as dry matter obtained on the basis of oven dried stalks. Screened pulp was beaten in a Hollander type beater to 55 ºSR freeness. Ten handsheets, with a grammage of 70±3 g/m^2, were made by using Rapid Kothen RK-21 paper sheet former according to TAPPI T 272 om-92.

Table 1 Pulping conditions for *I. tinctoria* and *I. buschiana* stalks
Tablica 1. Uvjeti pripreme celuloze od stabljika biljaka *I. tinctoria* i *I. buschiana*

Pulping conditions *Uvjeti pripreme celuloze*	
Active alkali / *aktivne lužine*	23 %
Sulfidity / *sulfidi*	25 %
AQ charge / *AQ udio*	0 %, 0.1 %, 0.3 %, 0.5 %
Cooking temperature / *temperatura kuhanja*	155 ºC
Cooking time / *vrijeme kuhanja*	90 min
Penetration / *prodiranje*	30 min
Liquor to stalk ratio / *omjer otapala i stabljika*	5/1 (L/kg)

2.5 Determination of physical and optical properties
2.5. Određivanje fizikalnih i optičkih svojstava

The breaking length, burst index, tear index, brightness, whiteness, opacity and yellowness were determined according to TAPPI T 494 om–88, TAPPI T 403 om–91, TAPPI T 414 om–88, ISO/DIS 2470, ISO/DIS 11475, ISO/DIS 2471 and ASTM E 313, respectively.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Chemical composition
3.1. Kemijski sastav

Table 2 shows the chemical properties and some solubility values of *Isatis* stalks and its comparison with several fibrous raw materials. Lignin contents of the studied *Isatis* stalks are comparable to hardwood and annual plants (20-24 %), and lower than softwoods (25-32 %). The holocellulose content of *Isatis* stalks were found as 67.1 and 70.1 %; most annual and coniferous plants were found between 61-82 %. α-cellulose content of *I. tinctoria* (48.5 %) and *I. buschiana* (32.9 %) were found to be comparable to other non-woods (Table 2). *I. tinctoria* and *I. buschiana* had higher ethanol-toluen-acetone, alkali and water solubility. The higher solubility resulted in lower pulp yield and higher BOD load in the effluent (Jahan *et al*., 2006).

3.2 Morphological characteristics
3.2. Morfološka svojstva

Morphological characteristics of *I. tinctoria* and *I. buschiana* stalk fibers and the comparison of several raw material fibers are given in Table 3. The image of the fibers is shown in Figure 1. The mean fiber length

Table 2 Chemical composition of *I. tinctoria* and *I. buschiana* stalks and other raw materials
Tablica 2. Kemijski sastav stabljike biljaka *I. tinctoria* i *I. buschiana* te drugih sirovina

Raw material *Sirovina*	**Holocellulose, %** *Holoceluloza, %*	**α-Cellulose, %** *α-celuloza, %*	**Lignin, %** *Lignin, %*	**Ash content, %** *Sadržaj pepela, %*	**Extractives, %** *Ekstraktivne tvari, %*	**1 % NaOH**	**Hot water, %** *Vruća voda, %*	**Cold water, %** *Hladna voda, %*	**References** *Literatura*
I. tinctoria	67.1	48.5	23.9	4.9	4.4	43.8	17.2	13.6	This study
I. buschiana	70.1	32.9	19.9	11.1	4.1	37.1	20.6	29.3	This study
A. membranaceus	76.7	49.8	23.6	5.5	-	29.4	8.5	7.2	Tutus *et al*., 2014
Poppy stalks / *stabljike maka*	79,8	51.7	19.2	4.7	-	30.4	10.4	5.1	Tutus *et al*., 2011
Cotton stalks / *stabljike pamuka*	75.6	39.8	18.2	2.5	6.1	30.9	14.3	11.7	Tutus *et al*., 2010a
Wheat stalks / *stabljike pšenice*	77.1	39.6	18.3	7.1	5.5	40.9	12.3	7.7	Tutus and Eroglu, 2003
Corn stalks / *stabljike kukuruza*	64.8	35.6	17.4	7.5	9.5	47.1	14.8	-	Eroglu *et al*.,1992
Tea wastes / *stpad od čaja*	60.8	26.5	36.9	4.5	15.2	54.1	31.4	10.9	Tutus *et al*., 2015
Bamboo / *bambus*	70.5	43.3	24.5	1.4	3.9	25.1	6.5	-	Deniz and Ates, 2002
Softwood / *meko drvo*	63-74	-	25-32	0.2-0.5	1-5.8	8-10	1-5	0.5-4	Kirci, 2006
Hardwood / *tvrdo drvo*	72-82	-	18-26	0.2-0.7	1-6.2	12-25	1-8	0.2-4	Kirci, 2006

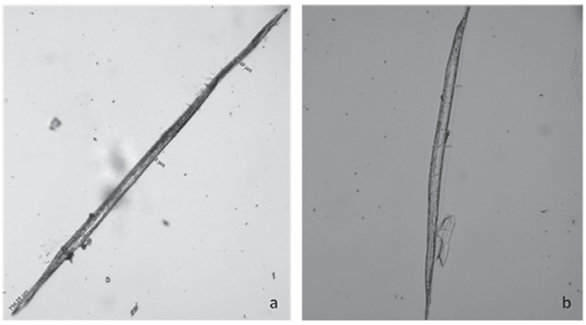

Figure 1 Fibers of macerated samples from *I. tinctoria* (a) and *I. buschiana* (b) stalks
Slika 1. Vlakanca macerata stabljike (a) *I. tinctoria* i (b) *I. buschiana*

of *I. tinctoria* and *I. buschiana* stalks was less than that of both softwood (2.7-4.6 mm) and hardwood (0.7-1.6 mm) fibers. The fiber width of *Isatis* stalks was less than that of hardwood fibers (20.0-40.0 μm), however comparable to wheat and cotton stalks, golpata fronds and *C. cardunculus* (Table 3). The lumen width of *Isatis* stalks was found to be higher than that of wheat straw, and less than that of *C. cardunculus*. The fiber parameters calculated with the fiber characteristics are given in Table 4. Felting power is widely used to determine the suitability of raw material for paper production (Tutus *et al*., 2015). The felting power of *I. tinctoria* and *I. buschiana* were 39.7 and 38.1, respectively, and these values were close to the hardwoods. Although the *Isatis* stalks would be classified as short fibers, overall morphological properties of *I. tinctoria* and *I. buschiana* stalk fibers were found satisfactory for papermaking trials.

Table 5 shows the relationships between paper physical properties and fiber morphological properties. Increases of fiber length and decreases of cell wall thickness have a significant effect on paper physical properties. Burst, tear and double fold strength increase with the increase of fiber length. With the increase of cell wall thickness, burst and double fold strength decrease, while tear strength increases (Dinwoodie, 1965).

3.3 Pulp yield
3.3. Prinos celuloze

Due to similar chemical composition and morphological characteristics of *I. tinctoria* and *I. buschiana*, the pulp and paper studies were performed by mixing the stalks of both *Isatis* species. In this study, the first pulping trials of *Isatis* stalks were performed using soda-AQ; however, pulp yield was found to be low. The values of delignification rate and screened yield were low; however, the screen reject value was high for the pulp obtained using soda-AQ (data not shown). Therefore, *Isatis* stalks were cooked by kraft-AQ at 23 % active alkali and 25 % sulfidity. As shown in Table 6, the increase of the AQ charge to 0.5 % also increased the total pulp yield to 34.93 %. Anthraquinone (AQ) is used as a digester additive in the production of pulp by alkaline processes, as well as by the Kraft, the alkaline sulfite or the Soda-AQ processes. The anthraquinone is a redox catalyst. The reaction mechanism may involve single electron transfer. AQ oxidizes the reducing end of polysaccharides in the pulp, i.e., cellulose and hemicellulose, and thereby protects it from alkaline degradation (peeling) (Samp, 2008). The conditions were selected just to evaluate the pulping potentials of *Isatis* stalks as raw material. It is, therefore, necessary to optimize the con-

Table 3 Fiber characteristics of *I. tinctoria* and *I. buschiana* stalks and other raw materials
Tablica 3. Svojstva vlakanaca stabljike *I. tinctoria* i *I. buschiana* te nekih drugih sirovina

	Wheat straw *Slama pšenice*	**Cotton stalks** *Stabljike pamuka*	**Golpata fronds** *Listovi golpate*	***Cynara cardunculus***	***I.tinctoria***	***I. buschiana***
Fiber length, mm *Duljina vlakanaca,* mm	0.7	2.1	1.7	1.3	0.6	0.6
Fiber width, μm *Širina vlakanaca,* μm	13.2	9.7	10.0	18.8	15.7	15.9
Lumen width, μm *Širina pora,* μm	4.0	-	-	9.1	8.8	7.5
Wall thickness, μm *Debljina stijenki,* μm	4.6	-	-	4.8	8.6	8.7
Reference *Literatura*	Deniz *et al*., 2004	Reddy and Yang, 2009	Jahan *et al*., 2006	Gominho *et al*., 2001	This study	This study

Table 4 Comparison of fiber parameters of *I. tinctoria* and *I. buschiana* stalks with hardwoods and softwoods (Alkan et al., 2003; Istek et al., 2009; Tutus et al., 2014)
Tablica 4. Usporedba parametara vlakanaca stabljike *I. tinctoria* i *I. buschiana* s vlakancima tvrdoga i mekog drva (Alkan i sur., 2003.; Istek *et al*., 2009.; Tutus *et al*., 2014.)

	Felting rate *Brzina filcanja*	**Elasticity coefficient** *Koeficijent elastičnosti*	**Rigidity coefficient** *Koeficijent krutosti*	**Runkel index** *Runkelov indeks*	***F* factor** *F-faktor*
I. tinctoria	39.7	47.2	26.4	1.1	150.1
I. buschiana	38.1	47.5	26.8	1.2	142.2
Softwoods *Meko drvo*	60-80	55-75	13-20	0.3-0.8	400-580
Hardwoods *Tvrdo drvo*	40-55	35-55	15-35	0.5-1.8	150-300

Table 5 The relationship between paper physical properties and fiber morphological properties (Bostanci, 1987; Bektas *et al*., 1999; Istek *et al*., 2009)
Tablica 5. Odnos fizikalnih svojstava papira i morfoloških svojstava vlakanaca (Bostanci, 1987.; Bektas *et al*., 1999.; Istek *et al*., 2009.)

Relationships *Odnosi*	**Burst strength** *Čvrstoća pucanja*	**Tear strength** *Čvrstoća cijepanja*	**Double fold strength** *Čvrstoća dvostruko savijenog papira*	**Paper density(*)** *Gustoća papira (*)*
Fiber length increases *Duljina vlakanaca se povećava*	+	++	+	-
Cell wall thickness increases *Debljina stijenke se povećava*	-	+	--	--
Cell wall thickness decreases *Debljina stijenke se smanjuje*	+	-	++	++
Fiber length / fiber width increases *Duljina /širina vlakanaca se povećava*			+	
Fiber curl increases *Uvijenost vlakanaca se povećava*	--	+	+	-

(*): Porosity, air permeability, water holding capacity and bulkiness are inversely proportional to density./ *Poroznost, propusnost zraka, sposobnost zadržavanja vode i voluminoznost obrnuto su proporcionalni gustoći.*
(+) Positive effect / *pozitivan utjecaj.* (++) Certainly positive effects. / *Sigurno pozitivan utjecaj.*
(-) Negative effect. / *Negativan utjecaj.* (--) Certainly negative effects. / *Sigurno negativan utjecaj.*

ditions in further investigations. As a comparison, the pulp yield of golpata fronds (Jahan *et al*., 2006), *C. cardunculus* (Gominho *et al*., 2001), cotton stalks (Akgul and Tozluoglu, 2009) were 36.2 %, 47 %, 37.98 %, kiwi pulp screened yield 44.39 % (Gencer, 2015) and Sorghum pulp screened yield 44.87 % (Gencer and Sahin, 2015), respectively.

3.4 Physical and optical properties
3.4. Fizikalna i optička svojstva papira

Handsheets were produced from *Isatis* stalk pulp to determine their physical and optical properties. The measured physical and optical properties are given in Table 7. According to the results, higher values of the breaking length, tear index and burst index were recorded for the beaten pulp than for the unbeaten pulp, while brightness and whiteness were higher in unbeaten pulp. In this study, AQ charge further increased the breaking length and burst index, while it decreased the tear index. In beaten pulp, 0.1 % AQ charge improved the brightness and whiteness by 6.3 % and 10.02 %, respectively, and decreased the yellowness by 2.3 %. The physical properties of a pulp sheet are closely related to morphological properties of pulp fiber (Young, 1981). The breaking length, tear index and burst index of cotton stalks (Jimenez *et al*., 2007) were 4.4 km, 0.26 mN·m²/g and 2.13 kPa·m² /g, respectively. The breaking length, tear index and burst index of *Paulownia elongata* paper sheets were 1.66 km, 2.1 mN·m²/g and 1.15 kPa·m²/g (Ates *et al*., 2008), respectively.

Table 6 Cooking conditions and pulp yield of *Isatis* pulp
Tablica 6. Uvjeti kuhanja i prinos celuloze od stabljika *I. tinctoria* i *I. buschiana*

Cooking No *Kuhanje broj*	**AQ charge, %** *AQ udio, %*	**Screened yield, %** *Prinos prosijavanja, %*	**Screen reject, %** *Škart prosijavanja, %*	**Total yield, %** *Ukupni prinos, %*
1	0	23.9	0.67	24.57
2	0.1	25.37	0.72	26.09
3	0.3	27.77	0.77	28.54
4	0.5	31.09	3.84	34.93

Table 7 Physical and optical properties of hand sheets made from beaten and unbeaten pulp
Tablica 7. Fizikalna i optička svojstva ručno izrađenih listova papira od mljevene i nemljevene celuloze

Cooking no *Kuhanje broj*	**Breaking length** *Duljina lomljenja* km	**Tear index** *Indeks cijepanja* mN·m²/g	**Burst index** *Indeks pucanja* kPa·m²/g	**ISO Brightness** *ISO sjajnost,* %	**ISO Whiteness** *ISO bjelina* %	**ISO Opacity** *ISO neprozirnost* %	**ISO Yellowness** *ISO žutilo* %
Unbeaten pulp / *Nemljevena celuloza*							
1	1.118	1.12	0.62	26.03	33.92	98.81	33.49
2	1.849	0.88	0.96	26.67	34.22	99.33	32.6
3	1.962	0.82	1.01	26.73	34.45	99.88	33.18
4	2.059	0.85	0.92	26.63	34.28	99.88	34.03
Beaten pulp / *Mljevena celuloza*							
1	3.091	1.14	1.98	23.64	30.35	99.77	33.2
2	3.330	1.03	2.17	25.22	33.73	99.65	32.44
3	3.984	1.06	2.56	24.46	31.54	99.78	33.34
4	3.808	0.90	2.62	23.58	30.71	98.65	34.71

These values were comparable with the properties of *Isatis* paper sheet strength.

4 CONCLUSIONS
4. ZAKLJUČAK

Using non-wood raw materials has become a critical issue in regions with inadequate forest or wood resources. Therefore, evaluating the potential agricultural fiber sources as raw material for pulp and paper industry has received considerable attention. *I. tinctoria* is a well known plant as an indigo dye plant. *I. tinctoria* is an annual plant that grows in 7-8 months after the sowing. To the best of our knowledge, *I. tinctoria* and *I. buschiana* were evaluated as raw material for making pulp and paper for the first time in this study. As a conclusion, holocellulose, α-cellulose and lignin in *Isatis* stalks were comparable to hardwood and several non-wood plants. It was found that physical strength was higher in beaten pulp, while optical properties were higher in unbeaten pulp. Although higher solubilities and lower felting coefficient will cause lower pulp yield and strength properties, *Isatis* stalks can be used for paper production when mixed with long fibrous materials. Besides, *Isatis* stalks can be used instead of wheat stalks in pulp and paper production as they have similar chemical and morphological properties. When considering the shortage of raw material in pulp and paper industry, the use of *Isatis* stalks with softwood pulp would contribute significantly to an economic supply of raw material for pulp and paper production.

Acknowledgement – Zahvala

We gratefully thank the Scientific and Technological Research Council of Turkey TUBITAK (Grant: 2209-A/2012) for funding this study.

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Analysis of Furniture Selling Places in Croatia, Slovenia and Slovakia

Analiza prodajnih mjesta namještaja u Hrvatskoj, Sloveniji i Slovačkoj

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 23. 12. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*079*
doi:10.5552/drind.2016.1545

ABSTRACT • *Nowadays, furniture retail sale is a very competitive area and besides large and well-known global brands, a high share of the overall market consists of independent retail shops. The owners and sellers of furniture are daily faced with the increasing requirements of the ever more demanding market, to which they must constantly and repeatedly adjust. The choice of furniture stores regarding to some of selling place attributes could affect customer's final decision about furniture purchase; however, there is little information about the relationship between furniture selling places attributes. In this study, the basic information is given regarding the selected furniture selling place attributes (size of selling area, number of salespersons, storage area, and number of suppliers) in Slovenia, Slovakia, and Croatia.*

Keywords: *furniture, selling place, analysis, Croatia, Slovenia, Slovakia*

SAŽETAK • *Danas uz velike trgovačke lance poznatih svjetskih brandova namještaja i mala nezavisna prodajna mjesta namještaja imaju važnu ulogu na cjelokupnom tržištu namještaja. Vlasnici i prodavači namještaja svakodnevno se pokušavaju prilagoditi sve zahtjevnijim željama i potrebama svojih kupaca. Nadalje, pojedina obilježja prodajnih mjesta namještaja mogu utjecati na kupčevu konačnu odluku o kupnji namještaja, što je glavni predmet istraživanja brojnih studija i radova. Nasuprot tome, vrlo je malo radova u kojima je istraživan međusobni utjecaj obilježja prodajnog mjesta namještaja, pa je cilj ovog rada bio istražiti neke od njih (veličinu prodajnog prostora, broj prodavača, veličinu skladišnog prostora i broj dobavljača), utvrditi njihov međusobni utjecaj te ustanoviti postoji li razlika među odabranim obilježjima prodajnih mjesta namještaja u Hrvatskoj, Sloveniji i Slovačkoj.*

Ključne riječi: *namještaj, prodajna mjesta, analiza, Hrvatska, Slovenija, Slovačka*

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1 INTRODUCTION
1. UVOD

Besides large and well-known global brands, a significant share of the overall market consists of independent retail shops (Yitong, 2007). Consumers do not only differ by age, gender and occupation, but also by their interests and preferences. Diversity does not exist only within consumers, but also within sellers. Sellers foreground task is to understand, monitor and meet customer needs and desires - regardless of who they are, what they want, or where they live (Schiffman and Kanuk, 2004; Kotler *et al.*, 2006; Kim and Mauborgne, 2007). In the past decade, the process of transition from a centrally planned to a market economy has brought structural economic changes to Central and Eastern European countries, to which countries like Slovenia, Slovakia and Croatia belong to, and particularly so to wood and furniture sector of these countries (Kaputa *el al.,* 2016; Pirc *et al*., 2010; Kitek Kuzman *et al.,* 2012). On the other hand, today these countries are also a part of European Union, worldly the largest region for furniture consumption and manufacturing in which retailing has been recognized and adopted to new conditions within a very short period of time. However, considering sustainable growth of furniture manufacturing, it is still necessary to encourage investment, and ensure access to global markets creating competitive conditions (Družić and Basarac Sertić, 2015). Among the countries that joined the EU, originally established in 2004, Slovakia valued furniture consumption at 646 million Euros in 2012, while Slovenia reached the amount of 284 million Euros (Centre for European Policy Studies, 2014). In July, 2013, Croatia became the youngest member of the EU with furniture consumption valued at 432 million Euros (Financial Agency 2014). According to the European Commission (2013), European furniture sale was valued at approximately 50 billion EUR in 2011, decreasing by 2.1 % if compared to 2010. Consumer spending on furniture is forecast to increase at a faster pace than in the past few years; global furniture sales grew by 5.5 % in 2014 (French, 2015). The market is still dominated by Germany, Italy, the UK and France, which accounted for over 69 % of EU27 sales in 2011. There are many elements that make up a store's image by considering the type of customers – sales personnel is one of them. According to Jones *et al.* (2005), among other elements, a customer satisfaction increases in relation to salesperson speed of response; a customer also expects to be served quickly and completely. Waiting for service is very often the first interaction between customer and service process (Davis and Heineke, 1998) and many service companies and stores worry about the waiting time, because the customer waiting time is considered as having a negative influence on consumer service perception (Bielen and Demoulin, 2007). The customer's purchasing power is the result of mixed issues. According to the Centre for European Policy Studies (2014), among other elements, these issues also include warehousing and sale personnel assistance in the process of sale. The availability of information offers the consumers the possibility of choice, while the purchase has become unbelievably easy and fast, which has made the selling place a very important point in the final choice of the product (Oblak, 1992). Today, big furniture stores are becoming more popular than before (Dong and Zhao, 2012) and furniture retail sale has become a very competitive area.

1.1 Research objectives
1.1. Ciljevi istraživanja

In 2012, the share of furniture consumption of these three countries, Slovenia, Slovakia, and Croatia, in the total share of EU furniture consumption was between 0.4 and 0.8 %. No significant difference between the shares of Croatian, Slovenian, and Slovakian furniture consumption in total share of EU furniture consumptions was found ($\chi^2 = 0.18$, $df = 2$, $p = 0.92$).

The choice of furniture stores regarding to some of selling place attributes could affect customer's final decision about furniture purchase. However, there is little information about the relationship between furniture selling place attributes. In an effort to compare and analyse furniture selling places, the following research goals were set:

- to determine the basic information on some furniture selling place attributes in Slovakia, Slovenia, and Croatia;
- to establish correlations between the size of furniture selling area and number of sellers in the selling places, storage area in the selling places and number of suppliers in the selling places in Croatia, Slovenia and Slovakia.
- to determinate the differences in attributes between furniture selling places in Croatia, Slovenia and Slovakia.

2 MATHERIALS AND METHODS
2. MATERIJALI I METODE

A questionnaire was used for surveying respondents (furniture selling places) for this study. This approach was selected because it provides the possibility of collecting data over a wide geographic area and low-cost data conversion (Zahs and Baker, 2007). The questionnaire consisted of the following items: general information on selling place (name and address), number of furniture suppliers, size of selling area (in m^2), size of storage area (in m^2), and number of sellers. The sample frame was a census of 400 furniture selling places in Slovakia, Slovenia, and Croatia. The list of furniture selling places was taken from the data base of the Croatian, Slovakian, and Slovenian Chambers of Commerce. A telephone survey, based on procedures recommended by Dillman (2000), was used in this study. In Croatia, the total number of usable surveys received was 258 with adjusted response rate of 64 %. In Slovenia, the total number of usable surveys received was 85 with adjusted response rate of 21 %, while in Slovakia, the total number of usable surveys received was 92 with adjusted response rate of 23 %.

The adjusted response rate was calculated using the following expression: Adjusting Response Rate = [Usable Surveys /Total sample – (Undeliverable + Unusable)]*100 %. Questionnaire data was entered into a *Microsoft Excel* data base. Statistical analysis and results interpretation were carried out using the statistical software *Statistica 10*. The research was conducted in 2011. Regression analysis was used to determine the correlation between the size of sales area and number of suppliers, size of storage space and number of sellers in Croatia, Slovenia and Slovakia. In order to determine whether there were significant differences in attributes between furniture selling places in Croatia, Slovenia and Slovakia, χ^2-test was used.

3 RESULTS
3. REZULTATI

3.1 Characteristics of furniture selling places in Croatia, Slovenia and Slovakia
3.1. Obilježja prodajnih mjesta namještaja u Hrvatskoj, Sloveniji i Slovačkoj

Comparing the three surveyed countries (Croatia, Slovenia, and Slovakia), as shown in Tab. 1, it can be seen that the largest furniture selling places were located in Slovenia (the average size of furniture selling place amounted to 498.20 m^2). In Croatia, the average size of furniture selling area was 405.92 m^2 while in Slovakia, the average size of furniture selling places was 345.40 m^2. As shown in Figure 1 and Figure 2, regarding the average number of furniture suppliers and the average size of the storage area of furniture showrooms, Slovenian furniture showrooms were noted as selling places having the largest number of furniture suppliers (average 20.07) and the largest size of the storage area (361.9 m^2). In Croatia, the average number of furniture suppliers was 11.1 and the average size of the storage area amounted to 257.2 m^2. In Slovakia, the average number of suppliers was 13.5 and the average size of the storage area was 143.3 m^2. Regarding the number of people employed in furniture selling places, as shown in Table 1, the largest number of people were employed in Slovakian showrooms (3.60 persons on average), followed by Croatia (3.36 on average), and Slovenia (3.28 persons on average) (Fig. 1 and Fig. 2).

3.1.1 Croatia
3.1.1. Hrvatska

In Croatia, according to the results, a simple linear regression model of correlation regarding the size of furniture selling area and the number of furniture suppliers was: $y = 346.03 + 5.391 \cdot x$. The correlation between the selling area and the number of furniture suppliers is shown using a regression coefficient of determination ($R^2 = 0.025$). The above regression coefficient of determination indicated that the model of linear regression explaining these two variables is not representative, meaning that the size of furniture selling place in Croatia explains only 2.5 % of the number of furniture suppliers. The adjusted coefficient of determination was 2.2 %.

Furthermore, observing the size of the selling area and the size of the storage area, a medium inten-

Table 1 Descriptive statistics of some characteristics of furniture selling places
Tablica 1. Deskriptivna statistika obilježja prodajnih mjesta namještaja

Country *Država*	N	Size of selling area, m^2 *Veličina prodajnog prosotra,* m^2		Number of suppliers *Broj dobavljača*		Size of storage area *Veličina skladišnog prostora,* m^2		Number of sellers *Broj prodavača*	
		Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Croatia / *Hrvatska*	258	405.92	463.27	11.11	13.71	257.19	2.55	3.36	2.55
Slovenia / *Slovenija*	85	498.20	453.48	20.07	20.73	361.93	629.16	3.28	1.58
Slovakia / *Slovačka*	92	345.43	525.70	13.51	16.26	143.26	246.80	3.60	3.91

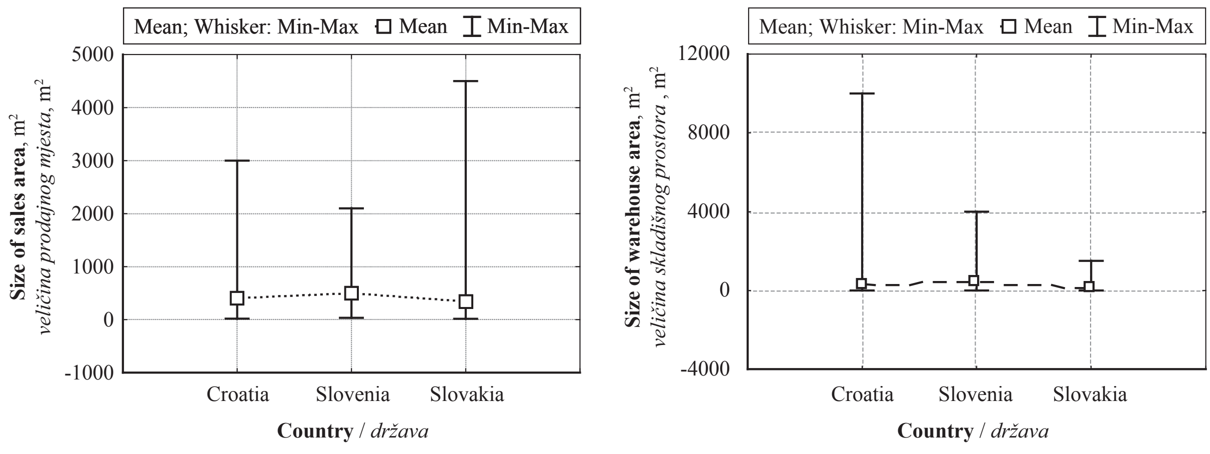

Figure 1 Size of selling area and size of storage area of furniture selling places in analyzed countries
Slika 1. Veličine prodajnih i skladišnih prostora prodajnih mjesta namještaja u analiziranim zemljama

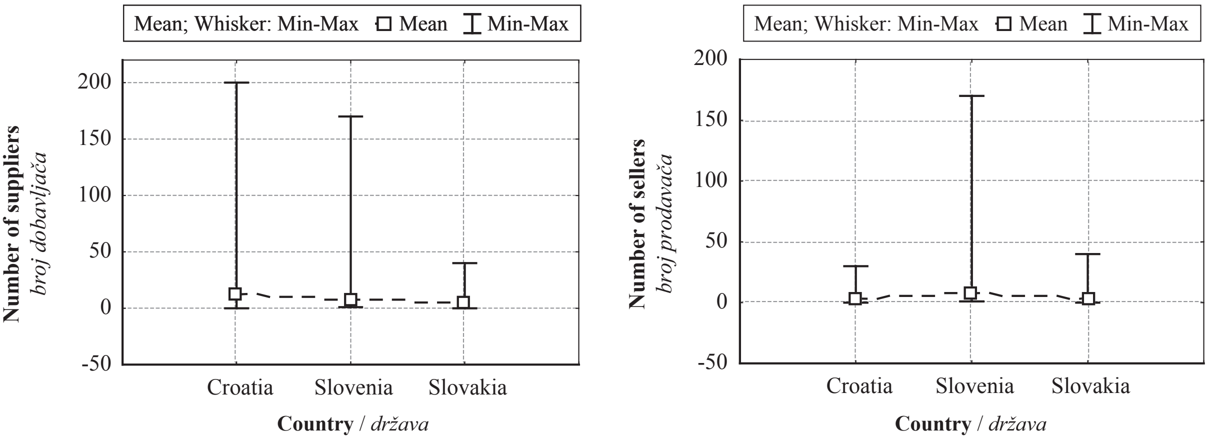

Figure 2 Number of suppliers and number of sellers of furniture selling places in analyzed countries
Slika 2. Broj dobavljača i broj prodavača na prodajnim mjestima namještaja u analiziranim zemljama

sity correlation was established ($R^2 = 0.362$). The coefficient of correlation was positive (i.e. the size of the storage area is enhanced with the size of furniture selling place) and statistically significant (r=0.602; p=0.0001).

Similarly, regarding the size of the furniture selling area and the number of furniture sellers, a medium intensity correlation was established. The coefficient of correlation was positive and statistically significant (r = 0.633; p=0.0001). Coefficient of determination (R^2) was 0.401 (Tab. 2).

3.1.2 Slovenia
3.1.2. Slovenija

In Slovenia, week dependence was established between the size of furniture selling area and the number of sellers, the number of furniture suppliers and the size of the storage area. Regression coefficient of determination (R^2) between the size of the selling area and the number of sellers was 0.032.

The coefficient of determination of regression between the selling area and the number of suppliers and between the selling area and the storage area was the same (number of suppliers: R^2=0.118; size of storage area: R^2 = 0.118).

A simple linear regression model of correlation between the size of furniture selling area and: (a) number of sellers, (b) number of furniture suppliers, and (c) size of the storage area was as follows: (a) $y = 330.333 + 51.142 \cdot x$. (b) $y = 347.248 + 7.522 \cdot x$, (c) $y = 408.717 + 0.247 \cdot x$. The coefficients of correlation regarding the size of the selling area and number of furniture suppliers (r = 0.344; p = 0.0013) and size of the storage area (r = 0.343; p = 0.0013) were statistically significant. On the other hand, the coefficients of correlation regarding the size of the selling area and number of sellers were not statistically significant (r = 0.178; p = 0.0103) (Tab 2.)

3.1.3 Slovakia
3.1.3. Slovačka

In Slovakia, using a simple regression analysis, a medium intensity correlation was established between the size of furniture selling area and storage area (R^2 = 0.330; simple regression model: $y = 170.111 + 1.224 \cdot x$) and between the size of furniture selling area and the number of sellers (R^2 = 0.399; simple regression model: $y = 39.376 + 85.068 \cdot x$). Furthermore, a weak intensity correlation was established between the size of the selling area and the number of furniture suppliers. The correlation is expressed using the regression coefficient of determination (R^2) that amounted to 0.012 (i.e. the size of furniture sales area explains only 1.2 % of the number of furniture suppliers).

Within all three analyzed countries (Croatia, Slovenia, and Slovakia), the results of a simple regression analysis between the variable "furniture selling area" and variables: size of storage area, number of furniture suppliers, number of sellers showed a weak correlation or a medium intensity correlation. In all observed comparisons, coefficients of correlations were positive at $\alpha = 0.05$ significance level and statistically significant (ex. Slovakia: size of selling area and number of suppliers) (Tab. 2).

Chi-square test was used to determinate differences within the size of furniture selling area, storage area, number of furniture suppliers, and number of sellers in Croatia, Slovenia and Slovakia. The null hypothesis was tested at $\alpha = 0.05$ significance level. The size of the storage area was not found to be significant at $\alpha = 0.05$ significance level between Croatia, Slovenia, and Slovakia ($\chi^2 = 21.51$; $df = 16$; $p = 0.160$). On the other hand, the size of the selling area ($\chi^2 = 18.28$, $df = 8$, $p = 0.019$), number of sellers ($\chi^2 = 16.44$, $df = 8$, $p = 0.036$), and the number of suppliers ($\chi^2 = 34.37$, $df = 10$, $p \leq 0.001$) were found to be significant at $\alpha = 0.05$ significance level (Fig. 3).

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČAK

In the current economic context, future consumers' choice of whether to save money or to spend it depends on their overall perception and expectations, which can be asserted by the Eurostat consumer confidence indicator that showed a negative balance with respect to spending money on major purchases, which includes furniture. In this study, the basic information

Table 2 Correlations of size of sales area and size of warehouse area, number of suppliers and number of sellers in analyzed countries
Tablica 2. Korelacije veličine prodajnog i skladišnog prostora, broja dobaljača i broja prodavača u analiziranim zemljama

		r	***R²***	***Adj R²***	***p***
Size of selling area in Croatia, m² *Veličina prodajnog prostora u Hrvatskoj,* m²	Number of suppliers / *Broj dobavljača*	0.160	0.025	0.022	**0.0102**
	Size of storage area, m² / *Veličina skladišnog prostora,* m²	0.602	0.362	0.360	**0.0001**
	Number of sellers / *Broj prodavača*	0.633	0.401	0.399	**0.0001**
Size of selling area in Slovenia, m² *Veličina prodajnog prostora u Sloveniji,* m²	Number of suppliers / *Broj dobavljača*	0.344	0.118	0.108	**0.0013**
	Size of storage area, m² / *Veličina skladišnog prostora,* m²	0.343	0.118	0.107	**0.0013**
	Number of sellers / *Broj prodavača*	0.178	0.032	0.020	**0.0103**
Size of selling area in Slovakia, m² *Veličina prodajnog prostora u Slovačkoj,* m²	Number of suppliers / *Broj dobavljača*	0.109	0.012	0.001	0.3013
	Size of storage area, m² / *Veličina skladišnog prostora,* m²	0.574	0.330	0.323	**0.0001**
	Number of sellers / *Broj prodavača*	0.632	0.399	0.393	**0.0001**

Legend/ *Legenda*: *r* – correlation coefficient / *koeficijent korelacije*; R^2– coefficient regression of determination / *koeficijent determinacije*; *Adj* R^2 – determination coefficient adjusted / *korigirani koeficijent determinacije*; *p* – level of significance / *razina značajnosti.*

was given on some furniture selling place attributes (size of selling area, number of sellers, storage area, and number of suppliers) in relatively new EU countries (Slovenia, Slovakia, and Croatia), and the test was determined for the correlations between the size of the selling area and other three sale place attributes (number of sale persons, storage area, and number of suppliers) in Slovenia, Slovakia, and Croatia. Additionally, the differences in three furniture selling place attributes between Croatian, Slovenian, and Slovakian furniture

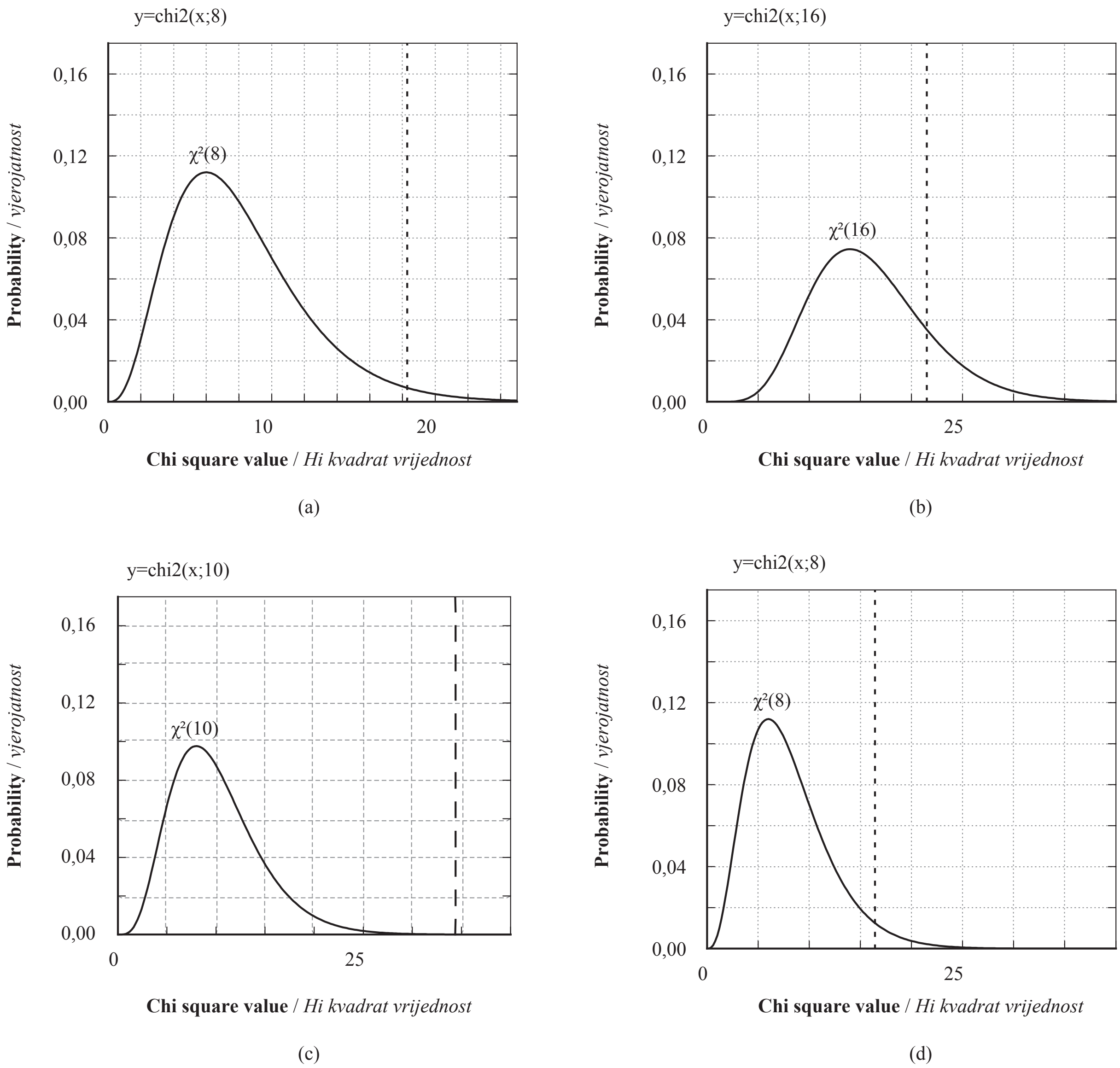

Figure 3 χ^2 distribution: (a) size of selling area; (b) size of storage area; (c) number of suppliers; (d) number of sellers
Slika 3. χ^2 distribucija: (a) veličina prodajnog prostora; (b) veličina skladišnog prostora; (c) broj dobavljača; (d) broj prodavača

selling places were determined. In Croatia, a higher level of correlation was established between selling place attributes. One of possible reasons of higher correlation between the selling area and other selling place attributes could be that the Croatian market is still traditionally oriented, the process of transition from the traditional sales functions is still dominating, customers are more oriented to seller face–to–face contact and less to contemporary technology, like internet selling platforms, than in Slovakia and Slovenia. According to the Centre for European Policy Studies (2014), some EU countries, including Slovakia, Slovenia, and Croatia, index of furniture consumption per capita are below EU average, so the results of this study indicate a glaring need to probe further into furniture selling place attributes, because the attributes of selling place play an important role in customer decision process when buying wood furniture.

This study has limitations, because it is looking at a specific point in time without longitudinal data. Nevertheless, additional cross-national studies in the European Union could validate the findings presented in this work. Furthermore, the findings of this research can only be generalized for surveying furniture selling places in Croatia, Slovenia, and Slovakia, which presents an important limitation. We suggest that future research should include additional cross-national studies in the EU for well-established and new members, as well as longitudinal studies to see how these furniture selling place attributes change over time.

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Physical Properties of Boards Manufactured with Hygrothermally Treated Tepa (*Laureliopsis Philippiana* Looser) Particles

Fizikalna svojstva ploča proizvedenih od hidrotermički obrađenog iverja drva tepe (*Laureliopsis philippiana* Looser)

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 29. 12. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*861.232;630*812.22; 630*812.23; 630*847.26*
doi:10.5552/drind.2016.1547

ABSTRACT • *Three layer particleboards were manufactured using hygrothermally treated and untreated Laureliopsis philippiana (tepa) particles with urea-formaldehyde (UF) resin. Hygrothermal treatment consisted of autoclaving particles at 150 °C for 90 min (430 kPa) in a steam saturated atmosphere. Density, moisture content, swelling and water absorption were determined. Equilibrium moisture, dimensional variation in length and thickness, as well as length and thickness coefficients per every 1 % change in board equilibrium moisture were also determined after acclimatization at different relative air humidity conditions (20 °C; 40, 50, 60, 70, 80 and 90 % RAH). There were significant differences between particleboards made from control and treated particles. Boards manufactured with treated particles showed a reduction in moisture content, swelling and water absorption. Dimensional stability analysis in response to relative air humidity (RAH) showed that the hygrothermal treatment causes a reduction in equilibrium moisture, a decrease in length and thickness dimensional variation, likewise a reduction in length and thickness swelling coefficients.*

Key words: *Particleboard, hygrothermal treatment, Laureliopsis philippiana, physical properties, dimensional stability*

SAŽETAK • *Za potrebe ovog ispitivanja troslojne su ploče iverice proizvedene od neobrađenoga i hidrotermički obrađenog iverja drva tepe (Laureliopsis philippiana) primjenom urea-formaldehidnog (UF) ljepila. Hidrotermička obrada sastojala se od zagrijavanja iverja pri 150 °C tijekom 90 minuta u atmosferi zasićenoj*

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vodenom parom (pri tlaku 430 kPa). Pritom su određeni gustoća, sadržaj vode, bubrenje i upijanje vode ploča iverica. Ravnotežni sadržaj vode, dimenzijske varijacije u smjeru duljine i debljine, kao i koeficijenti promjene duljine i debljine ploče iverice zbog promjene ravnotežnog sadržaja vode za 1 % određeni su nakon aklimatizacije pri različitim relativnim vlažnostima zraka (20 °C; 40, 50, 60, 70, 80 i 90 % RAH). Utvrđene su velike razlike među pločama ivericama izrađenima od neobrađenoga i hidrotermički obrađenog iverja. Naime, ploče proizvedene od hidrotermički obrađenog iverja imale su manji sadržaj vode, manje bubrenje i upijale su manje vode. Analiza dimenzijske stabilnosti ploča iverica u ovisnosti o promjeni relativne vlažnosti zraka (RAH) pokazala je da je hidrotermičkom obradom iverja prouzročeno smanjenje ravnotežnog sadržaja vode, smanjene su dimenzijske varijacije ploča u smjeru duljine i debljine, odnosno smanjeni su koeficijenti bubrenja u smjeru duljine i debljine ploče.

Ključne riječi: *ploča iverica, hidrotermička obrada, Laureliopsis philippiana, fizikalna svojstva, dimenzijska stabilnost*

1 INTRODUCTION
1. UVOD

High temperature heat treatment (thermo-modification) is known to improve dimensional stability of wood as well as its resistance to rot (Niemz *et al.,* 2010). Thermal modification drives structural and chemical changes in wood constituents, which may significantly alter their properties when compared to non-treated wood (Arnold, 2010).

1.1 Acidity
1.1. Kiselost

Density and chemical composition are among wood properties and characteristics that most affect particleboard quality. Chemical composition of wood has an effect in particular stages of the process (drying, gluing and setting). Chemical composition also affects the properties of the boards, since the presence of extractable compounds determines de pH value, and they can delay, hasten or inhibit the setting process (Poblete, 2001). Chemical reactions that occur during setting of the adhesives follow an optimum course with a specific pH range for each type of adhesive, and any variation will have an effect on the bonding properties among particles. *L. philippiana* wood exhibits high pH values (5.7 to 7.4), which is not favorable for the production of boards using acidic setting adhesives (UF) (Poblete, 2001). Wood pH decreases after high temperature thermal treatment (Niemz *et al.,* 2010). Thermal treatments cause decomposition of hemicelluloses and acidify the wood (Poblete, 1983), which could favor setting of the UF and improve physical properties of the board.

1.2 Effect of thermal treatment on physical properties of boards
1.2. Utjecaj toplinske obrade iverja na fizikalna svojstva ploča

Tomek (1966) states that thermal treatment of the particles decreases adsorption properties, resulting in a decrease in thickness swelling of 45 % to 50 % in particleboards manufactured with treated particles and UF. Boonstra *et al*. (2006) indicate that hygrothermolysis has a positive effect on thickness swelling, and hence thermal treatment of the wood before the manufacturing process could improve the dimensional stability of the particleboards.

1.3 Effect of thermal treatment on board dimensional changes
1.3. Utjecaj toplinske obrade iverja na dimenzijsku stabilnost ploča

Thermal treatment reduces wood contraction and swelling, improving its dimensional stability (Cao *et al.,* 2012). The difference between equilibrium moisture content of treated and non-treated wood remains when the air humidity changes (Edvarsden and Sandland, 1999). Most of the defects of the particleboards during their performance are related to thickness swelling, which is considerably greater than in other wood products of comparable density. This instability is caused by the incorporation of compressive tensions that are released when the moisture content increases (Suchsland and Enlow, 1968). A treatment with steam before manufacturing could cause a partial hydrolysis in the hemicelluloses, which increases compressibility of the wood, and significantly reduces the increment in internal tension during board pressing, making this process an effective method to produce dimensionally stable boards (Hsu *et al*., 1988). In this type of treatment, a pressure increment of 200 to 1000 kPa causes important increases in the dimensional stability (Giebeler, 1983).

1.4 Objectives
1.4. Ciljevi

The main objective of this study was to determine the effect of a hygrothermal treatment in a steam saturated atmosphere on *L. philippiana* particles and its impact on the physical properties of three layer particleboards. Specific objectives were to determine the changes in moisture content, swelling and water absorption after 2 and 24 hours, as well as to determine the equilibrium moisture and the dimensional stability after acclimatizing at different RAHs (20 °C; 40, 50, 60, 70, 80 and 90 %).

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Particles production and hygrothermal treatment
2.1. Proizvodnja iverja i njegova hidrotermička obrada

L. philippiana wood was harvested in the XIV Region de Los Ríos at the Andean Mountain in Chile. The wood was made into shavings and then, particles were obtained by using a Pallmann PZ2 mill. A quantity of the particles was treated in autoclave at 150 °C for 90 min at the pressure of 430 kPa, in a steam saturated atmosphere. At the end of the treatment, the particles were allowed to acclimatize to ambient conditions.

2.2 Drying of particles
2.2. Sušenje iverja

Hygrothermally treated and non-treated particles were subjected to a drying process, in a Heraeus particle dryer with air circulation at 70 °C until a moisture content of 4 % was reached.

2.3 Board manufacturing
2.3. Proizvodnja ploča

Hygrothermally treated and untreated *L. philippiana* particles were employed. As adhesive, UF (50 % solid) produced by Georgia Pacific Corp. with a molar ratio of 1:1.22 was applied. Particleboards with nominal densities of 600, 625, 650, 675 and 700 kg·m^{-3}, with dimensions of 53 x 53 cm and 15 mm thickness were produced. The adhesive was applied at 8 % loading (dry basis) by spraying in a Drais FSP-80 blender. Pressing was conducted in a Bürkle LA-160 press at a temperature of 180 °C for 180 s. The initial maximum pressure used was 3 N·mm^{-2} for 30 s, followed by a lower pressure of 1.5 N·mm^{-2} for 150 s. Two boards were produced for each nominal density, a total of 10 boards with non-treated particles and 10 boards with treated particles. The particle ratio was 70 % in the inner layer and 30 % in the outer layer.

2.4 Physical properties of the boards
2.4. Fizikalna svojstva ploča

Density (EN 323, 1993), moisture content (EN 322, 1993), swelling (EN 317, 1993) and water absorption (ASTM D 1037, 2012 in test specimens EN 317, 1993) were determined. The number of test specimens by treatment for physical properties (moisture content, swelling and water absorption) was 100. Density was determined for every test specimen.

2.5 Dimensional stability of the boards
2.5. Dimenzijska stabilnost ploča

4 test specimens 200 mm long by 20 mm wide of each board were prepared. Test specimens were acclimatized in a Heraeus Vötsch HPZ 50/ S – DV chamber at a constant temperature of 20 °C and a RAH of 40, 50, 60, 70, 80 and 90 %. Equilibrium moisture (EN 322, 1993), longitudinal and thickness dimensional variations (EN 318, 2002), and dimensional variations per every 1 % equilibrium moisture variation (Niemz and Poblete, 1996) were determined.

2.6 Statistical analysis
2.6. Statistička analiza

A simple linear regression analysis was conducted, correlating physical properties to density of the respective test specimen. Additionally, an analysis of variance was conducted with a 99 % confidence interval (p <0.01) (statistical program R), to determine differences among averages of properties. For the study of dimensional stability, average values (from 40 % to 90 % of RAH) of equilibrium moisture of the board were correlated with the averages values of longitudinal and thickness swelling.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Board physical properties
3.1. Fizikalna svojstva ploča

Table 1 shows the averages, standard deviation, coefficient of variation and p value, according to the analysis of variance for boards manufactured with hygrothermally treated and untreated particles.

There are significant differences (p <0.01) among physical properties of boards manufactured with hygrothermally treated and untreated particles. Particleboards

Table 1 Analysis of variance of means of physical properties of *L. philippiana* boards manufactured with hygrothermally treated and untreated particles
Tablica 1. Analiza varijance srednjih vrijednosti fizikalnih svojstava ploča proizvedenih od neobrađenoga i hidrotermički obrađenog iverja

Physical property *Fizikalna svojstva*	**Analysis of variance** / *Analiza varijance*						
	Untreated *Neobrađeno iverje*			**Hygrothermally treated** *Hidrotermički obrađeno iverje*			***p*-value** *p-vrijednost*
	$\bar{x}$ %	*sd* %	*cv* %	$\bar{x}$ %	*sd* %	*cv* %	
Moisture content / *sadržaj vode* (20 °C / 65 % RAH)	9.9	0.67	6.76	8.0	0.25	3.12	0.000*
Swelling after 2 hours *bubrenje nakon 2 sata*	34.8	2.90	8.34	8.9	0.89	10.00	0.000*
Swelling after 24 hours *bubrenje nakon 24 sata*	47.1	3.97	8.43	14.2	1.32	9.23	0.000*
Water absorption after 2 hours *upijanje vode nakon 2 sata*	97.4	10.78	11.07	60.9	9.95	16.36	0.000*
Water absorption after 24 hours *upijanje vode nakon 24 sata*	115.7	9.87	8.53	75.5	9.47	12.54	0.000*

$\bar{x}$ – Average value / *srednja vrijednost*, *sd* – standard deviation / *standardna devijacija*, *cv* – coefficient of variation / *koeficijent varijacije*,
* – significance at $p < 0.01$ / *signifikantno pri p < 0,01*.

manufactured with hygrothermally treated *L. philippiana* particles showed better physical properties.

3.1.1 Board moisture content (20 °C, 65 % RAH)
3.1.1. Sadržaj vode u pločama (pri 20 °C, 65 % RAH)

Boards manufactured with treated particles had lower moisture content than boards manufactured with untreated particles. The reduction in moisture was from 9.9 % in boards with untreated particles to 8.0 % in boards with treated particles. Similar results are reported by other authors (Mendes *et al*. 2013). The moisture reduction in boards manufactured with treated particles is related to chemical changes within the wood. Studying the effect of hygrothermal treatment on *L. philippiana* particles, Crespo *et al.* (2013) determined a decrease in wettability, a significant increase in extractable hydrophobic compounds and a reduction in pH value, changes caused by chemical alterations within the wood, particularly of hemicelluloses. Other authors state that an increase in the relative crystalline cellulose may also have an influence, with hydroxyl groups poorly accessible to water molecules, and the crosslinking of the lignin chain, hindering access to free hydroxyl groups (Burmester, 1975; Tjeerdsma *et al.,* 1998).

3.1.2 Swelling and water absorption after 2 and 24 hours
3.1.2. Bubrenje i upijanje vode nakon 2 h i nakon 24 h

Swelling and water absorption after 2 and 24 hours of immersion were lower in boards manufactured with treated particles (Table 1). A decrease in swelling was recorded from 34.8 % to 8.9 % and from 47.1 % to 14.2 % after 2 and 24 hours, respectively. A decrease of water absorption from 97.4 % to 60.9 % after 2 hours and from 115.7 % to 75.5 % after 24 hours was determined. This trend is in agreement with results reported by Tomek (1966), Boonstra *et al.* (2006) and Poblete and Peredo (1990). The increase in the amount of extractable hydrophobic compounds and the reduction in wettability in treated *L. philippiana* particles determined by Crespo *et al.* (2013), could explain the changes in the physical properties. Crespo *et al.* (2013) also reported a significant reduction in the pH value (6.7 to 4.8) and an increase in acidity, which favors the adhesive setting process (UF), contributing to the improvement in physical properties. The linear regression analysis showed no correlation between density, moisture content and swelling after 2 and 24 hours. Water absorption values and their relationship to density after 2 and 24 hours are presented in Figure 1.

Regardless of the treatment, the board density increase caused a decrease in *L. philippiana* board water absorption (Figure 1). This is due to the fact that boards of less density have more space within their structure, allowing a greater amount of water to penetrate. Linear regression analysis reported a high correlation and significance at p <0.01 between density and water absorption after 2 hours and after 24 hours (Figure 1). This indicates that water absorption decreases as board density increases.

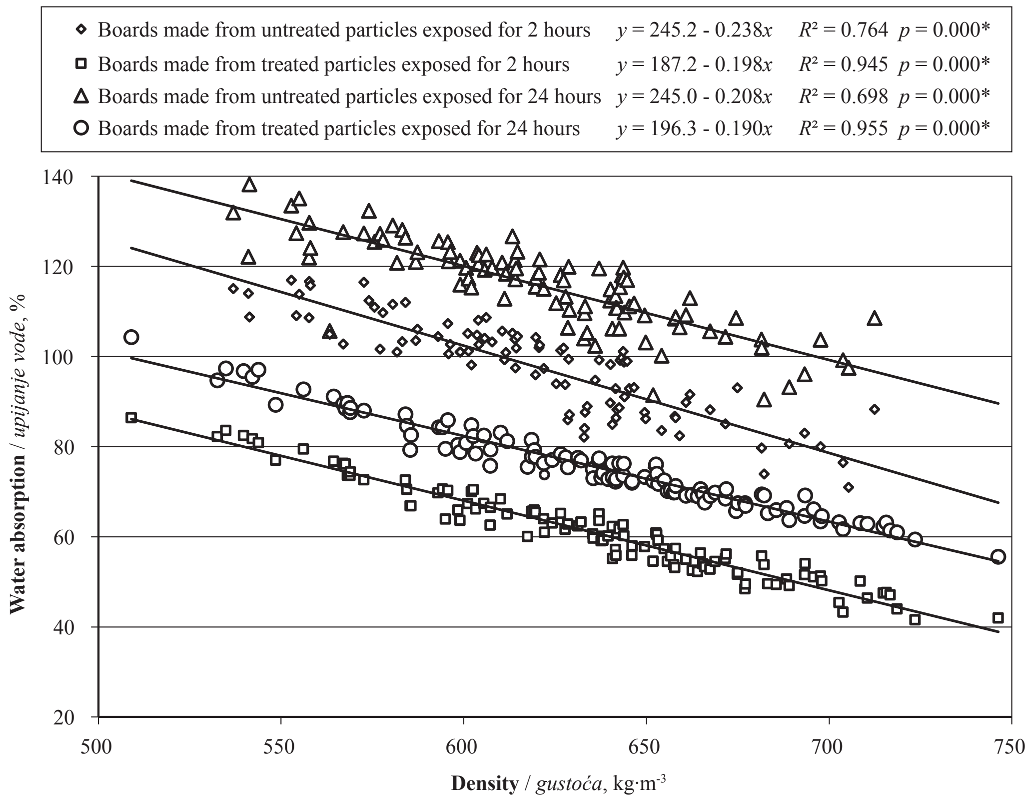
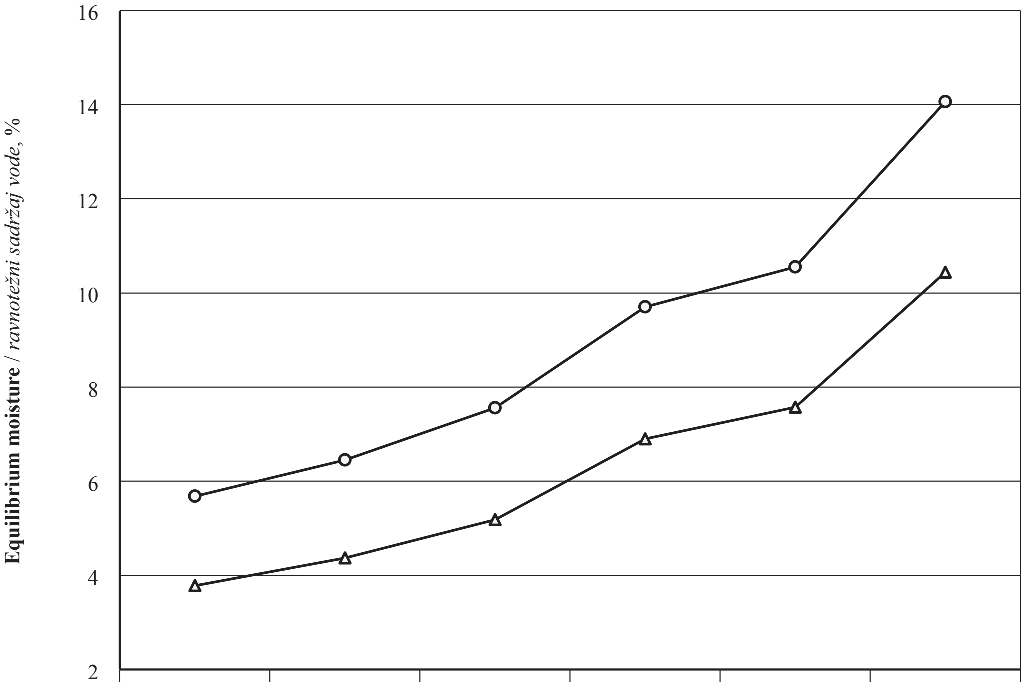


Figure 1 Effect of density on water absorption (2 and 24 hours) of *L. philippiana* boards manufactured using untreated and hygrothermally treated particles
Slika 1. Utjecaj gustoće ploče proizvedene od neobrađenoga i hidrotermički obrađenog iverja drva tepe na upijanje vode (nakon 2 h i nakon 24 h)



	40 % RAH	50 % RAH	60 % RAH	70 % RAH	80 % RAH	90 % RAH
UT	5.68	6.45	7.56	9.70	10.55	14.06
T	3.78	4.37	5.18	6.90	7.57	10.44

Figure 2 Equilibrium moisture values at different RAH conditions and 20 °C in boards manufactured using hygrothermally treated (T) and untreated (UT) *L. philippiana* particles
Slika 2. Vrijednosti ravnotežnog sadržaja vode ploča proizvedenih od neobrađenoga i hidrotermički obrađenog iverja drva tepe pri različitoj vlažnosti zraka i temperaturi 20 °C

3.2 Boards dimensional stability
3.2. Dimenzijska stabilnost ploča

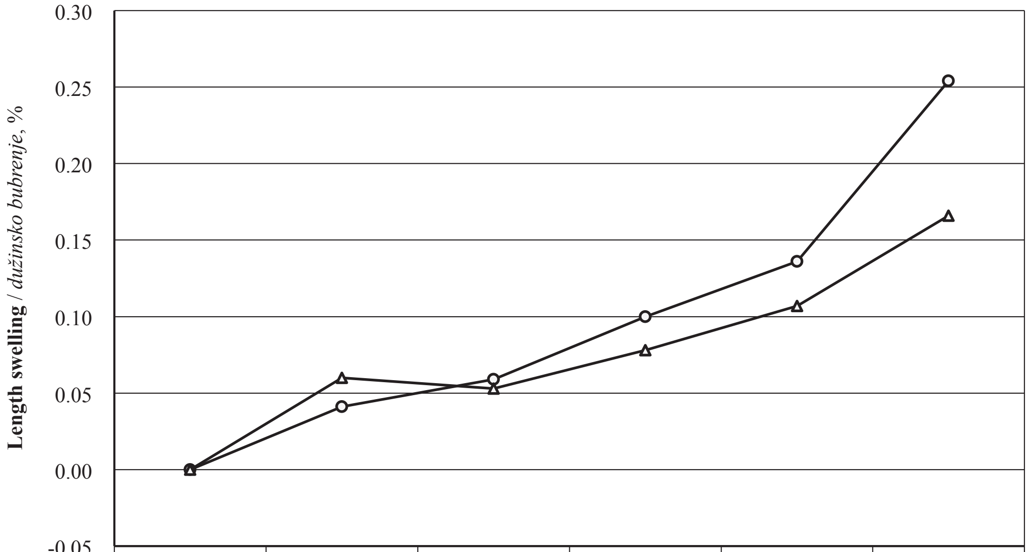
3.2.1 Equilibrium moisture with changes in RAH
3.2.1. Ravnotežni sadržaj vode u pločama u ovisnosti o vlažnosti zraka

Equilibrium moisture of boards at different RAH conditions at 20 °C are presented in Figure 2.

A significant reduction in equilibrium moisture content was registered in boards manufactured with hygrothermally treated particles. When RAH was increased from 40 % to 90 %, in boards manufactured with untreated particles, an increase of the equilibrium moisture from 5.68 % to 14.06 % was recorded, whereas the boards manufactured with treated particles showed an increase from 3.78 % to 10.44 %. Popper *et al.* (2005) studied the effect of thermal treatment of solid wood on the equilibrium moisture and swelling, with RAHs between 11 % and 93 % at a constant temperature of 22 °C. These researchers registered a reduction in both properties, indicating that the changes in the chemical composition would be the cause for the reduction. Crespo *et al.* (2013) stated that the hygrothermal treatment increases the amount of hydrophobic compounds in hygrothermally treated *L. philippiana* particles and also reported an acidification of treated particles, which has a positive effect on the UF setting, since *L. philippiana* is a species with pH values close to neutral. Both changes in the chemical composition of the particles are reflected in a decrease of equilibrium moisture of boards.

3.2.2 Dimensional variation in length and thickness
3.2.2. Varijacije dimenzija ploča u smjeru duljine i debljine

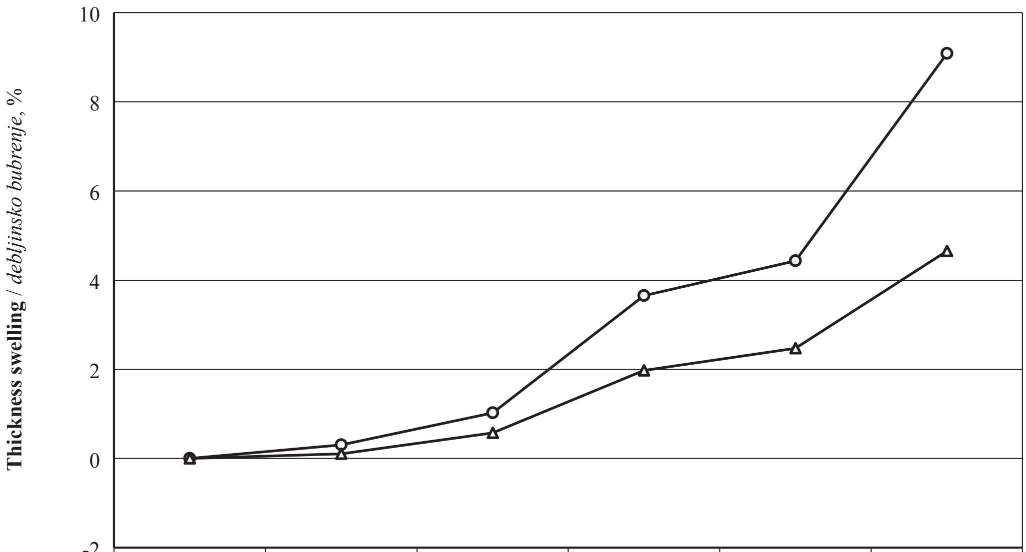
Figures 3 and 4 show the dimensional variation (length and thickness) in boards at different RAH conditions. Boards manufactured with hygrothermally treated particles, regardless of the RAH, presented less dimensional variation in length and thickness than boards manufactured with untreated particles. The difference between treated and untreated particles increases proportionally to increments in RAH. It should also be noted that from 60 % RAH on, significant and increasing differences in dimensional variation in length and thickness of hygrothermally treated and untreated boards were observed. At 90 % RAH, the greatest differences in length and thickness swelling were present. The length dimensional variations at 90 % RAH decrease from 0.254 % in boards with untreated particles to 0.166 % in boards with treated particles. In the case of thickness swelling, the decrease was from 9.081 % in boards with untreated particles to 4.656 % in boards with treated particles. The improvement in dimensional stability recorded in boards manufactured with hygrothermally treated particles is in agreement with the results reported by Hsu *et al.* (1988), who stated that the linear expansion and thickness swelling of particleboards glued with UF, caused by variation in moisture content, were substantially reduced by hygrothermal treatment of



	40 % RAH	50 % RAH	60 % RAH	70 % RAH	80 % RAH	90 % RAH
UT	0	0.041	0.059	0.100	0.136	0.254
T	0	0.060	0.053	0.078	0.107	0.166

Figure 3 Dimensional variation in length at different RAH conditions in boards manufactured using untreated (UT) and hygrothermally treated (T) *L. philippiana* particles
Slika 3. Varijacije dimenzija u smjeru duljine ploča proizvedenih od neobrađenoga (UT) i hidrotermički obrađenog (T) iverja drva tepe pri različitoj vlažnosti zraka i temperaturi 20 °C

the particles. Hsu *et al*. (1988) reported that thickness swelling was reduced from 12.1 % to 3.6 % and linear expansion from 0.48 % to 0.24 %. In the case of boards manufactured with hygrothermally treated particles and UF, the improvement of the dimensional stability could be related to the increase in extractable hydrophobic compounds by hemicelluloses degradation, reported in hygrothermally treated *L. philippiana* particles by Crespo *et al.* (2013). As reported, the increase in acidity in hygrothermally treated *L. philippiana* particles also contributed to an improvement in board dimensional stability, since this chemical change allows for better setting of the UF, improving the particle-adhesive-particle association.



	40 % RAH	50 % RAH	60 % RAH	70 % RAH	80 % RAH	90 % RAH
UT	0	0.306	1.027	3.651	4.431	9.081
T	0	0.109	0.577	1.976	2.475	4.656

Figure 4 Dimensional variation in thickness at different RAH conditions in boards manufactured using untreated (UT) and hygrothermally treated (T) *L. philippiana* particles
Slika 4. Varijacije dimenzija u smjeru debljine ploča proizvedenih od neobrađenoga (UT) i hidrotermički obrađenog (T) iverja drva tepe pri različitoj vlažnosti zraka i temperaturi 20 °C

Table 2 First degree equations and determination coefficients of dimensional variation in thickness and length and different RAH conditions in boards manufactured using hygrothermally treated and untreated *L. philippiana* particles.
Tablica 2. Jednadžbe prvog stupnja i koeficijenti determinacije ovisnosti dimenzijskih varijacija ploča u smjeru duljine i debljine o vlažnosti zraka za ploče proizvedene od neobrađenoga i hidrotermički obrađenog iverja drva tepe

Property / *Svojstvo*	**Condition** / *Uvjeti*	**Equation** / *Jednadžba*	R^2
Thickness swelling *debljinsko bubrenje*	Untreated / *neobrađeno*	*TS* = 0.028 *RAH* -0.159	0.981
	Hygrothermally treated / *hidrotermički obrađeno*	*TS* = 0.021 *RAH* -0.061	0.918
Length swelling *bubrenje u duljinu*	Untreated / *neobrađeno*	*LS* =1.104 *RAH* -6.858	0.985
	Hygrothermally treated / *hidrotermički obrađeno*	*LS* = 0.724 *RAH* -2.986	0.993

TS – Thickness swelling / *debljinsko bubrenje*, LS: Length swelling / *bubrenje u duljinu*, RAH – Relative air humidity / *relativna vlažnost zraka.*

In Table 2, the first degree equations are defined, as well as the determination coefficient for the relationship between the average equilibrium moisture and thickness and length swelling. According to the regression analysis, there is a high correlation between equilibrium moisture, length and thickness swelling at different RAH. The obtained equations can predict board dimensional variations. Similar results were obtained by Niemz and Poblete (1996).

4.3 Dimensional variations in relation to a 1 % change in equilibrium moisture of the boards
4.3. Varijacije dimenzija ploča s obzirom na promjenu ravnotežnog sadržaja vode u pločama za 1 %

Length and thickness swelling coefficients per every 1 % equilibrium moisture change in boards were obtained as a quotient of length and thickness swelling at 90 % RAH, which was then divided by the result of the subtraction of equilibrium moisture at 90 % RAH and equilibrium moisture at 40 % RAH. The length and thickness swelling coefficients for every 1 % change in equilibrium moisture of the boards were lower in boards manufactured with hygrothermally treated particles. The decrease of boards manufactured with non-treated particles compared to boards manufactured with treated particles was of 0.030 % to 0.025 % for longitudinal swelling, and 1.083 % to 0.700 % for thickness swelling. The values obtained in the current study for swelling coefficient of the boards are similar to the values reported by Niemz and Poblete (1996) of boards manufactured with thermally untreated particles. The reduction in the thickness swelling coefficient caused by the hygrothermal treatment is in agreement with results reported by Suchsland and Enlow (1968), who stated that the specific thickness swelling (percent swelling per 1 % change in moisture content) during exposure to 90 % relative humidity conditions decreases in thermally treated 3-layer particleboards.

5 CONCLUSIONS
5. ZAKLJUČAK

Hygrothermal treatment of *L. philippiana* particles has positive effects on physical properties and dimensional changes of boards. A decrease in equilibrium moisture content, swelling and water absorption after a 2 and 24 hours immersion was determined in boards manufactured with hygrothermally treated particles. In this research, trials results from dimensional stability showed that equilibrium moisture, longitudinal and thickness swelling are reduced in boards manufactured with hygrothermally treated particles. Consequently, longitudinal and thickness swelling coefficients are also reduced for every 1 % change in equilibrium moisture of the boards. It can be concluded that hygrothermal treatment of *L. philippiana* particles at 150 °C for 90 min at the pressure of 430 kPa*,* is an alternative to improve dimensional stability of boards manufactured for this species.

Acknowledgements – Zahvala

This study was supported by a scholarship from the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT) from Chile, and by the Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT) from Ecuador.

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Evaluation of Common Wheat Stubbles (*Triticum aestivum* L.) for Pulp and Paper Production

Procjena mogućnosti upotrebe strnjike obične pšenice (*Triticum aestivum* L.) za proizvodnju celuloze i papira

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 12. 1. 2016.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*861.069; 630*862.1*
doi:10.5552/drind.2016.1603

ABSTRACT • *The aim of the study was to determine the properties of pulp and paper produced from wheat stubble (Triticum aestivum L.), using soda-oxygen-sodium borohydride ($NaBH_4$) cooking method. Whole wheat straw (Triticum aestivum L.) was also used for comparison with stubbles. The morphological and chemical properties of the raw materials were investigated. The results showed that stubble had high holocellulose, cellulose, and alpha-cellulose contents and low lignin content. Fiber length, fiber width, lumen diameter, and cell wall thickness were measured in order to determine suitability of the fibers for pulp and paper production. The values were used to calculate fiber parameters. The effects of these parameters on paper strength were also discussed. The effect of $NaBH_4$ on the yield and chemical, physical, and optical properties of pulp and paper were investigated. The addition of $NaBH_4$ increased pulp yield by 4.1 %, and improved the physical and optical properties of the pulp. The physical and optical properties of the stubble pulp were better than those of whole wheat straw pulp. It was concluded that these characteristics demonstrate the suitability of wheat stubbles for pulp and paper production.*

Key words: *stubble, wheat straw, soda-oxygen, pulp, paper, sodium borohydride*

SAŽETAK • *Cilj istraživanja bio je odrediti svojstva celuloze i papira proizvedenih od strnjike pšenice (Triticum aestivum L.) metodom kuhanja s dodatkom soda-kisik-natrijborohidrida (NaBH4). Radi usporedbe, određena su i svojstva celuloze i papira izrađenih od slame pšenice (Triticum aestivum L.). Određena su i analizirana morfološka i kemijska svojstva istraživanih sirovina. Rezultati istraživanja pokazali su da strnjika pšenice ima visok sadržaj holoceluloze, celuloze i α-celuloze te nizak sadržaj lignina. Radi utvrđivanja prikladnosti vlakanaca za proizvodnju celuloze i papira, izmjereni su duljina vlakanaca, širina vlakanaca, promjer pora i debljina stanične stijenke. Dobivene su vrijednosti iskorištene za izračun parametara vlakanaca. Također je analiziran utjecaj tih parametara na čvrstoću papira. Istražen je utjecaj $NaBH_4$ na prinos celuloze te na kemijska, fizikalna i optička svojstva celuloze i papira. Dodatak $NaBH_4$ povećao je prinos celuloze za 4,1 % i poboljšao fizikalna i optička svojstva celuloze. Fizikalna i optička svojstva celuloze izrađene od strnjike pšenice bila su bolja od svojstava celuloze proizvedene od pšenične slame. Zaključeno je da svojstva celuloze proizvedene od strnjike pšenice potvrđuju pogodnost te sirovine za proizvodnju celuloze i papira.*

Ključne riječi: *strnjika, pšenična slama, soda-kisik, celuloza, papir, natrijev borohidrid*

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1 INTRODUCTION
1. UVOD

Shortage of raw materials for pulp and paper production has led paper-makers to find new raw material resources. Several studies have been carried out in order to discover these resources. Annual plants and agricultural wastes are supplement to wood-based raw materials for pulp and paper production. Lignocellulosic annual plants have been used in pulp and paper production as early as the 19th century. Due to greater pulp and paper production, the need for annual plants showed a rapid increase especially after the Second World War and many small and large-scale mills were established for the pulp and paper production from annual plants (Eroglu, 1983; Tutus, 2000; Akgul,2007).

Agricultural residuals have an important place in terms of potential production within the world and are one of the most important raw materials that could be utilized in the pulp and paper industry (Cheng, 1993). Also, agricultural waste or pruning support more organisms than living plants (Paul and Clark, 1989). These organisms infect the future cereals. For this reason, stubble should be converted to more beneficial products. Gencer (2015) reported that paper of standard quality could be made from kiwi pruning.

In general, pulping of non-woods is easier compared to wood. Non-woods have low lignin content and, therefore, require fewer chemicals during cooking, where the raw material is chemically treated under high temperature and pressure to separate lignin from the fibers. Although kraft or sulfate is the preferred pulping procedure for wood, non-woods are generally cooked by soda and sulfite as well as sulfate processes (Chandra, 1998).

Stubble is defined as short stalks, which are left standing in fields after wheat or other cereal crops have been harvested. Stubble remaining in the soil after harvest of grain is a source of organic substances. Unfortunately, it is usually burned after harvest in Turkey (Sahinbas, 2015).

Burning stubble:
- destroys organic substances,
- makes land sensitive to water and wind erosion,
- creates smoke that causes air pollution but also traffic accidents,
- causes land to be infertile.

The fire decreases the clay ratio of the soil and reduces the capacity of water absorption and ratio of plant nutrients (Kara and Bolat, 2009).

Stubble can be an important raw material for pulp and paper production. Stubble height for the cereal straws is about 18-20 cm. The harvest index of wheat straw is about 1/ 2.66 (seed/straw). This index is reduced to 1/1.81 (seed/straw) with collecting and transportation losses. This ratio can change depending on stubble height and transportation conditions (Tutus *et al.,* 2009). According to this rate, in 2014, world and Turkey stubble amounts were 605.3 and 16.2 million tonnes, respectively (Faostat, 2015). Due to the lignocellulosic fiber structure, wheat straws are used in paper and board, composite materials, and animal feeding industries (Aksoy *et al*., 2014).

Turkey, as one of the major cereal producers in the world, has the potential to produce a significant amount of wheat straw. In this study, the chemical, physical and optical properties of stubble treated with soda-oxygen-$NaBH_4$ were studied.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials
2.1. Materijali

This study was performed at the Kahramanmaras Sutcu Imam University Faculty of Forestry, Pulp and Paper Production Laboratory. The raw materials used in this study were harvested from Kahramanmaras-Turkey at the end of the growing season.

2.2 Chemical analysis and fiber properties
2.2. Kemijska analiza i svojstva vlakanaca

The raw materials were analyzed for α-cellulose, lignin, ash and water contents, and NaOH (1 %) solubilities using TAPPI Standard Tests Methods (1992). Extractives were measured using the ASTM standard procedures (2013). The holocellulose and cellulose contents were determined according to Wise's (1962) chlorite and Kurschner-Hoffer (1993) nitric acid method, respectively. Fiber length and width, lumen diameter, and cell wall thickness of the raw material were measured with a microscope. To measure the fiber morphologic properties of the specimens (0.5 mm thick and 2 cm long in parallel to fiber), the chloride method was applied. In this method, specimens were immersed into chloride solution until they were defibered and measurements were done with an Olympus BX51 microscope.

2.3 Pulping procedure
2.3. Priprema celuloze

Air dried samples were cut into pieces about 6 cm long. 12 cooking experiments were performed on stubbles, using soda-oxygen-$NaBH_4$ processes to determine the optimum pulping conditions (Table 1). The optimum conditions were also performed on whole wheat straw for comparison.

Cooking experiments were conducted in an electrically-heated rotary digester of 15 L capacity, and 25 $kg \cdot cm^{-2}$ maximum pressure. All pulps were washed and screened on a 0.15 mm slotted screen. The screened pulp yields and screen rejects are also presented.

Viscosity measurement of pulp plays an important role in identifying the characteristics of the pulp such as polymerization degree or cellulose chain length (Yasar *et al*., 2016), while the kappa number is an indication of the residual lignin content or bleachability of pulp. Viscosity and kappa number of the pulp were measured according to TAPPI T 230 om-08 and TAPPI T 236 om-13, respectively. The screened pulp was beaten in the hollander beater to 50±3 °SR (Schopper Riegler) freeness level according to Tappi T 200 sp-96 and ten handsheets per tested sequence with grammages of 70 $g \cdot m^{-2}$ were prepared using a Rapid-Kothen

Table 1 Pulping conditions of stubbles
Tablica 1. Uvjeti pripreme celuloze od strnjike pšenice

Pulping conditions/ *Uvjeti pripreme celuloze*	**Unit** / *Jedinica*	**Value** / *Vrijednost*
NaOH charge / *udjel NaOH*	%	16
$NaBH_4$ charge / *udjel* $NaBH_4$	%	0, 0.1, 0.3, 0.5
Oxygen pressure / *tlak kisika*	Bar	7
Cooking temperature / *temperatura kuhanja*	°C	140
Time to maximum temperature / *vrijeme do postizanja maksimalne temperature*	min	40
Time at maximum temperature / *vrijeme pri maksimalnoj temperaturi*	min	50
Liquor to raw material ratio / *omjer otapala i sirovine*	L/kg	5/1

sheet former according to ISO 5269/2. Breaking length (TAPPI T 494 om-01), burst index (TAPPI T 403 om-2), tear index (TAPPI T 414 om-12) brightness (ISO 2469) and opacity (TAPPI T 425 om-96) of handsheets were also investigated.

2.4 Statistical analysis
2.4. Statistička analiza

The SPSS 15.0 statistical package was used. Data of chemical, physical and optical properties of the pulp were analyzed using a computerized statistical program to determine variance, and by carrying out the Duncan test at a $P \leq 0.05$ confidence level.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Chemical composition and fiber properties
3.1. Kemijski sastav i svojstva vlakanaca

The chemical composition of the stubble and whole wheat straw used in this study are given in Table 2 with those of some wood species and annual plants. The holocellulose content of stubble was approximately equal to that of hardwood and higher than that of softwood. This is because both stubbles and hardwoods have a higher hemicellulose content and lower lignin content when compared to softwood. The high NaOH (1 %) solubility is due to the presence of low molecular weight carbohydrates and other alkali-soluble matters (Tutus and Eroglu, 2003). Also, NaOH solubility indicates the extent of fiber degradation during the pulping process (Zawawi *et al.,* 2014). Cold water solubility provides a measure of tannins, sugars, gums, and coloring matter. Hot water solubility also removes starches (ASTM, 2013). Because of high silica content, the ash content of the straws was found to be higher than that of other species (Table 2). The holocellulose content of the stubble was higher than that of the whole wheat straw and approximately equal to that of hardwoods.

When compared to previous studies, the results of the chemical analysis show that the stubble was consistent with the literature (Table 2). Only the ash con-

Table 2 Chemical composition and solubility of some annual plants and wood species
Tablica 2. Kemijski sastav i topljivost nekih jednogodišnjih biljaka i vrsta drva

Annual plants and wood species *Jednogodišnje biljke i vrste drva*	**Chemical composition**						**Solubility**			**Literature**
	Holocellulose, % *Holoceluloza, %*	Cellulose, % *Celuloza, %*	α-celluloza, % *α-celuloza, %*	Lignin ,% *Lignin, %*	Ash, % / *Pepeo, %*	Extractives, % *Ekstraktivne tvari, %*	NaOH (1 %), %	Hot water, % *Vruća voda, %*	Cold water, % *Hladna voda, %*	
Stubbles / *strnjika*	78*	53*	40 ns	17*	7.1*	5.5*	42.1*	12.9*	8.97*	Current Study
Whole wheat straws *slama pšenice*	73*	51*	39 ns	18*	7.8*	5.1*	43.7*	14.6*	11.5*	Current Study
A. membranaceus	77	37	50	24	5.5	5.6	29.4	8.4	7.20	Tutus *et al.,* 2014
Papaver somniferum	80	41	52	19	4.7	-	30.3	10.4	5.10	Tutus *et al.,*2011
Cotton straw / *slama pamuka*	76	46	40	18	2.5	6.1	30.9	14.2	11.7	Tutus *et al,.* 2010
Cotton straw / *slama pamuka*	72	-	42	19	2.4	6.1	42.9	17.8	16.7	Akgul, 2007
Cotton carpel / *pamuk*	72	43	31	21	5.5	6.6	48.9	12.2	8.39	Alma *et al.,* 2005
Wheat straw / *slama pšenice*	77	52	40	18	7.1	5.5	40.9	12.2	7.65	Tutus 2000
Semen secalis	74	52	44	15	3.2	9.2	39.2	13.0	10.2	Usta and Eroglu, 1987
Corn straw / *stabljike kukuruza*	65	46	36	17	7.5	9.5	47.1	14.8	-	Eroglu *et al.,* 1992
Nicotiana tabacum	68	-	38	20	7.3	6.5	42.9	19.1	15.8	Tank *et al.,* 1985
Lake cane / *jezerska trska*	78	50	48	19	3.0	4.0	28.3	3.8	3.30	Kirci, 1996
Hibiscus Cannabinus	81	54	37	15	4.1	5.0	34.9	12.8	11.7	Dogan, 1994
Softwoods / *meko drvo*	63-74	55-61	-	25-32	0.2-0.5	1-6	8-10	1-5	0.5-4	Kirci, 2006
Hardwoods / *tvrdo drvo*	72-82	38-55	-	18-26	0.2-0.7	1-6	12-25	1-8	0.2-4	Kirci 2006

*Significant at 0.05 level and ns Non-significant level in Independent Samples T-Test. / **Signifikantno pri razini 0,05 i ns nesignifikantno pri testiranju T-testom.*

Table 3 Comparison of fiber parameters of stubbles and whole wheat straws with the parameters of some other fibers (Topcuoglu, 1985; Kırcı, 1996; Alkan *et al.,* 2003, Tutus and Eroglu, 2003, Istek *et al.,* 2008, Tutus *et al*., 2010, Tutus *et al.*, 2014)
Tablica 3. Usporedba parametara vlakanaca dobivenih od strnjike i slame pšenice s parametrima vlakanaca dobivenih od drugih sirovina (Topcuoglu, 1985.; Kırcı, 1996.; Alkan et al., 2003.; Tutus and Eroglu, 2003.; Istek *et al*., 2008.; Tutus *et al.*, 2010.; Tutus *et al.*, 2014.)

Species / *Vrsta*	**Felting rate** *Brzina filcanja*	**Elasticity coefficient** *Koeficijent elastičnosti*	**Rigidity coefficient** *Koeficijent krutosti*	**Runkel index** *Runkelov indeks*	***F* factor** F-faktor
Stubble / *strnjika*	60	27	37	2.8	16
Whole Wheat Straw / *slama pšenice*	62	27	36	2.7	17
Crambe orientalis	24	79	10	0.3	23
Crambe tataria	36	70	15	0.4	24
Reed stalks / *stabljike trske*	103	52	24	0.9	44
Cotton stalks / *stabljike pamuka*	33	63	18	0.6	29
Sunflower stalks / *stabljike suncokreta*	58	71	15	0.4	38
Rye straw / *slama raži*	38	61	20	0.7	22
Tobacco stalks / *stabljike duhana*	40	29	36	3.0	20
Hardwoods / *tvrdo drvo*	45 to 65	35 to 65	15 to 35	0.5 to 2	16 to 30
Softwoods / *meko drvo*	60 to 80	70 to 80	15 to 20	0.3 to 0.5	50 to 60

tent of the stubble was higher than that of softwoods and hardwoods. The oxide-added SOAQ pulping process of wheat straw offers a practical solution to the silica problem that has inhibited the widespread use of cereal straw as a papermaking fiber (Tutus and Eroglu, 2003). This is explained by phytoliths (microfossils of opal silica) formation (Ball *et al.,* 1999; Halvarsson *et al.,* 2010).

The stubble fiber length, fiber width, lumen diameter, and cell wall thickness were found to be 0.894 mm, 14.86 µm, 3.94 µm, and 5.46 µm, respectively. The respective values for whole wheat straw were 0.876 mm, 14.11 µm, 3.79 µm, and 5.15 µm. According to that, the fiber dimensions of stubble were similar to those of whole wheat straw. The fiber parameters were also calculated according to the Equations:

Felting power = Fiber length / fiber width (1)

Elasticity coefficient = Lumen diameter · 100 / fiber width (2)

Rigidity coefficient = Cell wall thickness / fiber diameter ·100 (3)

Runkel's classification = Cell wall thickness · 2 / lumen diameter (4)

F Factor = Fiber length/cell wall thickness · 100 (5)

The calculated fiber parameters are given in Table 3 along with the parameters of some other species. Today, as fiber and short fiber pulp concepts are widely used in paper industry, the measurement of fibers constituting pulp and accordingly the relations between pulp properties also become important. For example, increases in fiber length affect strength properties but cause poor paper formation (Kirci, 2006; Akgul and Tozluoglu, 2009).

Felting power is one of the criteria for the suitability of raw material for paper production. This power is important for physical properties of the paper such as breaking length, burst and tear index. It is wanted to be between 70-90 for softwood and 40-60 for hardwood. The felting power of stubble and whole wheat straw was found to be 60.16 and 62.08, respectively, and to be similar to that of hardwood. The Runkel value is the ratio of fiber cell wall thickness and its lumen and it determines the suitability of a fibrous material for pulp and paper production. If a wood species has a high Runkel value, its fiber will be stiff and less flexible and have poor bonding ability (Kiaei *et al.,* 2014). The Runkel values of the raw materials were higher than those of other species. This means that these raw materials have thick cell walls. The rigidity coefficient of stubble and whole wheat straw were found to be similar to that of hardwoods. This value has a negative effect on tensile, tear, burst and double fold resistance of the paper (Hus *et al.,* 1975).

3.2 Chemical, physical and optical properties of pulp
3.2. Kemijska, fizikalna i optička svojstva celuloze

Chemical, physical and optical properties of pulp are given in Table 4. The pulp was beaten to 50±3 °SR in a laboratory beater and test papers were produced with a Rapid Kothen RK-21 paper machine.

According to the same Table 4, 7 bars is the most appropriate value of oxygen pressure. The increase of oxygen pressure during the cooking process has a positive effect on the kappa number, pulp viscosity and DP, breaking length, tear index, and brightness value. The oxygen pressure of 7 bars should be used in other studies related to the same subject. In Table 4, the optimal value of $NaBH_4$ was determined as 0.3 % and 0.5 %. However, considering the economic importance of using the Soda-Oxygen-$NaBH_4$ method for the pulp production, the most appropriate ratio of $NaBH_4$ was accepted as 0.3 %. The increase of the $NaBH_4$ ratio during the cooking process has a positive effect on the pulp yield, kappa number, pulp viscosity and DP, tear

Table 4 Cooking conditions, pulp yields and some chemical, physical and optical properties of pulp
Tablica 4. Uvjeti kuhanja, prinos celuloze i neka kemijska, fizikalna i optička svojstva celuloze

Cooking No *Kuhanje broj*	**Oxygen pressure** *Tlak kisika* bar	**$NaBH_4$ ratio** *Omjer $NaBH_4$* (%)	**Black liquor** *Crno otapalo* pH	**Screened yield** *Prinos prosijavanja* %	**Screen reject** *Škart prosijavanja* %	**Total yield** *Ukupni prinos* %	**Kappa Number** *Kapa broj*	**Viscosity** *Viskoznost* $cm^3 \cdot g^{-1}$	*DP*	**Breaking length** *Duljina lomljenja* km	**Tear Index** *Indeks cijepanjam* $N \cdot m^2 \cdot g$	**Burst Index** *Indeks pucanja* $kPa \cdot m^2 \cdot g^{-1}$	**Brightness (ISO)** *Sjajnost (ISO)*	**Opacity** *Neprozirnost* %
1	3	0	13.0	45.14	7.41	52.55	74.31	753	1098	5.799	3.08	3.12	28.26	88.32
2	5	0	12.8	45.99	6.65	52.64	56.51	722	1049	6.021	3.19	3.55	32.07	85.59
3	7	0	13.5	46.05	6.88	52.93	49.62	657	945	6.186	4.54	3.63	34.81	84.41
4	3	0.1	13.4	47.04	6.32	53.36	65.45	731	1063	5.525	5.31	3.98	29.64	89.18
5	5	0.1	13.3	47.58	6.26	53.84	63.10	736	1071	5.823	3.60	4.12	32.64	88.94
6	7	0.1	13.0	48.90	5.62	54.52	48.21	749	1092	6.002	4.02	4.27	35.95	87.93
7	3	0.3	13.2	49.14	5.72	54.86	72.98	759	1107	5.899	3.59	4.23	30.34	90.27
8	5	0.3	13.0	49.44	5.36	54.80	55.95	767	1121	5.952	3.37	4.14	34.51	89.20
9	7	0.3	12.8	49.11	5.87	54.98	44.55	769	1124	6.242	3.98	4.05	38.17	88.19
10	3	0.5	12.8	50.26	5.36	55.62	57.38	737	1073	5.616	4.55	3.55	31.53	91.21
11	5	0.5	13.6	51.86	5.42	57.29	56.07	742	1080	5.905	3.94	4.11	37.21	85.69
12	7	0.5	13.5	51.19	6.00	57.19	45.51	750	1093	6.244	3.07	4.59	39.48	87.83
13*	7	0.3	13.3	48.18	3.98	52.16	56.07	742	1080	5.978	3.36	4.03	37.18	87.16

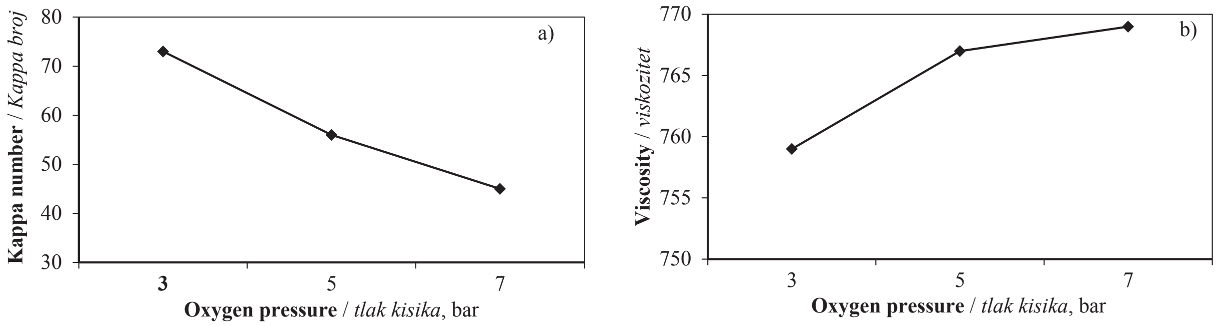

Figure 1 Effects of oxygen pressure on kappa number (a) and viscosity (b)
Slika 1. Utjecaj tlaka kisika na (a) kapa broj i (b) na viskoznost

Table 5 Effects of oxygen pressure on chemical, physical, and optical properties of the stubble pulp
Tablica 5. Utjecaj tlaka kisika na kemijska, fizikalna i optička svojstva celuloze proizvedene od strnjike pšenice

Oxygen pressure *Tlak kisika* bar	**Yield** *Prinos* %	**Kappa No** *Kapa broj*	**Viscosity** *Viskoznost* $cm^3 \cdot g^{-1}$	**Breaking length** *Duljina lomljenja* km	**Tear Index** *Indeks cijepanjam* $N \cdot m^2 \cdot g$	**Burst Index** *Indeks pucanja* $kPa \cdot m^2 \cdot g^{-1}$	**Brightness (ISO)** *Sjajnost (ISO)*	**Opacity** *Neprozirnost* %
3	54.86	73c	759a	5.90a	4.05a	3.59b	30.34a	90.27b
5	54.80	56b	767a	5.95a	4.14a	3.37a	34.52b	89.20a
7	54.98	45a	769a	6.24b	4.23a	3.98c	38.17c	88.19a

*$NaBH_4$ charge was kept 0.3 % and mean values with the same lower-case letters are not significantly different according to Duncan's mean separation test. / *Udjel $NaBH_4$ bio je 0,3 %, a srednje vrijednosti s istim slovom nisu signifikantno različite prema Duncanovu testu.*

index, and burst index. Variance analysis and Duncan test were performed using these data.

Increasing the oxygen pressure decreases the kappa number (Figure 1a) and increases viscosity (Figure 1b), breaking length, burst index, tear index, and brightness (Table 5). In our experiments, the yield was independent of oxygen pressure (Table 5). However, for experiments using wheat straw over a greater range of oxygen pressure (6-14 bar), the yield was lowered by approximately 1 % at the highest pressure (Deniz, 1994; Tutus, 2000).

The lower kappa number at higher oxygen pressure is consistent with other experiments using wheat straws (Tutus, 2000).

3.3 Effect of $NaBH_4$ on pulp physical, optical and chemical properties
3.3. Utjecaj $NaBH_4$ na fizikalna, optička i kemijska svojstva celuloze

The pulping additive $NaBH_4$ acts as a catalyst by protecting the end groups from a peeling reaction, which increases the screened pulp yield (Istek and Ozkan, 2008).

Figure 2 shows the effects of $NaBH_4$ on the screened yield and viscosity. Adding of $NaBH_4$ increased screened yield (Figure 2a) and viscosity (Figure 2b) and DP (Table 4).

Other kraft-$NaBH_4$ studies of *Eucalyptus grandis* (Ayata, 2008) and red pine wood (Temiz, 2006) have shown a decrease in kappa number with the addition of $NaBH_4$. Yield increases have been observed when adding $NaBH_4$ to cooking solution during pulp production (Petterson and Rydholm, 1961; Tutus and Alma, 2005) and soda-oxygen cooking (Hafizoglu, 1982; Tutus, 2004).

$NaBH_4$ content, which has an important effect on the soda-oxygen-$NaBH_4$ cooking, the obtained pulp yield at various oxygen pressure, and the summary of the Duncan tests, which was done with some chemical properties and important physical and optical properties, are given in Table 6.

It was established that the most appropriate oxygen pressure was 7 bars. While the increase of oxygen pressure during the cooking process has a positive effect on the kappa number, pulp viscosity and DP,

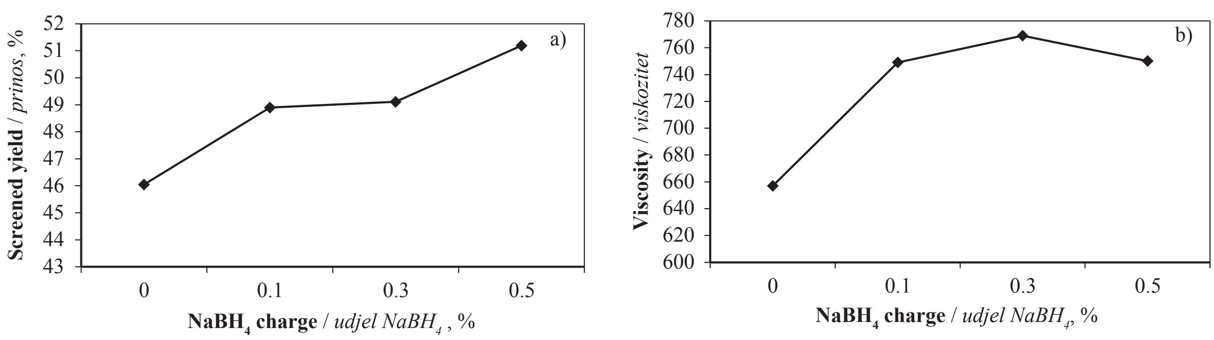

Figure 2 Effects of $NaBH_4$ charge on screened yield (a) and viscosity (b)
Slika 2. Utjecaj udjela $NaBH_4$ na (a) prinos prosijavanja i (b) na viskoznost

Table 6 Effects of $NaBH_4$ on chemical, physical, and optical properties of the stubble pulp
Tablica 6. Utjecaj udjela $NaBH_4$ na kemijska, fizikalna i optička svojstva celuloze proizvedene od strnjike pšenice

$NaBH_4$ charge *Udjel $NaBH_4$*	**Yield** *Prinos* %	**Kappa No** *Kapa broj*	**Viscosity** *Viskoznost* $cm^3 \cdot g^{-1}$	**Breaking length** *Duljina lomljenja* km	**Tear Index** *Indeks cijepanja* $mN \cdot m^2 \cdot g$	**Burst Index** *Indeks pucanja* $kPa \cdot m^2 \cdot g^{-1}$	**Brightness (ISO)** *Sjajnost (ISO)*	**Opacity** *Neprozirnost* %
0	52.9	50c	657c	6.2a	3.6c	4.5a	34.8b	84.4b
0.1	54.5	48b	749b	6.0b	4.1b	4.0b	35.9b	87.9a
0.3	54.9	45a	769a	6.2a	4.0b	3.9b	38.1a	88.1a
0.5	57.2	46b	750b	6.2a	4.6a	3.1c	39.5a	87.8a

*Oxygen pressure was kept at 7 bars and mean values with the same lower-case letters are not significantly different according to Duncan's mean separation test. / *Tlak kisika bio je 7 bara, a srednje vrijednosti s istim slovom nisu signifikantno različite prema Duncanovu testu.*

breaking length, tear index and brightness value, it also has a negative effect on the other chemical, physical and optic properties. The oxygen pressure of 7 bars should also be used for the other studies related to the same subject.

4 CONCLUSION
4. ZAKLJUČAK

The optimal cooking conditions for the chemical, physical and optical properties during the pulp production with soda-oxygen- $NaBH_4$ method is presented in Table 7 below.

Consequently, the following advantages could be obtained by using stubbles and $NaBH_4$ for pulp and paper production:

1. Pulp made from stubble has properties similar to those made from whole wheat straw pulp;
2. Harvesting of stubble would increase the availability of fiber in countries such as Turkey where wood resources are limited;
3. The addition of $NaBH_4$ protects the reducing end groups from peeling reaction and increases screened pulp yield;
4. Pulp made with the addition of $NaBH_4$ have higher brightness and are easier to bleach but have lower opacity;
5. Turkey has 73 percent of boron reserves in the world, which makes $NaBH_4$ an attractive additive in this region.

Table 7 The optimal cooking conditions during pulp production with soda-oxygen- $NaBH_4$ method
Tablica 7. Optimalni uvjeti kuhanja pri proizvodnji celuloze metodom kuhanja s dodatkom soda-kisik-natrijborohidrida

Pulping conditions *Uvjeti kuhanja*	**Unit** *Jedinica*	**Value** *Vrijednost*
NaOH charge / *udjel NaOH*	%	16
$NaBH_4$ charge / *udjel $NaBH_4$*	%	0.3
Oxygen pressure / *tlak kisika*	bar	7
Cooking temperature *temperatura kuhanja*	°C	140
Time to maximum temperature *vrijeme do postizanja maksimalne temperature*	Min	40
Time at maximum temperature *vrijeme pri maksimalnoj temperaturi*	Min	50
Liquor to raw material ratio *omjer otapala i sirovine*	L/kg	5/1

Acknowledgement – Zahvala

This research was supported by the Kahramanmaras Sutcu Imam University, Research Project Coordination Unit, under project number 2011/7-14 YLS.

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Biophysical Bases for Vibroacoustic Diagnostics of Standing Sounding Wood

Biofizikalni temelji vibroakustične dijagnostike zvučnosti rastućeg stabla

Preliminary paper • Prethodno priopćenje
Received – prispjelo: 20. 2. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*812.12; 630*812.42*
doi:10.5552/drind.2016.1514

ABSTRACT • *At the turn of the third millennium, scientists and experts of many countries are still trying to puzzle out 'the mystery of Stradivari', using for this purpose advanced technological solutions in the fields of physics, mathematics, chemistry, biology, etc. It has been undoubtedly proved that one of the basic secrets of the great master's violin sounding is in the recognition of the proper material. Unfortunately, Stradivari, Amati, Guarneri and other great representatives of the Old Italian school did not leave any hints, but it has been recorded that they selected wood for the string-plate, the main sounding part of a violin, by tapping, and they designed an instrument judging from the 'sonority' factors known to them only. Using modern scientific terms, it is possible to ascertain that it was the professional skill of the master to decode the percussion-acoustic response of the source material that predetermined the quality of the product. The results of the work done cannot claim to disclose any secrets in the field. For this purpose, significant complex research is necessary, both fundamental and applied, integrating the efforts of scientists and experts in different areas: physicists, acousticians, wood scientists, foresters and, the main thing, the recognized masters in the sphere of manufacturing corresponding musical instruments. This paper presents the first results of implementing the technique based on the excitation of fluctuations of a trunk by a special shock device with further recording, decoding and analyzing acoustic response, matching it with the conditions of growth and general morphology of a tree, i.e. its size, crown form and length, trunk habit, etc. As such a work does not have any analogues and, consequently, there is no 'acoustic standard' of a sounding tree for the moment, the data obtained were analyzed in accordance with general provisions of acoustic diagnostics. Thus, the basic acoustic parameters accepted are vibrating activity, power consumption of spectral characteristics, amount of resonance peaks, vibration absorbing and damping, frequency distribution of a spectrum.*

Key words: *spruce tree, sounding wood, shock device, acoustic response, impedance, vibration absorbing, frequency, histogram*

SAŽETAK • *Na početku trećeg tisućljeća znanstvenici i stručnjaci iz mnogih zemalja još pokušavaju odgonetnuti „tajnu Stradivarija" koristeći se naprednim tehnološkim rješenjima iz područja fizike, matematike, kemije, biologije i drugih znanosti. Nepobitno je dokazano da je jedna od osnovnih tajni velikog majstora violina umijeće prepoznavanja odgovarajućeg materijala za izradu violina. Nažalost, Stradivari, Amati, Guarneri i drugi poznati predstavnici stare talijanske škole nisu ostavili nikakve naputke o izboru najboljeg materijala. No povijesna je činjenica da su oni drvo za gudačku ploču, glavni zvučni dio violine, odabirali kuckanjem po površini drva i dizajnirali instrument izabirući materijal prema zvučnosti, a obilježja dobre zvučnosti bila su poznata samo njima.*

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Suvremenim znanstvenim rječnikom može se reći da su ti veliki majstori imali profesionalnu vještinu dekodiranja akustičnog odgovora izvornog materijala koji je unaprijed određivao kvalitetu proizvoda. Na temelju rezultata provedenih istraživanja ne može se tvrditi da su otkrivene sve tajne tog umijeća. Za tu bi svrhu bilo potrebno provesti obuhvatna i kompleksna istraživanja, i temeljna i primijenjena, integrirajući napore znanstvenika i stručnjaka s različitih područja: fizičara, akustičara, drvnih tehnologa, šumara i, što je najvažnije, priznatih majstora iz područja proizvodnje odgovarajućih glazbenih instrumenata. U radu su prikazani prvi rezultati primjene tehnike mjerenja koja se temelji na pobuđivanju vibracija debla posebnim uređajem, uz snimanje, dekodiranje i analizu akustičnog odgovora te uzimanjem u obzir uvjeta rasta i općih morfoloških obilježja stabla, odnosno njegove veličine, oblika krošnje i dužine, oblika debla i sl. S obzirom na to da ne postoje analogna istraživanja, odnosno da još ne postoji „akustični standard" za zvučnost drva, dobiveni su podaci analizirani u skladu s općim odredbama akustične dijagnostike. Prihvaćeni osnovni akustični parametri jesu vibracije, potrošnja energije i spektralna svojstva zvuka, broj rezonantnih pikova, apsorpcija i prigušenje vibracija te raspodjela frekvencija spektra.

Ključne riječi: *drvo smreke, zvučnost drva, pobudni uređaj, akustični odziv, impedancija, apsorpcija vibracija, frekvencije, histogram*

1 INTRODUCTION
1. UVOD

It is well-known that existing techniques for quality diagnostics of so-called sounding wood for manufacturing string-plates, the main sounding part of a violin, are based on laboratory study of timber assortments.

Meanwhile, sharp practical necessity for the development of nondestructive ways of 'sounding' trees selection long before their felling through dendro-acoustic diagnostics has long been overdue. This would offer real opportunities not only for rational target use of the available stocks of this highly valuable natural raw material, but, the main thing, preserve the gene resources of the sounding spruce trees and some other species by revealing unique specimens and their reproducing on specialized plantations.

For achieving this goal, the '*shock-acoustic*' technique, which is a relatively new one for this field but widely used in others, can play a significant role.

As far as wood represents a product of biological development and essentially differs from other materials, e.g., it displays anisotropy of physical-mechanical and acoustic properties, complex biophysical research of trees directly in forest environment is necessary for working out the technique given.

2 THEORETICAL BACKGROUND
2. TEORIJSKA OSNOVA

The speed of acoustic wave distribution and physical-mechanical characteristics of any material are in close correlation, which is proved by the results of numerous research works; however, it is necessary to bear in mind that these studies are basically devoted to isotropic bodies.

One of the widely-used methods here is ultrasonic pulse technique implemented to control the properties of metal, concrete and other materials (Gladylin, 2000; Aleshchenko *et al*., 2001; Yermolov and Lunger, 2004). It is based on the measurement of a delay of the pulse radiated and received after passing the material layer. The characteristic features of the method are operational efficiency and simplicity.

Wood, as a product of biological origin, represents anisotropic matter having unequal parameters of physical-mechanical properties in different directions relative to the fibers, not excluding the acoustic ones. In comparison with an isotropic body, this circumstance essentially complicates carrying out the acoustic measurements of this material with standard methods and limits their practical application.

Even more obstacles arise when introducing non-destructive diagnostics of acoustic quality of standing wood, e.g., when selecting sounding wood for manufacturing a string-plate, the main sounding part of many musical instruments.

First of all, in this case there is no opportunity to carry out longitudinal measurements of wood without cutting a tree and manufacturing standard samples, e.g., bars with dimensions of 200x200x300 mm according to National State Standard GOST 16483.21 'Methods of sampling for defining physical-mechanical properties after technological processing', the national standard of Russia.

Secondly, the processes of longitudinal or cross-section fluctuations in wood are much more complex than in isotropic bodies. Therefore, the theory of elastic waves for the description of acoustic properties of wood is applicable in the limited number of cases, predominantly for the samples in the form of long rods. In other words, to exclude scale factor, the phenomena of interference and dispersion (in this case, in conditions of ultrasonic wave propagation in a rod), it is necessary to observe the following ratio (Goldsteins, 1975; Fedyukov and Makaryeva, 1993):

$$L \geq 1.5l, \qquad a\ \lambda = C / f \tag{1}$$

where

L – linear dimensions of the sample, m;

λ – wave length, m;

C – speed of ultrasonic wave propagation in wood, m/s;

f – signal working frequency, Hz.

As the correlation of the tree diameter and its height does not meet these requirements, the application of ultrasonic pulse methods for cross-section (diagonal) measurements of trunk wood may cause significant errors.

For nondestructive diagnostics of resonance properties of standing trees, two basic study lines are more realistic and preferable: visual-biomorphological and dendro-acoustic.

The former, *visual-biomorphological line,* is based on the correlation of wood quality and hereditary genetic features of a given tree species, habitat conditions (including geographical region) and silvicultural-forest inventory parameters of forest stands. Together, they form corresponding properties of wood, which can be ascertained according to external biomorphological attributes of a tree: the crown form and length, the trunk habit, the bark color and structure, cones and seed scales, color and form, etc.

However, it is important to bear in mind that such an indirect method of diagnostics is not deprived of the elements of subjectivity; therefore, it cannot always provide high accuracy of forecasting of wood technical quality.

The latter line, *dendro-acoustic one,* can include several techniques. For example, the *trial-acoustic* method is more objective in comparison with the visual-biomorphological one. It is based on taking a wood cross-section radial core-sample about 4 mm in diameter from a tree trunk and studying its physical-mechanical properties, including the resonance ones (Fedyukov and Makaryeva, 1995; Bucur, 1983).

Not belittling the accomplishments of this way of revealing resonance properties of standing wood, it is expedient to remember an ancient way of quality wood selection in a forest by tapping trees. Using modern scientific terminology, it is possible to consider a vibroimpulsive method of express diagnostics of body wood technical quality under the acoustic response.

The purpose of the present work is to reveal the opportunity of implementation of a vibroimpulsive method for nondestructive estimation of acoustic quality of standing wood as potential resonance raw material.

3 MATERIAL AND METHODS
3. MATERIJAL I METODE

To perform research in forest environment, the devices manufactured by well-known firms "Robotron" (Germany) and "Bruel & Kjaer" (Denmark) were used: 00017- and 00023- type pulse sound meters, 02060-type recorder of a signal level, 7004-type measuring tape recorder, 3348-type real time spectrum analyzer, 4367-type accelerometer, 8200-type sensor.

A special hammer was designed to make a tree vibrate, and a batch production accumulator was used as an energy source.

Before analyzing the results obtained, let us consider the key diagrams of the devices and the acoustic parameters studied.

The shock device is a hammer, the head of which bears a built-in 8200-type force sensor and 4367-type accelerometer. The bar handle of the hammer is freely held by the fixing spindle, which makes it possible to attach the shock device to a tree without any efforts (Fig. 1).

The hammer creates mechanical impact on a tree after being lowered from a certain height due to realization of potential energy (Fig. 2). The force with which the hammer strikes the tree is measured by the 8200-type force sensor, and the acoustic signal of trunk excitation is registered by 4367-type accelerometer.

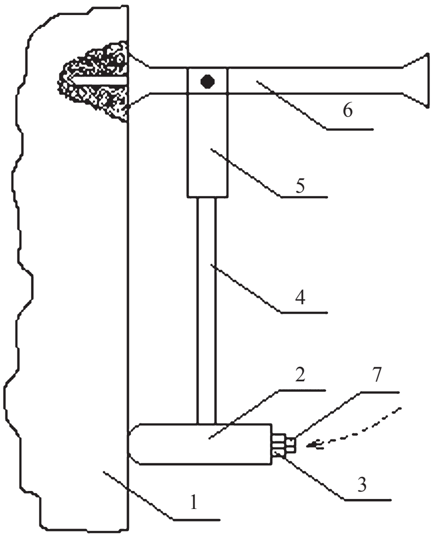

Figure 1 Shock device key diagram (1 – wood, 2 – hammer head, 3 – force sensor, 4 – bar handle, 5 – axle, 6 – fixing spindle, 7 – accelerometer)
Slika 1. Shema pobudnog uređaja (1 – drvo, 2 – glava čekića, 3 – senzor sile, 4 – ručka, 5 – osovina, 6 – učvršćenje vretena, 7 – akcelerometar)

To define the acoustic characteristics of a standing tree, specifically, point impedance, it is necessary to move over from the level of signals expressed in dB for force *F* and speed *C* to absolute values of these parameters. With that in mind, calibration of the hammer by a standard technique with impactor was carried out in laboratory conditions for force *F*. As a result, corresponding calibrating curve dependences of force *F*, Hz on the size of sound meter readings values *A*, dB were received.

To translate the values of speed *C*, dB, into absolute values, m/s, reference values of GOST 12.1.012-78. 'Vibration' were used.

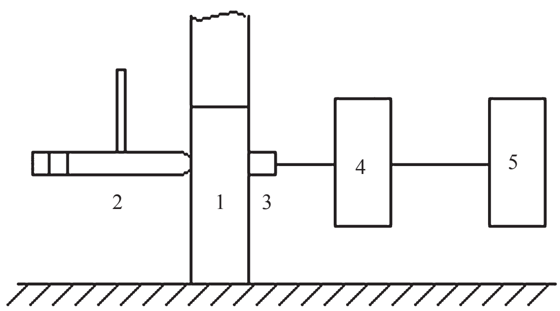

Figure 2 Key diagram of vibroacoustic response taking and recording (1 – tree trunk, 2 – hammer, 3 – 4367-type accelerometer, 4 – 00023-type sound meter, 5 – 02060-type recorder of a signal level (or 7004-type measuring tape recorder))
Slika 2. Dijagram snimanja vibroakustičnog odgovora (1 – trupac, 2 – čekić, 3 – akcelerometar, tip 4367, 4 – zvukomjer, tip 00023, 5 – snimač razine signala, tip 02060 ili kasetofon, tip 7004)

The time of contact of the hammer and the tree studied was defined in laboratory environment on the samples of room-dry wood t_1 and at the humidity close to its newly felled condition t_2. The time was defined according to the width of a signal duration at the amplitude level of 0.7. The following values were received: $t_1 = 0.53$ m/s; $t_2 = 0.85$ m/s.

Vibroacoustic response. Taking and recording the vibroacoustic response of tree *A* (dB) representing its reaction to impact disturbance was made in 1/3 octave band according to the following key diagram (Fig. 2).

The impact was made in the debarked point at breast height on one side of a trunk, and the accelerometer-piezoelectric detector connected with sound meter was fixed on the opposite side. Recording of the acoustic response was performed with the help of the signal level recorder or measuring tape recorder through corresponding circuit connection to the sound meter depending on the goal.

The signal level recorder was used to record the changes of the response on the tape with the impacts at certain time. The speed of recording was 30 mm/s.

The measuring tape recorder recorded a signal from piezoelectric detector with the view of spectral analysis of vibroacoustic response in real time. It was impossible to register the acoustic response through the tape recorder directly due to loud noise similar to the one from harvesting machinery and other sources.

The signal from the tape recorder was further recorded on a ring of magnetic tape and analyzed with a spectrometer in real time. At repeated recurrence of the signal studied, the maximum spectrum was represented on the screen of a spectrometer. The frequency and amplitude of resonance peaks were defined with the help of a control line in the digital image.

The analysis of vibroacoustic spectra of standing trees was made in the ranges of 1 kHz; 2 kHz; 10 kHz.

Note that the relative size of signal vibration acceleration level registered is the key parameter of vibroacoustic response measurement:

$$A(dB) = 20 \cdot \log \frac{a_{meas}}{a_0} \tag{2}$$

where

a_{meas} – acceleration measured, m/s^2;

a_0 – threshold value of acceleration equal to 10^{-3} m/s^2.

Sample data *A* (dB) for a certain tree depending on the frequency of 1/3 octave band are given in Tab. 2.

Vibroacoustic absorption. The work was carried out according to the conventional vibroacoustic absorption measurement technique and differed from the research of acoustic response in the measuring system circuit (Fig. 3).

The level of signals from the hammer side and the opposite side of a tree were registered simultaneously. Conventional absorption ΔB (dB) was defined as difference between the values of initial signal B^1 (dB) and final signal B^2 (dB):

$$\Delta \hat{A} = B^1 - B^2 \tag{3}$$

Dividing the value received with the value of a tree diameter, m, conventional vibroacoustic absorption per unit length was estimated, i.e. ΔB, *dB*/m.

'Point impedance' is known to be an integral value defined as

$$Z = \frac{F}{C} \tag{4}$$

Table 1 Sample tree characteristics according to the results of measurement of standing and felled trees
Tablica 1. Obilježja uzoraka stabala prema rezultatima mjerenja dubećih i posječenih stabala

Tree index number *Broj i oznaka stabla*	**Height** *Visina* m	**Breast height diameter** *Promjer na prsnoj visini*	**Diameter at height 0.2 *H*** *Promjer na visini 0,2 H*	**Diameter at height 0.5 *H*** *Promjer na visini 0,5 H*	**Diameter at height 0.7 *H*** *Promjer na visini 0,7 H*	**Height to the first branch alive** *Visina do prve žive grane* m	**Alive crown length, % of the total trunk length** *Duljina žive krošnje, postotak ukupne duljine debla*
A1	22.8	28	25	19	12	7.9	63
A2	24.8	41	36	24	14	8.9	64
A4	23.0	31	28	22	14	9.0	61
A5	23.5	32	27	22	16	9.1	61
A9	23.53	32	28	22	14	8.4	64
D1	28.0	39	35	27	20	8.4	70
D3	26.0	36	33	27	20	10.0	61
D7	25.4	36	33	28	20	7.6	70
D9	26.2	34	31	24	20	10.3	61
D14	30.0	42	38	31	15	5.9	80
D17	26.0	33	29	20	17	7.4	71
D18	25.7	33	29	23	13	8.2	68
D19	25.6	31	26	22	14	12.5	51
B1	34.0	58	51	41	36	6.8	80
B2	26.8	40	34	26	21	9.4	64
B3	33.6	50	46	37	32	7.2	76
B6	28.9	43	37	32	23	19.4	67
B8	26.0	34	27	21	14	9.5	63
B10	28.0	33	29	23	18	8.5	69

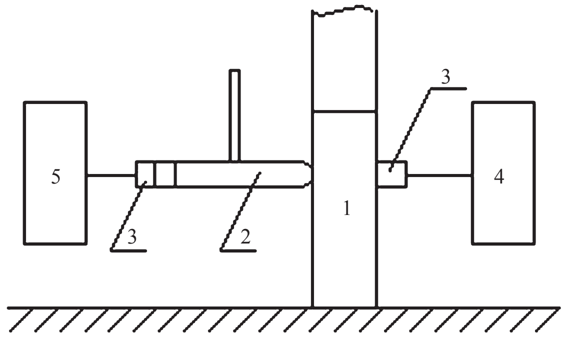

Figure 3 Key diagram of vibroabsorbtion measurement (1 – tree trunk, 2 – hammer, 3 – accelerometer, 4 – 00023-type sound meter, 5 – 00017-type sound meter)
Slika 3. Dijagram mjerenja apsorpcije vibracija (1 – deblo, 2 – čekić, 3 – akcelerometar, 4 – zvukomjer, tip 00023, 5 – zvukomjer, tip 00017)

where
Z – acoustic impedance, H·s/m;
F – effective force, H;
C – object speed created by this force, m/s.

Impedance constituents were measured according to the diagram (Fig. 4).

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

The method of vibroacoustic diagnostics of wood quality was tested on 19 spruce trees at the age of 200-250 years growing in northern parts of the Kirov region on the territory of Murashinsky timber enterprise. The diameter of tree trunks at breath height was 0.28-0.58 m, and their height was 22.8-32.0 m.

Test trees differed by biomorphological attributes, e.g, branching type and crown form (length), habit (diameter change along the trunk), bark structure, cones and, especially, their seed scales size. The geographical region under consideration is a zone of introgressive hybridization of the species, therefore aboriginal clones of Norway spruce *(Picea abies)* and Siberian spruce *(Picea obovata)* in their pure form can be found rather seldom there. More often, their intermediate hybrid forms can be come across.

The trial areas, conditionally labeled A, D and B, were laid out in bilberry scrub forests differing from each other in productivity:

A – III yield class, rather low relief with attributes of humidifying (rather bad conditions);

D – II yield class, upland (average conditions);

B – I yield class, smooth hill slope (the best conditions).

The basic characteristics of sample trees on trial areas A, D and B are given in Tab. 1.

As shown in Tab.1, sample trees have high crown and, for this species, a rather big length of trunk without branches. Such a choice of trees is made purposefully in order to get a maximum yield of sonorous assortments used for manufacturing musical instruments, in particular, kantele, after calibration and laboratory testing by standard methods.

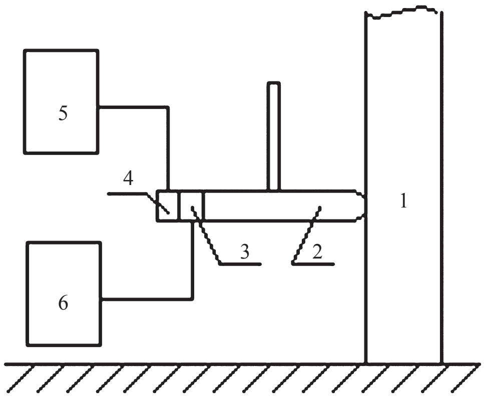

Figure 4 Impedance measurement key diagram (1 – tree trunk; 2 – hammer; 3 – 8200-type force sensor; 4 – 4367-type accelerometer; 5 – 00017-type sound meter; 6 – 0023-type sound meter)
Slika 4. Dijagram mjerenja impedancije (1 – deblo, 2 – čekić, 3 – senzor sile, tip 8200, 4 – akcelerometar, tip 4367, 5 – zvukomjer, tip 00017, 6 – zvukomjer, tip 0023)

The following results of vibroacoustic diagnostics of the trees on the specified trial plots were received.

According to *vibroacoustic response* in 1/3 octave bands, judging from the average value, the trees from trial plots A (5 pieces), D (9 pieces) and B (6 pieces) appeared to be the best ones.

The advantage of group A trees consisted in the increase in the level of the response in low-frequency area and displacement of a maximum towards high frequencies. However, being compared individually in view of this attribute, the trees from sample plots other than plot A appeared to stand out as well; those were samples A2, D19, and B10 (Tab. 2).

For better perception and comparison of the data obtained, the frequency dependence of the response value is presented in the form of histogram, passing from relative units to absolute ones. According to the form of the histogram, the vibroacoustic response of the trees studied can be divided into 4 types having the following attributes:

T_1 – presence of resonance peaks in the low frequency region comparable in amplitude with the main peak in the range of 600+800 Hz; it includes trees A2, A5, D18 and B10;

T_2 – high frequency peak prevails in the frequency range of 2000+3000 Hz, low frequency peak is not expressed; trees D19 and B2;

T_3 – additional resonance is absent in both low frequency and high frequency regions; trees D2, D3, D6, D14, B1 and B3;

T_4 – three resonance peaks comparable in amplitude are present; trees A1, A4, B2 and B10.

On the example of typical samples A2, D19, B1 and B10 strongly differing in habit and other biomorphological parameters, histograms of the acoustic response of the above specified types are given below (Fig. 5).

Table 2 Values of acoustic response of the trees (*A*, dB) at various frequencies in 1/3 octave filters
Tablica 2. Vrijednosti akustičnog odgovora stabala (*A*, dB) pri različitim frekvencijama 1/3 oktave

Frequency, Hz *Frekvencija, Hz*	**Mean values of acoustic response of the samples** *Srednje vrijednosti akustičnog odgovora uzoraka*			**Best trees for acoustic response** *Akustični odgovor najboljih uzoraka*		
	A	D	B	A2	D19	B10
31.5	49.8	49.7	42.2	55.5	57.5	58.0
40	53.1	50.6	42.0	55.0	58.5	54.0
50	54.6	50.6	45.4	53.5	60.0	55.0
63	53.8	49.4	44.0	53.0	59.0	49.5
80	54.1	50.3	44.3	55.0	57.0	48.0
100	57.0	54.3	44.1	57.0	55.0	49.0
125	58.0	55.7	49.4	56.0	50.5	54.0
160	57.8	58.2	51.0	55.0	59.0	62.0
200	55.6	54.6	47.1	50.0	55.0	58.0
250	56.4	53.8	51.0	58.0	56.0	58.5
315	58.9	60.6	56.4	60.0	63.5	60.0
400	62.7	62.9	62.3	62.0	66.0	62.0
500	71.8	68.8	73.2	75.0	75.0	70.0
630	77.6	78.4	77.2	80.0	74.0	76.0
800	84.4	82.8	80.9	84.0	81.5	87.0
1000	79.7	77.7	76.8	82.5	76.0	78.0
1050	73.4	77.9	73.4	74.5	77.0	72.0
1600	76.9	77.0	73.2	72.0	83.0	72.0
2000	78.8	77.1	75.0	79.5	83.5	80.0
2500	77.7	74.3	72.3	72.0	85.5	77.0
3150	79.2	76.0	76.1	82.0	84.5	78.5
4000	75.3	73.6	72.9	81.5	65.0	74.0
5000	68.4	75.6	64.5	68.5	69.5	67.0
6300	62.9	65.3	62.6	66.0	67.5	61.7
8000	62.7	59.2	58.1	62.5	67.5	62.0
Mean value *Srednja vrijednost*	65.6	64.6	60.6	66.0	67.5	64.9

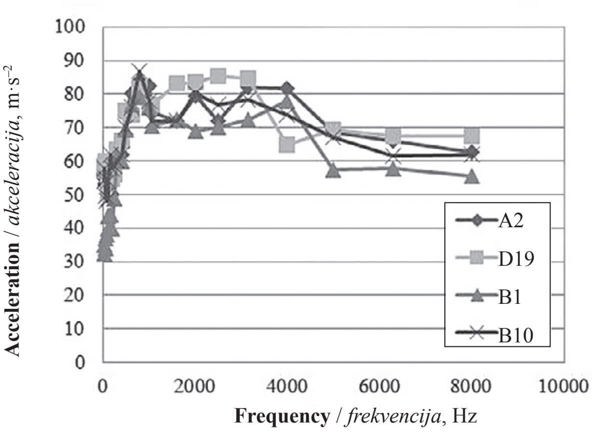

Figure 5 Acoustic response histograms: 1 – A2 tree, 2 – D19 tree, 3 – B1 tree; 4 – B10 tree
Slika 5. Histogrami akustičnih odgovora: 1 – stablo A2, 2 – stablo D19, 3 – stablo B1, 4 – stablo B10

As one type histogram reflects the trees having different exterior, it is possible to conclude that there is no regular correlation between vibroacoustic response of a tree and its biomorphology. Most likely, greater influence is exercised by other parameters, e.g., macro- or microstructure of wood, possible defects of trunk wood, etc. The role of genetic factors cannot be excluded either.

The analysis of vibroacoustic parameters energy response was carried out using the spectrogram in real time by defining the ratio of ΔS spectrum area square in Δf band to S_o total area of all the spectrum. Notably, in the total range of 0-10 kHz frequencies, ΔS areas are considered in Δf 0-2, 2-4, 4-6 and more than 6 kHz ranges (Tab. 2).

According to Tab. 3, the trees have maximum value $\Delta S/S_0$ in the low frequency range more often, particularly, up to 2 kHz. Meanwhile, several samples have the maximum of this factor displaced towards higher frequencies, which is specific for trees A4, D1, D7, B2, B8 and B10.

The number of resonance peaks in the same frequency ranges is given in Tab. 4. It is obvious that D19 tree is the best in 'resonance' saturation, and A1 tree is the worst one.

Vibration absorption is a significant characteristic of wood acoustic properties. Research has shown that, in the range of 20-20000 Hz, the vibration absorption changes from 50.4 up to 98.3 dB/m. One more prominent feature was revealed: the dispersion of separate trees values within the limits of a trial plot exceeded the dispersion of mean values received in total on these plots.

The common consistence pattern for all the trees includes the presence of minimum vibration absorption

Table 3 Spectrum energy characteristics according to frequency ranges
Tablica 3. Obilježja energijskog spektra prema frekvencijskim rasponima

Tree index number *Oznaka uzorka stabla*	**$\Delta S/S_0$ values (%) in a frequency range (kHz)** *$\Delta S/S_0$ vrijednosti (%) u frekvencijskom rasponu (kHz)*			
	0-2	2-4	4-6	more than 6
A1	61	24	11	4
A2	33	24	15	28
A4	13	27	9	51
A5	45	33	7	15
D1	32	22	22	24
D3	44	28	17	11
D7	30	20	19	31
D14	40	25	14	21
D17	38	29	13	20
D18	44	24	19	13
D19	31	25	15	29
B1	34	29	15	22
B2	25	24	19	37
B6	36	25	21	19
B8	29	21	20	30
B10	27	28	17	28

Table 4 Distribution of the number of resonance peaks in frequency range 0÷10 kHz
Tablica 4. Raspodjela broja rezonantnih maksimuma u frekvencijskom području od 0 do 10 kHz

Tree index number *Oznaka uzorka stabla*	**Number of peaks (pcs.) in frequency ranges (kHz)** *Broj maksimuma u frekvencijskom rasponu (kHz)*				**Total number of peaks, pcs.** *Ukupan broj rezonantnih maksimuma*
	0-2	2-4	4-6	more 6	
A1	5	5	3	0	13
A2	6	4	5	6	21
A4	13	9	10	17	49
A5	8	5	2	1	16
D1	11	10	13	20	54
D3	9	6	7	12	31
D7	6	12	9	14	41
D14	10	10	13	16	49
D17	9	12	11	17	48
D18	9	11	10	16	46
D19	10	10	9	30	59
B1	8	8	5	11	32
B2	10	9	6	20	45
B6	15	12	8	20	55
B8	6	9	10	20	45
B10	7	10	10	14	41

in the area of basic resonance at frequencies of 600-1000 Hz.

It is necessary to note that vibration absorption does not practically correlate with other acoustic parameters of a tree. For example, the best in relation to spectrum energy response D19 tree has no significant advantages against the worst A1 one. If compared with respect to vibration absorption, they yield 95.3 and 92.8 dB/m accordingly.

The acoustic impedance was assessed within Z_1 frequency range of 20-20000 Hz, and within Z_2 frequency band Δf=800, 1000 Hz as a parameter of ideal speed of impact power consumption. The results of the measurements are shown in Tab.5.

Tab. 5 shows, that there is no significant difference between the trees as far as acoustic impedance is concerned. The only exception is D19 tree, the impedance of which exceeds the average value of other trees in frequency band Δf 800, 1000 Hz almost 3 times.

5 CONCLUSIONS
5. ZAKLJUČAK

At the turn of the third millennium, scientists and experts of many countries are still trying to puzzle out ‘the mystery of Stradivari’, using for this purpose advanced technological solutions in the fields of physics, mathematics, chemistry, biology, etc.

Table 5 Impedance values in different frequency ranges
Tablica 5. Vrijednosti impedancije u različitim frekvencijskim rasponima

Tree index number *Oznaka uzorka stabla*	**Impedance value, 10^4 H·s/m** *Vrijednost impedancije, 10^4 H·s/m*	
	Z_1	Z_2
A1	1.96	1.12
A2	1.86	1.24
A4	1.80	0.82
A5	1.52	0.80
A9	1.81	0.91
D1	2.34	-
D3	1.17	1.11
D7	2.04	0.70
D9	1.86	0.99
D14	2.04	0.94
D17	2.06	1.06
D18	1.92	0.94
D19	1.86	3.08
B1	1.80	0.53
B2	1.70	1.22
B3	1.50	0.96
B6	1.60	0.59
B8	1.70	0.53
B10	1.70	-

It has been undoubtedly proved that one of the basic secrets of the great master's violin sounding is in the recognition of the proper material. Unfortunately, Stradivari, Amati, Guarneri and other great representatives of the Old Italian school did not leave any hints, but it has been recorded that they selected wood for the string-plate, the main sounding part of a violin, by tapping, and they designed an instrument judging from the 'sonority' factors known to them only. Using modern scientific terms, it is possible to ascertain that it was the professional skill of the master to decode the percussion-acoustic response of the source material that predetermined the quality of the product.

The results of the work done cannot claim to disclose any secrets in the field. For this purpose, significant complex research is necessary, both fundamental and applied, integrating the efforts of scientists and experts in different areas: physicists, acousticians, wood scientists, foresters and, the main thing, the recognized masters in the sphere of manufacturing corresponding musical instruments.

Meanwhile, we can limit ourselves to the following basic conclusions which, to a certain extent, can be an incentive for further shock-acoustic studies of standing spruce trees:

1. Trees have different vibroacoustic parameters even within the limits of one species and in similar environments;
2. However, not all vibroacoustic parameters represent practical interest during express-diagnostics and nondestructive selection of standing resonance raw material;
3. Amplitude-frequency analysis of vibroacoustic response in 1/3 octave band gives maximal acoustic information on a tree;
4. In this respect, the presence of a resonance peak in the frequency range of $f \geq 2500$ Hz determines wood acoustic characteristics;
5. It is possible to assess the quality of wood as potential resonance raw material by the form of the response spectral characteristics envelope in real time with sharply expressed basic resonance and presence of resonances in frequency band of $f > 4$ kHz;
6. There are real physical-theoretical preconditions and technical opportunities for creating a special compact device for express-diagnostics of acoustic quality and nondestructive selection of standing resonance raw material through the 'vibration shock' method.

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A Preliminary Characterization of Eco-Innovators and Eco-Designers in Slovenia

Preliminarno istraživanje obilježja ekoinovacija i ekodizajna u Sloveniji

Preliminary paper • Prethodno priopćenje
Received – prispjelo: 7. 12. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*079*
doi:10.5552/drind.2016.1546

ABSTRACT • *Eco-innovation is crucial to Europe's economic competitiveness; environment-friendly technologies have a positive impact on businesses and contribute to job creation. A survey of perceptions and attitudes about eco-innovation and eco-design among 712 Slovenian enterprises was conducted. The survey included micro, small and medium enterprises, and large companies. Analysis of the survey revealed that eco-design in Slovenia is underexploited. Only approximately 50 % of the 657 respondents have established an innovative environment for sustainable development or support for eco-innovation processes. Based on the survey results, it was concluded that further development and promotion will require comprehensive policies at the local and national levels. Specifically, policy solutions should advocate combining eco-innovation and adopting a life-cycle design approach. These policies could result in the development of successful innovations at a breakthrough level. Eco-innovation and eco-design present Slovenian enterprises with the opportunity to create new markets where they could dominate and prosper. Furthermore, Slovenia could become an important contributor to the European Union goal of becoming a smart, sustainable, and inclusive economy by fully satisfying the objectives of four "Europe 2020" Flagship initiatives, while simultaneously contributing to reducing climate change.*

Key words: *eco-design, eco-innovations, opinion, market potential, analysis, Slovenia*

SAŽETAK • *Ekoinovacije imaju ključno značenje za ekonomsku konkurentnost Europe; okolišno prihvatljive tehnologije pozitivno utječu na poslovanje poduzeća i pridonose stvaranju novih radnih mjesta. Istraživanje percepcije i stajališta o ekoinovacijama i ekodizajnu provedena su u 712 slovenskih poduzeća. Istraživanjem su obuhvaćena mikropoduzeća, mala i srednja poduzeća te velike tvrtke. Analiza rezultata ankete pokazala je da je ekodizajn u Sloveniji nedovoljno iskorišten. Samo je oko 50 % od 657 anketiranih tvrki uspostavilo inovativno okruženje za održivi razvoj ili uvelo potpore za ekološke inovacijske procese. Na temelju rezultata istraživanja zaključeno je da daljnji razvoj i promocija ekoinovacija i ekodizajna zahtijevaju opsežne politike na lokalnoj i nacionalnoj razini. Naime, politička rješenja trebaju promicati kombinaciju ekoinovacija i usvajanje novog pristupa dizajnu uzimajući u obzir životni ciklus proizvoda. Takve politike mogu dovesti do razvoja uspješnih inovacija. Ekoinovacije i*

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ekodizajn za slovenska su poduzeća prilika za stvaranje novih tržišta na kojima bi mogli dominirati i napredovati. Nadalje, Slovenija bi mogla postati važan čimbenik u ostvarenju težnje Europske unije da postane pametno, održivo i inkluzivno gospodarstvo i da u potpunosti zadovolji ciljeve četiriju ključnih inicijativa strategije „Europa 2020", a da pritom istodobno pridonosi smanjenju klimatskih promjena.

Ključne riječi: *ekodizajn, ekoinovacije, mišljenje, tržišni potencijal, analiza, Slovenija*

1 INTRODUCTION
1. UVOD

Increased need for sustainable development has spurred many changes in the ways commercial activities are now organized. Numerous interventions - spanning over a product's entire life cycle stages from raw material extraction to the end consumption (Berkhout and Smith, 1999; Massard *et al*., 2014; Glavonjić and Oblak, 2012) - have been devised to reduce environmental impact of these activities so that a harmonious balance between economic development and environmental well-being can be achieved. Many of these interventions have resulted in new products, new processes, and new business systems- all aimed at reducing industrial footprint on the global environment. Collectively, these environmentally friendlier new products, new processes, and new business systems are labeled as eco-innovations (Klewitz and Hansen, 2014), and are considered crucial in global efforts to achieve dynamic sustainability in different aspects (Braungart *et al*., 2007; Baumgartner, 2011; Ojurović *et al*., 2013; Pujari, 2006; Oblak and Glavonjić, 2014).

Defining eco-innovation is not a trivial task, although several definitions have been proposed (Fussler and James, 1996; Charter and Clark, 2007; Oblak and Jošt, 2011; Kemp and Pearson, 2007; Berginc *et al*., 2011; Carrillo-Hermosilla *et al*., 2010). In general, these definitions emphasize that eco-innovations reduce the environmental impact caused by consumption and production activities, whether the main motivation for their development or deployment is environmental or not. The Organization for Economic Co-operation and Development (OECD) provided a more precise definition of eco-innovation by highlighting the two characteristics that distinguish it from typical innovation. First, it is an innovation that reflects the concept explicit emphasis on a reduction of environmental impact, whether such an effect is intended or not, and second, it is not limited to innovation in products, processes and organizational methods, but also includes innovation in social and institutional structures (OECD, 2009). Therefore, eco-innovation comprises all forms of innovation activities that result in or are directed at improved environmental protection. An eco-innovation has three aspects: a target, which is the main focus of the innovation; a mechanism, which is the method for changing the target; and impacts, which are the resulting effects on environmental conditions (OECD, 2009). Correspondingly, companies focusing on innovations with these aspects are considered eco-innovative companies. Integral to eco-innovation is the concept of eco-design. It is an approach to product design with special consideration for the environmental impacts of the product throughout its entire lifecycle. Eco-design developed as a response to growing concern and understanding of the ecological impact of production.

Previous research has predominantly focused on examining eco-innovations at the level of individual firms. For example, Pirc Barčić *et al.* (2011) examined innovation and innovativeness in the medium-low tech wood industry in the U.S. Additionally, Pirc Barčić and Motik (2013) identified the connection between the concepts of innovation and innovativeness of certain internal and external company factors. Others have examined consumer response to eco-innovations. For example, Rehfeld *et al*. (2007) found high prices remain the largest obstacle for consumers of environmental products. However, Toppinen et al. (2013) analyzed consumer perceptions of the environmental and social sustainability of wood products in the Finnish market and found out that consumers are more willing to pay more for environmentally and socially sustainable products. Green *et al*. (1994) empirically analyzed the characteristics of firms in the UK participating voluntarily in a public program that aimed at the promotion of environmental product and process innovations. Rennings *et al*. (2006) focused on the influence of different characteristics of the EU environmental management and auditing scheme (EMAS) on technical environmental innovations and concluded that a careful design of EMAS is important for environmental and performance facility.

Amidst this growing body of literature, general characterization of eco-innovative companies is not fully considered, particularly pertaining to countries that are not economically prominent, yet are environmentally progressive. Slovenia presents a great example of such a context. The country has a small share in global trade, has recently transitioned to a capitalistic society wherein innovation and private entrepreneurship is more prevalent, and is now part of European Union where environmental standards are very well established. The primary purpose of this paper is to map out general characterization of eco-innovation in Slovenia.

1.1 European eco-industries and eco-innovation
1.1. Europska ekoindustrija i ekoinovacije

All enterprises, including service enterprises, engaging in energy- and environment-related activities as their core source of income, are considered eco-industries (European Commission, 2013). The European Commission distinguishes amongst two broad categories of eco-industries. The first consists of small and innovative companies concerned with renewable energy, waste recycling, environmental auditing and consultancy; the second consists of more capital intensive enterprises providing goods and services in specific areas such as waste, wastewater, transport.

The eco-industry has grown to become one of Europe's biggest industrial sectors. Pollution management, which encompasses technologies and services in waste management, air pollution control, soil remediation, and recycling, along with resource management, which includes renewable energy plants and water supply, are currently the two most important sectors of eco-industry. The eco-industry contributes to economic growth, employment in the EU and focuses on policies promoting a cleaner environment. The sector covers approximately 2.5 % of the EU's Gross Domestic Product (GDP) and has an annual turnover of around EUR 550 million. Employment in eco-industries was estimated to be around 3.4 million people, which represents around 1 % of the total workforce (Eco-Innovation Action Plan, 2012).

Furthermore, annual growth in employment is trending upwards, most notably in the field of renewable energy and recycling (European Commission, 2014). Rademaekers *et al*. (2012) showed that improving resource efficiency leads to job creation. However, many of these new jobs will require retraining existing workers rather than create jobs for additional workers.

Europe controls a significant share of certain segments of the global eco-industry market: more than 70 % in the global market for solar power plants and automated materials separation. The global market for eco-industries was valued at roughly EUR 1.15 trillion per year in 2010. Furthermore, there is broad consensus that the global market could nearly double to EUR 2 trillion per year by 2020. The EU is also a leader in R&D in the area of synthetic biofuels and energy storage technologies (European Commission, 2011b). With more than 3 million employees in the eco-industry, and with the growing demand for environmentally-friendly products and services, Europe is well positioned to meet the environmental challenges of the future.

Given that green technologies have a favorable impact on companies and contribute to job creation, eco-innovation is vitally important to Europe's economic competitiveness. The implementation of eco-design within European industries would further contribute to the EU transition into a smart, sustainable, and inclusive economy, fully following the objectives of four Europe 2020 Flagship initiatives. Through research and development of new innovative products and services, in close transnational cooperation with academia, research institutes and industry, the EU industrial eco-design approach has the potential to address key action points of the EU's "Innovation Union" initiative. Furthermore, "A resource-efficient Europe" initiative (especially the Low-carbon economy 2050 roadmap, Roadmap to a Resource Efficient Europe, and Strategy for the sustainable competitiveness of the EU construction sector) could be addressed through the promotion of use of renewable materials. Widespread implementation of eco-design practices would also directly contribute to the realization of the "An industrial policy for the globalization era" initiative (European Commission, 2014), where the industrial competitiveness is the cornerstone of the EU 2020 Industrial policy ("Industry must be placed center stage if Europe is to remain a global economic leader"). European support of eco-innovations in the industry is clear, and directed; for example, in 2008, Europe's first public funding opportunity specifically addressing eco-innovations was announced (CIP-Eco innovation, 2013).

The EU recently developed the Eco-Innovation Scoreboard (Eco-IS), which assesses and rates the eco-innovation performance of an individual country compared with other EU member states and the EU as a whole. The index is based on 16 indicators, which are aggregated into five components: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, environmental outcomes, and socio-economic outcomes. These ratings indicate the overall performance of individual member states in different dimensions of eco-innovation compared to the EU average. The Eco-IS also presents the strengths and weaknesses of each member state. The Eco-IS complements other methods of measuring innovativeness and aims to promote a holistic view on economic, environmental and social performance (Eco-Innovation Observatory, 2014). The actions taken in Europe to support eco-innovation clearly demonstrate that eco-innovation as well as eco-design already plays critical roles in European efforts to achieve a sustainable and low carbon economy.

1.2 Slovenia and eco-innovation
1.2. Slovenija i ekoinovacije

Slovenia lacks a coherent policy framework to systematically encourage energy efficiency, resource efficiency, and system eco-innovations. In fact, no specific policy to support eco-innovations has been developed. However, eco-innovations are being (indirectly) supported by different measures adopted within various policies (innovation, environmental, economic). Support from these policies has resulted in increased investments by Slovenian enterprises into innovation.

In the last five years, 97 % of all Slovenian companies have introduced at least one innovation to reduce production costs, compared with 86 % overall in the EU (European Commission, 2011a). Slovenian companies have introduced an average of 3.6 material cost reduction innovations over the last five years. Among Slovenian companies that introduced an eco-innovation in their production processes in 2010 and 2011, 4 % found they reduced consumption of input materials by over 40 % (the same figure as in the EU overall). A reduction in consumption of 5 % to 19 % was recorded by 46 % of companies, while only 4 % of Slovenian companies that have successfully introduced an eco-innovation failed to reduce production costs (European Commission, 2011a).

Although Slovenian enterprises do invest in eco-innovations, Slovenia is not among the leaders in the development of green technologies. The Eco-IS ranks Slovenia's overall eco-innovation performance slightly above the average performance of all 27 EU Member States (see Fig. 1).

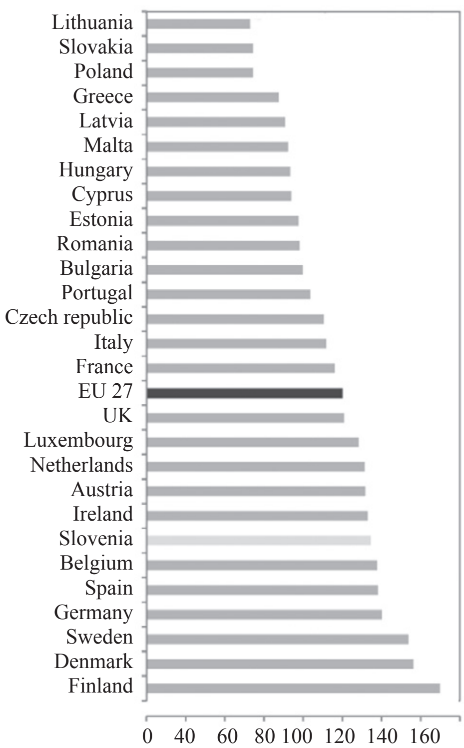

Figure 1 EU27 Eco-Innovation Scoreboard (Eco-IS) results for the 2011: composite index (Eco-Innovation Observatory, 2014)
Slika 1. Rezultati ekoinovacija EU27 (Eco-IS) za 2011. godinu: kompozitni indeks (Eco-innovation observatory, 2014.)

The Eco-IS Socio-economic outcomes indicator is interesting, especially as Slovenia leads EU in this category but underperforms in the eco-innovation inputs category (see Fig. 2). Underperformance in this area may stem from the fact that Slovenia has not identified eco-innovation as a priority horizontal approach to simultaneously improving national economic competitiveness and developing new products and services. As of 2013, 54 % of Slovenian SMEs have not been planning to begin developing green products or services (Flash Eurobarometer 381, 2013). Unfortunately, Eco-innovations in Slovenia are sporadic and limited to only several progressive and export-oriented companies (Eco-innovation observatory, 2014). For example, the goal of making buildings more energy efficient is a challenge for the construction industry, but also presents an opportunity for innovative concepts and for building and device technologies. One reason for Slovenia's moderate rating on the Eco-IS may be ineffective research and development, and poor collaboration between academic institutions and the industry. Furthermore, Slovenia lacks a coherent policy framework to systemically encourage eco-innovations and change production and consumption patterns. However, since investments in eco-innovation (technological and non-technological) are a requirement of developing green products, a well-managed approach in this area would be needed on the national level. To exploit the transition to a green economy, Slovenia must take a systematic approach to promoting development areas, where it has abundant skills, raw materials, technology, etc. After all, advancing eco-innovations is one of the key opportunities for Slovenia, as it is for other member states, to successfully contribute to the objectives of the EU 2020 strategy.

It is against this background that a survey was conducted to characterize eco-innovative companies in Sloveina, as shown below, and then outline the results of the survey.

2 MATHERIAL AND METHODS
2. MATERIJAL I METODE

The Ministry of Economic Development and Technology of the Republic of Slovenia conducted an anonymous web-based survey covering eco-design and eco-innovations for small and medium-sized enterprises and large companies. The questionnaire was devel-

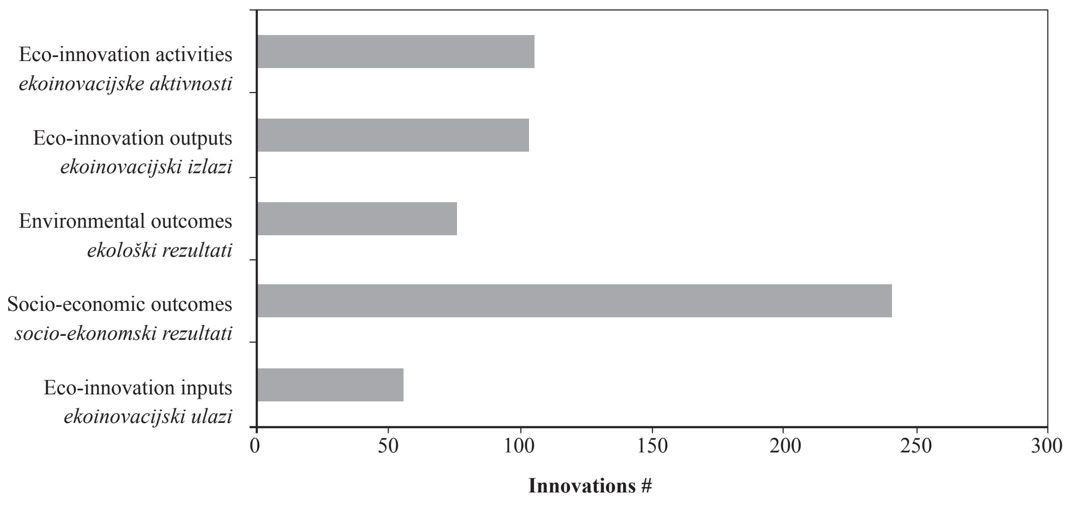

Figure 2 Components of the eco-innovation composite index for Slovenia, 2013 (EU average = 100) (Eco-Innovation Observatory, 2014)
Slika 2. Sastavnice ekoinovacijskoga kompozitnog indeksa za Sloveniju, 2013. (prosjek EU = 100) (Eco-innovation observatory, 2014.)

Table 1 The eco-innovation related questions used in the survey and frequency of responses to each question
Tablica 1. Pitanja iz ankete vezana za ekoinovacije i broj odgovora na svako od njih

	Question / *Pitanje*	**Frequency** *Broj odgovora*
1.	Does your company have a department/officer responsible for innovation? *Ima li vaša tvrtka odjel / službenika odgovornoga za inovacije?*	647
2.	Do you have a system in place to develop your human resources in relation to innovation? *Imate li sustav za razvoj ljudskih resursa vezanih za razvoj inovacija?*	622
3.	If you are active in the field of eco-innovations development, to which of the listed elements do your eco-innovation developments relate to: product, service, production process, supply chain, other? *Ako ste aktivni u području razvoja ekoinovacija, na koji se od navedenih elemenata odnosi razvoj vaših ekoinovacija: na proizvod, na usluge, na proces proizvodnje, na opskrbni lanac ili na nešto drugo?*	513
4.	If you are active in the field of eco-innovations, select the appropriate stage of development of your firm: - Already developed and in use - In design stage - In development stage *Ako ste aktivni u području ekoinovacija, odaberite odgovarajući stupanj razvoja ekoinovacija u vašoj tvrtki:* *- već su razvijene i primjenjuju se* *- u fazi su projektiranja* *- u razvojnoj su fazi.*	382 380 383
5.	To which of the listed areas do your eco-innovations relate to: Energy efficiency, Closed-loop recycling, Renewable resources, Natural materials, Water consumption, New materials, Other, Food and beverage processing? *Na koje se od navedenih područja odnose vaše ekoinovacije: na energetsku* učinkovitost, *na recikliranje, na obnovljive izvore, na prirodne materijale, na potrošnju vode, na nove materijale, na ostalo, na proizvodnju hrane i pića?*	335
6.	Are you applying the principles of eco-design by developing new product/service? *Primjenjujete li načela ekodizajna u razvoju novog proizvoda/usluge?*	344
7.	If you are applying the principles of eco-design, select the reasons why you decided to do so (multiple answers are possible). *Ako primjenujete načela ekodizajna, odaberite razloge zbog kojih ste se odlučili da to činite (moguće je više odgovora).*	312
8.	If you are not using the principles of eco-design, select the reasons why (multiple answers are possible). *Ako ne primjenjujete načela ekodizajna, odaberite razloge zašto se njima ne koristite (moguće je više odgovora).*	232

oped by a research group of experts of architecture, wood technology, managemnet, design, and construction. A web survey approach based on the procedures recommended by Dillman (2000) allowed for data collection over a broad geographic area and for low cost data entry. The questions relate to EU indicators of innovations, and innovation management systems. The survey was pre-tested to ensure clarity and practicability with several companies.

The web-based survey (Dillman, 2000; Evans and Mathur, 2005) was administered between 9th July 2012, to 31st August 2012. 712 invitations to participate were sent out. The Ministry of Economic Development and Technology provided hosting for the survey.

In addtion to demographic questions, 8 questions related to company attitudes and activities related to innovation management, eco-innovation and eco-design were asked in the survey (see Table 1).

2.1 Sample
2.1. Uzorak

The sample consisted of 712 production and service oriented Slovenian companies registered as members of the Chamber of Commerce and Industry in Slovenia. The manager responsible for production was the target person of the survey. In total 657 questionnaires were completed, resulting in a response rate of 92 %. Due to the unusually high response rate, nonresponse bias was not assessed. However, not all participants responded to all questions. In many cases this is because not all questions were applicable to all respondents. For example, only 513 respondents reported participating in eco-innovations; therefore, only these respondents completed questions specifically about the eco-innovations of their company.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Respondent demographics
3.1. Podaci o tvrtkama koje su odgovorile na anketu

The majority of respondents (60 %) were micro sized organisations (1-10 employes), but representatives of small (11-50 employees), medium (51-250 employees), and large (more than 250 employees) firms also responded (see Table 2). Respondents represented firms in the manufacturing sector (27 %), the professional, scientific and technical activities sector (25 %),

Table 2 Respondent company demographics
Tablica 2. Podaci o tvrtkama koje su odgovorile na anketu

Company size *Veličina tvrtke*	**Employees** *Broj zaposlenih*	**Annual revenue, EUR, millions** *Godišnji prihod, mil. EUR*	**Frequency** *Učestalost*	**Percent, %** *Udjel, %*
Micro / *mikro*	1-10	< 2	427	60
Small / *mala*	11-50	< 10	108	15
Medium / *srednja*	51-250	< 250	104	15
Large / *velika*	> 250	> 250	73	10
		Total / *Ukupno*	712	100

Table 3 Responsible for innovations
Tablica 3. Osobe odgovorne za inovacije

Gender / *Spol*	**Frequency** *Učestalost*	**% of responses (% of total)** *Postotak odgovora (od ukupnog broja)*
Female /*žene*	102	70 (33)
Male / *muškarci*	236	30 (14)
Total / *Ukupno*	338	100 (47)

Table 4 Age of the person responsible for innovation
Tablica 4. Starost osoba odgovornih za inovacije

Age *Starost*	**Frequency** *Učestalost*	**% of responses (% of total)** *Postotak odgovora (od ukupnog broja)*
21-40	145	43 (20)
41-60	174	52 (24)
Over 60 *stariji od 60*	18	5 (2)
Total /*Ukupno*	337	100 (46)

the information and communications sector (14 %), and the construction sector (11 %), and 23 % belonged to other sectors. Of those who shared gender and age information of the person responsible for innovation, the responsible persons were mostly male, and between the age of 21-60 (see Table 3 and Table 4). Furthermore, the responsible persons mostly held university degrees (39 %), a scientific masters degree or a doctorate (24 %). Furthermore, 12 % held higher education degree, 9 % college degree, 12 % high school degree, and 2 % vocational school degree. Most responding companies were from the Gorenjska and Osrednjaslovenska regions (see Fig. 3). This is unsurprising, as these regions are the Ljubljana metropolitan areas and have the highest populations and a dense concentration of businesses.

3.2 Innovation support
3.2. Potpora inovacijama

We wanted to know if there was a responsible innovation officer, developer or an innovator for innovations, so the question if the company has a department or officer responsible for innovation was answered by 90 % of respondents. Many companies have established an innovative environment for sustainable development or support for eco-innovation and innovation processes. Yet, the majority of companies (51 %) do not have an officer or department specifically responsible for innovation. Most of the companies, reporting structural innovation support, have a staff

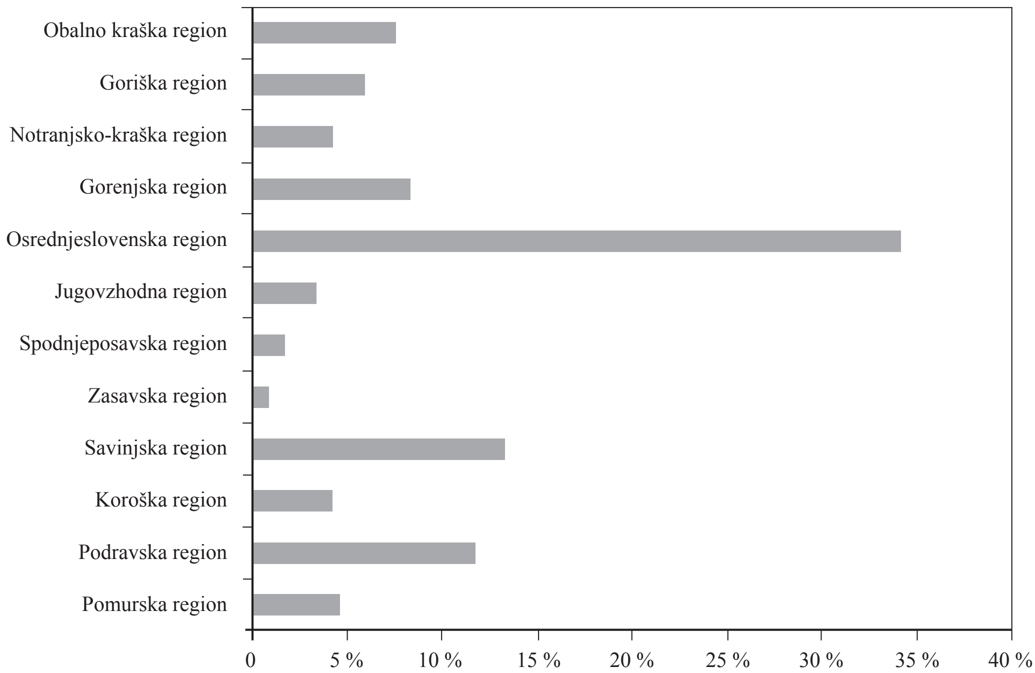

Figure 3 Respondents' company location (n = 344)
Slika 3. Lokacija tvrtki koje su odgovorile na anketu (n = 344)

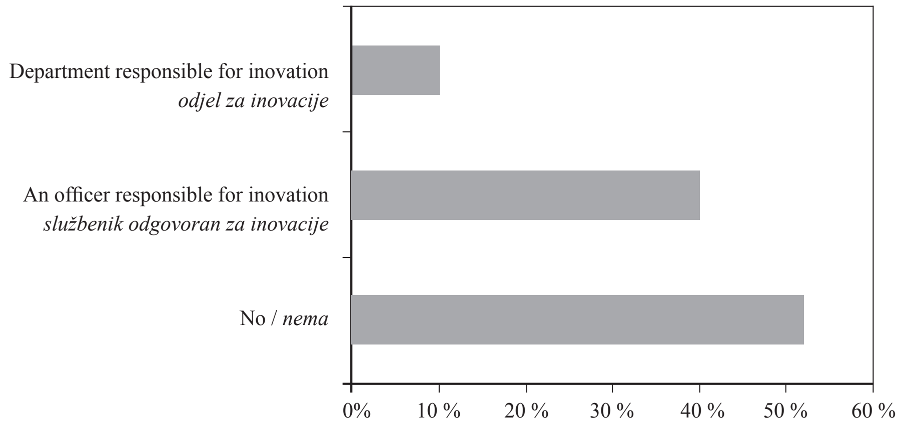

Figure 4 Responses to the question "Does your company have a department/officer responsible for innovation?" (n=647)
Slika 4. Odgovori na pitanje *Ima li vaša tvrtka odjel/službenika odgovornoga za inovacije?* (n = 647)

member responsible for innovation (39 %), while just over 10 % of the survey respondents have a department responsible for innovation (see Fig. 4).

3.3 Types of eco-innovation and the stage of their development
3.3. Vrste ekoinovacija i stupanj njihova razvoja

It was found that 72 % of total responses of the enterprises participating in the survey actively pursue eco-innovations. Furthermore, the majority of eco-innovations in development by Slovenian enterprises relate to products, services and production processes, while a smaller share relate to the supply chain. The vast majority of companies active in the area of eco-innovation focus on products (55 %) and services (48 %). The proportion of those focusing on production processes in the area of eco-innovation is relatively high (39 %), while the proportion focusing on eco-innovation in the supply chain is relatively low (14 %) (see Fig. 5).

The main arguments given for not investing in innovation were the company's small size, the newness of the company, a lack of financial resources for research and development of more sustainable products, no political control or support of sustainable companies, etc. Small companies cited their small size (some surveyed companies have only one employee), their lack of financial resources to dedicate to innovation, that innovation is not needed, or that consumer education about responsible product properties takes too much time. Medium sized enterprises showed great concern about regulations, a lack of political support and the expense of qualified human resources. These concerns demonstrate the need for outside support (from the government, from NGO's, from the EU or wherever, as long as you can support it).

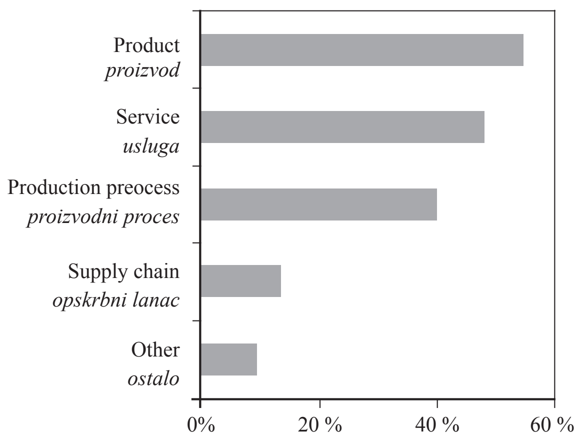

Figure 5 Answers to the question "If you are active in the field of eco-innovation development, to which of the listed elements do your eco-innovation developments relate to?" (n = 513)
Slika 5. Odgovori na pitanje Ako ste aktivni u razvoju ekoinovacija, na koju se od navedenih sastavnica odnosi razvoj vaših ekoinovacija? (n = 513)

As stated before, Slovenia has not identified eco-innovation as a priority means to simultaneously improve national economic competitiveness, while also developing new products and services. The results of the survey further emphasize the need for systematical aproach into investments of eco-innovations and eco-design on the national level, including support defined in national priorites and action plans. Eco-innovation development progress is similarly distributed between innovations that have already been developed and are in use, those in the design stage, and those in the development stage.

The survey results revealed that the majority of respondents focus on energy efficiency eco-innovations (59 %). Addtionally, many firms are active in eco-innovations related to closed-loop recycling and renewable resources (39 % each) (see Table 5). Although 513 respondents responded that they are active in the field of eco-innovation, only 335 provided categorical information about their innovations. Energy efficiency investments are not surprising given Europe's prioritization of this topic, and its clear path to cost reductions. The closed-loop recycling concept is a valuable eco-design concept that can help companies compete and achieve market success. 'Closed-loop recycling' reduces a company's dependence on raw materials, and probably many firms are innovating this area. In order to meet environmental challenges such as climate change, much attention has been paid to innovation as

Table 5 Companies that reported focusing their eco-innovations on specific categories (*n* = 335)
Tablica 5. Broj tvrtki koje su odgovorile da su njihove ekoinovacije vezane za određenu kategoriju (*n* = 335)

Eco-innovation category *Kategorija ekoinovacija*	**Frequency** Broj odgovora	**% of responses (% of total)** *Postotak odgovora (od ukupnog broja)*
Energy efficiency / *energetska učinkovitost*	197	59 (26)
Closed-loop recycling / *recikliranje*	129	39 (17)
Renewable resources / *obnovljivi izvori*	131	39 (17)
Natural materials / *prirodni materijali*	94	28 (12)
Water consumption / *potrošnja vode*	90	27 (12)
New materials / *novi materijali*	61	18 (8)
Other / *ostalo*	45	13 (6)
Food and beverage processing / *proizvodnja hrane i pića*	24	7 (3)
Total / *Ukupno*	771	

a way to use renewable resources. Additional information provided along with the 'Other category' included citing: agriculture, alternative processes, spatial planning, organic cleaners, reduction of CO_2, healthy living environments, waste separation, noise analyses, and paper consumption, amongst others, as their eco-innovation focus areas.

3.4 Enterprises applying the principles of eco-design
3.4. Poduzeća koja primjenjuju načela ekodizajna

Seventy-six percent of responding enterprises (262 out of 344) apply principles of eco-design. Figure 6 summarizes the most frequent reasons (and associated weights) for doing so. The most common supporting argument was to reduce the impact on the environment. Reducing the environmental impact of product may stem from legislative requirements, project and client requirements, corporate awareness for the importance of eco-design in environmental protection. Other frequent answers were an awareness for the marketing potential of environmentally friendly products, competitive advantage, reductions in cost, and improvements in corporate reputation.

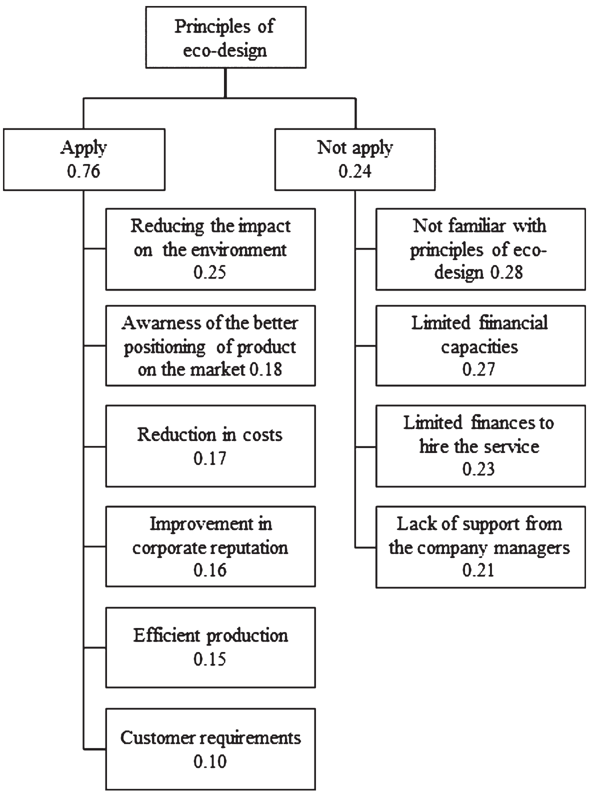

Figure 6 Diagram of weights of reasons for apllying and not applying the principles of eco-design
Slika 6. Dijagram pondera razloga za primjenu ili neprimjenu načela ekodizajna

Respondents who do not currently apply eco-design principles (82) most commonly stated they are not familiar with principles of eco-design and they are still studying this area, that they have limited financial capacities, eco-inovations are in the process of being introduced, that they are waiting for a response from the market in a sense of buying more sustainable products. They also mentioned that they have limited financial capacities, that it is too expensive and that they do not have sufficient skills at their disposal. Some potential solutions are training courses for managers and other employees, EU/National grants or hiring trained professionals working more closely with research organizations. There is also a lack of support from the company managers who do not recognize the market potentional of eco-innovative products and technologies.

4 CONCLUSIONS
4. ZAKLJUČAK

The survey of more than 650 executives revealed that less than half of responding Slovenian enterprises have established an innovative environment for sustainable development or support for eco-innovation and innovation processes. The majority of eco-innovations in development in Slovenian enterprises relate to products, services and production processes, while a smaller share relate to the supply chain. The results of the survey should be used in preparation of further more in-depth interviews for companies. They could be used in preparation of further documents, like action plans and strategies in the field of eco-innovations and eco-design. The decision makers in Slovenia should support enterprises in their eco-innovation activities and continue with implementation of the initiatives, action plans and strategies in research and development and innovation, with the focus on eco-innovation. The results may have implications for the wood sector firms as the emphasis on renewable resources becomes mainstream. Additionally, the government should support eco-innovation by public tender calls, following the European CIP Eco-innovation, and support clusters of applicants and projects which demonstrate an added value and have a high potential for market replication. Clearly, national policies on eco-innovation need to be underpinned by international agreements that all countries will take action to reduce their environmental impacts. The right government policy is needed to ensure synergies between business, science, culture and the environment, which would support the clusters able to jointly deliver successful eco-innovations.

In order to become leaders in eco-design, Slovenian enterprises will have to overcome several challenges, including training designers and strengthening their role, and motivating companies to invest in new, innovative approaches by combining commercial, environmental and social benefits. Only industries focusing on eco-innovations can contribute to the EU goal to become a smart, sustainable, and inclusive economy. Furthermore, eco-design is an important tool for reducing the environmental impact of new products and services, contributes to the creation of products with higher added value and is closely linked with the development of eco-inn ovation. The capacity of eco-innovations to provide new business opportunities and contribute to the transformation towards a sustainable society depends on the interplay of listed activities and the engagement of key stakeholders in the innovation process. Only enterprises able to successfully innovate are likely to dominate and prosper in the new markets they create and can position themselves to master change.

Acknowledgements – Zahvala

The authors acknowledge the Ministry of Economic Development and Technology, Republic of Slovenia for sharing the survey results. Author Manja Kitek Kuzman wishes to thank the Slovenian Research Agency, program P4-0015-0481 and Ministry of Education, Science and Sport RS in the frame of the WoodWisdom-Net? Project W3B Wood Believe. Martina Zbašnik-Senegačnik would like to acknowledge the Slovenian Research Agency for financial support within the frame of the program P5-0068.

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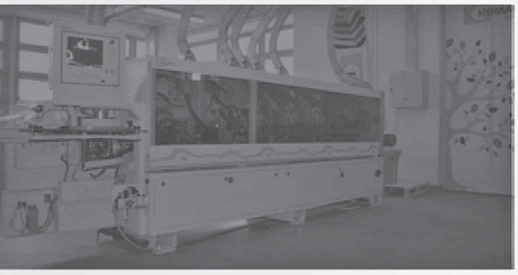



NOTE FROM THE ORGANIZING COMMITTEE

We would like to invite all of you to participate in IWMS 23, this very significant seminar. The seminar will be held in Ozarow Mazowiecki, close to Warsaw, Poland from 28 May to 31 May 2017. You are warmly invited to attend and contribute to IWMS-23, and to join the post-seminar industrial tour (1 June – 2 June 2017). This is the first time for Poland, and simultaneously for the Central Europe, to host the International Wood Machining Seminar. IWMS 23 is the 23rd in a series of world-class seminars started in 1963. IWMS-23 provides a forum for leading international researchers and practicing engineers to present and discuss recent advances in wood cutting tools, processes and machinery. IWMS 23 continues to have the same objectives as the previous Seminars.

IWMS 23 is being held at the Mazurkas Conference Centre in Ozarow Mazowiecki, close to Warsaw, Poland. Warsaw is a very interesting city for visitors, and the surrounding areas provide many attractions.

For the convenience of participants, IWMS 23 is being held immediately following the nearby 2017 Ligna Hannover fair.

Yours sincerely

Kazimierz ORLOWSKI (IWMS 23 Co-Chair) and Piotr BEER (IWMS 23 Chair)

CALL FOR PAPERS

Abstracts are invited from seminar participants. Title, authors, affiliation, abstract (not exceeding 300 words), and presentation type (oral or poster) should be sent to IWMS-23 Secretariat by email before October 31, 2016 (23iwms@gmail.com). Full paper submission deadline: March 1, 2017

IMPORTANT DATES AND DEADLINES

Abstract submission deadline	October 31, 2016	Early bird registration deadline	December 31, 2016,
Notification of acceptance	December 1, 2016,	Full paper submission deadline	March 1, 2017

International Wood Machining Seminar

28.05 - 31.05.2017 - WARSAW - POLAND**

POST SEMINAR TOUR

An optional post-seminar tour (June 1-2, 2017) will also be offered to all attendees and accompanying persons. The guided tour will visit some primary and secondary wood products manufacturers belonging to the IKEA Industry in Wielbark, and on June 2, 2017 the furniture plant Szynaka Meble in Lubawa. The tour will start and end in Ozarow Mazowiecki (Mazurkas Conference Centre).

ABOUT THE ORGANIZERS

Among the hosts are: the Faculty of Wood Technology of the Warsaw University of Life Sciences (WULS-SGGW, the University dates from 1816), the Faculty of Mechanical Engineering of the Gdansk University of Technology (the University was founded in 1904), and The Polish Chamber of Commerce of Furniture Manufacturers (OIGPM, established in 1996).

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Wood Technology Committee of the Polish Academy of Sciences, IKEA Industry, Furniture Plant Szynaka Meble, The Wood Technology Institute, Inwestor Publishing (Wydawnictwo Inwestor), The Polish Chamber of Commerce of Furniture Manufacturers, IUFRO 5.04.08 – Sawing, milling and Machining

CONTACT

Ogólnopolska Izba Gospodarcza Producentów Mebli, 23rd IWMS Organizing Committee, Al. Stanów Zjednoczonych 51, 04-028 Warszawa, Poland
e-mail: iwms2017@gmail.com
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FAGARA HEITZII AUBRÉV. & PELLEGR.

NAZIVI

Fagara heitzii Aubrév. & Pellegr. naziv je botaničke vrste iz porodice *Rutaceae.* Trgovački su nazivi drva te vrste olon (Njemačka, Francuska, Gabon), olon tendre (Francuska), leichtes olon (Njemačka), bongo (Gabon, Kamerun), lomogo, lomvoura, mongo, nongo (Gabon), mbanza (Kongo), olong (Gvineja) i okanham (Nigerija).

NALAZIŠTE

Stabla vrste *Fagara heitzii* nalazimo u zapadnoj Africi. Areal im se proteže od Sierra Leonea do Angole, a rastu i u Kamerunu, Gvineji, Gabonu i Kongu.

STABLO

U svojoj domovini drvo naraste 20 – 25 metara visoko, dužina debla mu je 15 – 20 metara, a prsni promjer 0,6 – 0,9 (1,2) metra. Kora drva je raspucana, katkad hrapava, sivozelena, blijeda, ali može biti i žućkastocrvena. Debljina kore je do 2,0 centimetra.

DRVO

Makroskopska obilježja

Bjeljika i srževina međusobno se teško razlikuju. Bjeljika je žućkastobijela do sivobijela, a srž je žućkastobijele do slamnato žute boje, pokatkad i zelenkastožuta. Drvo je rastresito porozno, a godovi se teško raspoznaju. Traheje i drvni traci vidljivi su samo pod povećalom, na radijalnoj su površini sjajni. Tekstura drva je fina i jednolična, mramorastog je izgleda, matirana do dekorativna.

Mikroskopska obilježja

Na poprečnom presjeku traheje su raspoređene pojedinačno i u parovima. Promjer traheja iznosi 135...240...310 mikrometara, a gustoća im je 1...3...6 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 16 %. Pore su često ispunjene kristalima. Aksijalni je parenhim paratrahealan, rijedak, vrpčast. Volumni udio aksijalnog parenhima iznosi oko 5 %. Drvni su traci homogeni do blago heterogeni, visine 170...260...345 mikrometara i širine 18...34...47 mikrometara, odnosno 2 – 3 stanice. Gustoća drvnih trakova je 4...6...7 na 1 mm poprečnog presjeka. Volumni udio drvnih trakova iznosi oko 13 %. U drvnim tracima i aksijalnom parenhimu ima kristala. Drvna su vlakanca libriformska. Dugačka su 610...1135...1425 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 2,0...2,5...3,0 mikrometara, a promjer lumena 12,0...18,0...25,0 mikrometara. Volumni udio vlakanaca iznosi oko 66 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	oko 480 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	450...520...560 kg/m^3
Gustoća sirovog drva, ρ_s	700...850 kg/m^3
Poroznost	oko 68 %
Radijalno utezanje, β_r	oko 3,7 %
Tangentno utezanje, β_t	5,7...6,1 %
Volumno utezanje, β_v	9,2...11,1 %

Mehanička svojstva

Čvrstoća na tlak	36,0...52,0 MPa
Čvrstoća na savijanje	80,0...100,0 MPa
Čvrstoća na vlak, okomito na vlakanca	1,6...2,2 MPa
Čvrstoća na smicanje	oko 6,5 MPa
Modul elastičnosti	10 200 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro i bez teškoća ručno i strojno obrađuje. Lako se čavla i dobro drži vijke. Lako se ljušti i reže.

Sušenje

Drvo se vrlo brzo i lako suši, no sklono je vitoperenju.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva srednje je otporna na gljive uzročnice truleži (razred otpornosti 3) i srednje otporna na termite (razred otpornosti M). Srž je slabo do srednje permeabilna (razred 2 – 3).

Uporaba

Drvo vrste *Fagara heitzii* upotrebljava se u industriji furnira i furnira za izradu šperploča, za unutarnju stolariju, za proizvodnju kutija i sanduka te dijelova namještaja.

Sirovina

Drvo se kao sirovina isporučuje u obliku trupaca dužine 4 metra, najčešće srednjeg promjera 0,6 metara.

Napomena

Drvo nije na popisu ugroženih vrsta međunarodne organizacije CITES niti na popisu međunarodne organizacije IUCN Red list. Drvo sličnih svojstava imaju i ove vrste drveća: *Fagara macrophylla* Engl., *Fagara inaequalis* Engl., *Fagara* spp., *Hura crepitans* L., *Chloroxylon swietenia* DC., *Citrus medica* L., *Zanthoxylum flavum* Vahl., *Triplochiton scleroxylon* K. Schum. Poznato je oko 40 vrsta roda *Fagara*. Kora drva tradicionalno se iskorištava u medicinske svrhe.

Literatura

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4. ***1964: Wood dictionary, Elsevier publishing company, Amsterdam.
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prof. dr. sc. Jelena Trajković
doc. dr. sc. Bogoslav Šefc

Upute autorima

Opće odredbe

Časopis *Drvna industrija* objavljuje znanstvene radove (izvorne znanstvene radove, pregledne radove, prethodna priopćenja), stručne radove, izlaganja sa savjetovanja, stručne obavijesti, bibliografske radove, preglede te ostale priloge s područja biologije, kemije, fizike i tehnologije drva, pulpe i papira te drvnih proizvoda, uključujući i proizvodnu, upravljačku i tržišnu problematiku u drvnoj industriji.

Predaja rukopisa podrazumijeva uvjet da rad nije već predan negdje drugdje radi objavljivanja ili da nije već objavljen (osim sažetka, dijelova objavljenih predavanja ili magistarskih radova odnosno disertacija, što mora biti navedeno u napomeni) te da su objavljivanje odobrili svi suautori (ako rad ima više autora) i ovlaštene osobe ustanove u kojoj je istraživanje provedeno. Kad je rad prihvaćen za objavljivanje, autori pristaju na automatsko prenošenje izdavačkih prava na izdavača te na zabranu da rad bude objavljen bilo gdje drugdje ili na drugom jeziku bez odobrenja nositelja izdavačkih prava.

Znanstveni i stručni radovi objavljuju se na hrvatskome, uz sažetak na engleskome, ili se pak rad objavljuje na engleskome, sa sažetkom na hrvatskom jeziku. Naslov, podnaslovi i svi važni rezultati trebaju biti napisani dvojezično. Ostali se članci uglavnom objavljuju na hrvatskome. Uredništvo osigurava inozemnim autorima prijevod na hrvatski. Znanstveni i stručni radovi podliježu temeljitoj recenziji najmanje dvaju recenzenata. Izbor recenzenata i odluku o klasifikaciji i prihvaćanju članka (prema preporukama recenzenata) donosi Urednički odbor.

Svi prilozi podvrgavaju se jezičnoj obradi. Urednici će od autora zahtijevati da tekst prilagode preporukama recenzenata i lektora, te zadržavaju i pravo da predlože skraćivanje ili poboljšanje teksta. Autori su potpuno odgovorni za svoje priloge. Podrazumijeva se da je autor pribavio dozvolu za objavljivanje dijelova teksta što su već negdje objavljeni te da objavljivanje članka ne ugrožava prava pojedinca ili pravne osobe. Radovi moraju izvještavati o istinitim znanstvenim ili tehničkim postignućima. Autori su odgovorni za terminološku i metrološku usklađenost svojih priloga. Radovi se šalju elektroničkom poštom na adresu:

drind@sumfak.hr ili techdi@sumfak.hr

Upute

Predani radovi smiju sadržavati najviše 15 jednostrano pisanih A4 listova s dvostrukim proredom (30 redaka na stranici), uključujući i tablice, slike te popis literature, dodatke i ostale priloge. Dulje je članke preporučljivo podijeliti na dva ili više nastavaka. Tekst treba biti u *doc formatu*, u potpunosti napisan fontom *Times New Roman* (tekst, grafikoni i slike), normalnim stilom, bez dodatnog uređenja teksta.

Prva stranica poslanog rada treba sadržavati puni naslov, ime(na) i prezime(na) autora, podatke o zaposlenju autora (ustanova, grad i država) te sažetak s ključnim riječima (duljina sažetka približno 1/2 stranice A4).

Posljednja stranica treba sadržavati titule, zanimanje, zvanje i adresu (svakog) autora, s naznakom osobe s kojom će Uredništvo biti u vezi.

Znanstveni i stručni radovi moraju biti sažeti i precizni. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčavaju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale uzdignutim arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablica, a označavaju se uzdignutim malim pisanim slovima, abecednim redom.

Latinska imena trebaju biti pisana kosim slovima (italicom), a ako je cijeli tekst pisan kosim slovima, latinska imena trebaju biti podcrtana.

U uvodu treba definirati problem i, koliko je moguće, predočiti granice postojećih spoznaja, tako da se čitateljima koji se ne bave područjem o kojemu je riječ omogući razumijevanje ciljeva rada.

Materijal i metode trebaju biti što preciznije opisane da omoguće drugim znanstvenicima ponavljanje pokusa. Glavni eksperimentalni podaci trebaju biti dvojezično navedeni.

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuje se upotreba SI jedinica. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri njihovu prvom spominjanju u tekstu. Za pisanje formula valja se koristiti Equation Editorom (programom za pisanje formula u MS Wordu). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosima (italicom). Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

Broj slika mora biti ograničen samo na one koje su prijeko potrebne za objašnjenje teksta. Isti podaci ne smiju biti navedeni i u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčane, arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti napisan hrvatskim i engleskim jezikom.

Slike je potrebno rasporediti na odgovarajuća mjesta u tekstu, trebaju biti izrađene u rezoluciji 600 dpi, crno-bijele (objavljivanje slika u koloru moguće je na zahtjev autora i uz posebno plaćanje), formata jpg ili tiff, potpune i jasno razumljive bez pozivanja na tekst priloga.

Svi grafikoni i tablice izrađuju se kao crno-bijeli prilozi (osim na zahtjev, uz plaćanje). Tablice i grafikoni trebaju biti na svojim mjestima u tekstu te originalnog formata u kojemu su izrađeni radi naknadnog ubacivanja hrvatskog prijevoda. Ako ne postoji mogućnost za to, potrebno je poslati originalne dokumente u formatu u kojemu su napravljeni (*excel* ili *statistica* format).

Naslovi slika i crteža ne pišu se velikim tiskanim slovima. Crteži i grafikoni trebaju odgovarati stilu časopisa (fontovima i izgledu). Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice. Fotomikrografije moraju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : l".

Diskusija i zaključak mogu, ako autori žele, biti spojeni u jedan odjeljak. U tom tekstu treba objasniti rezultate s obzirom na problem postavljen u uvodu i u odnosu prema odgovarajućim zapažanjima autora ili drugih istraživača. Valja izbjegavati ponavljanje podataka već iznesenih u odjeljku *Rezultati*. Mogu se razmotriti naznake za daljnja istraživanja ili primjenu. Ako su rezultati i diskusija spojeni u isti odjeljak, zaključke je nužno napisati izdvojeno. Zahvale se navode na kraju rukopisa. Odgovarajuću literaturu treba citirati u tekstu, i to prema harvardskom sustavu (*ime – godina*), npr. (Bađun, 1965). Nadalje, bibliografija mora biti navedena na kraju teksta, i to abecednim redom prezimena autora, s naslovima i potpunim navodima bibliografskih referenci. Popis literature mora biti selektivan, a svaka referenca na kraju mora imati naveden DOI broj, ako ga posjeduje (http://www.doi.org) (provjeriti na http://www.crossref.org).

Primjeri navođenja literature

Članci u časopisima: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. Naziv časopisa, godište (ev. broj): stranice (od – do). Doi broj.

Primjer

Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

Knjige: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. (ev. izdavač/editor): izdanje (ev. svezak). Mjesto izdanja, izdavač (ev. stranice od – do).

Primjeri

Krpan, J., 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb, Tehnička knjiga.

Wilson, J. W.; Wellwood, R. W., 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551- 559.

Ostale publikacije (brošure, studije itd.)

Müller, D., 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forstund Holzvvirt schaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Web stranice

***1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node00.html. First published 1997 (pristupljeno 27. siječnja 2010).

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Instructions for authors

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The "Drvna industrija" ("Wood Industry") journal publishes scientific papers (original scientific papers, review papers, previous notes), professional papers, conference papers, professional information, bibliographical and survey articles and other contributions related to biology, chemistry, physics and technology of wood, pulp and paper and wood products, including production, management and marketing issues in the wood industry.
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E-mail: drind@sumfak.hr

Details

Papers submitted shall consist of no more than 15 single-sided DIN A-4 sheets of 30 double-spaced lines, including tables, figures and references, appendices and other supplements. Longer papers should be divided into two or more continuing series. The text should be written in doc format, fully written using Times New Roman font (text, graphs and figures), in normal style without additional text editing.
The first page of the paper submitted should contain full title, name(s) of author(s) with professional affiliation (institution, city and state), abstract with keywords (approx. 1/2 sheet DIN A4).
The last page should provide the full titles, posts and address(es) of each author with indication of the contact person for the Editor's Office.
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Latin names shall be printed in italics and underlined.
Introduction should define the problem and if possible the framework of existing knowledge, to ensure that readers not working in that particular field are able to understand author's intentions.
Materials and methods should be as precise as possible to enable other scientists to repeat the experiment. The main experimental data should be presented bilingually.
The results should involve only material pertinent to the subject. The metric system shall be used. SI units are recommended. Rarely used physical values, symbols and units should be explained at their first appearance in the text. Formulas should be written by using Equation Editor (program for writing formulas in MS Word). Units shall be written in normal (upright) letters, physical symbols and factors in italics. Formulas shall be consecutively numbered with Arabic numerals in parenthesis (e.g. (1)) at the end of the line.
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Example of references

Journal articles: Author's second name, initial(s) of the first name, year: Title. Journal name, volume (ev. issue): pages (from - to). DOI number.

Example:
Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

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Examples:
Krpan, J. 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb: Tehnička knjiga.
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