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Comparison of Birch and Beech Wood in Terms of Economic and Technological Properties for Plywood Manufacturing

Usporedba ekonomskih i tehnoloških svojstava brezovine i bukovine za proizvodnju furnirske ploče

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ABSTRACT • *The aim of this study was to investigate the use of birch wood, one of the most important wood species used in the plywood industry, especially in Europe, the Nordic countries, Poland, Belarus and Russia as an alternative to beech wood. For this purpose, comparison was made of their economic and technological properties. In five-ply plywood manufacturing, beech (Fagus orientalis Lipsky) and birch (Betula pendula) veneer sheets were used with melamine urea formaldehyde (MUF) and urea formaldehiyde (UF) resins. Some mechanical properties such as shear strength, bending strength and modulus of elasticity of plywood panels were conducted according to EN 314-1 and EN 310, respectively. Mean mechanical strength obtained for birch plywood panels was quite above the limit values specified in the related standards. When taking into consideration the annual increment of beech and birch trees in 1 ha and the time they need to reach suitable diameters for the manufacturing of rotary cut veneers, it was calculated that birch trees provide 2.46 times more physical harvesting than beech trees.*

Keywords: *birch, beech, economic comparison, technological properties, plywood*

SAŽETAK • *U radu je istraživana uporaba brezovine kao jedne od najvažnijih vrsta drva koja se upotrebljava kao alternativa bukovini za proizvodnju furnirskih ploča, posebice u Europi, u nordijskim zemljama, Poljskoj, Bjelorusiji i Rusiji. Za potrebe rada uspoređivana su njihova ekonomska i tehnološka svojstva. U proizvodnji furnirske ploče od pet slojeva upotrijebljeni su listovi furnira od bukovine (Fagus orientalis Lipsky) i brezovine (Betula pendula), koji su slijepljeni ljepilom na bazi melamin-urea-formaldehidnih (MUF) i urea-formaldehidnih (UF) smola. Ispitana su mehanička svojstva furnirskih ploča prema normi EN 314-1 i EN 310, i to čvrstoća na smicanje, čvrstoća na savijanje i modul elastičnosti. Dobivene srednje vrijednosti čvrstoće brezovih i bukovih furnirskih ploča bile su znatno iznad graničnih vrijednosti navedenih u normama. Kada se u obzir uzme godišnji prirast bukve i breze na 1 ha šume i vrijeme potrebno za postizanje odgovarajućih promjera za proizvodnju ljuštenih furnira, izračunano je da breza osigurava 2,46 puta više raspoložive količine za sječu od bukve.*

Ključne riječi: *breza, bukva, ekonomska usporedba, tehnološka svojstva, furnirska ploča*

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1 INTRODUCTION
1. UVOD

Plywood is a wood composite with good physical and mechanical properties and can be used in construction and furniture industry. Its production in the world and Europe in 2016 exceeded 159 and 8 million cubic meters, respectively (FAO, 2018). European Union (EU) imports of panels (mainly plywood) increased by 9 % to Euro 2.79 billion in 2017. This follows a 3 % rise in 2016 and an 11 % increase in 2015. Most of this gain was due to a rise in plywood imports from Russia and other Eastern European countries. The value of EU plywood imports from China and tropical countries was generally stable or declining in 2017 (Industry News and Markets, 2018).

Wood species are an important factor for technological properties and sale price of plywood panels. Beech wood is the most widely used wood species for plywood manufacturing in Turkey. Beech forests indigenously grow in central Europe, in the Balkan peninsula, from Greece and Bulgaria up to the Caucasus along the Black Sea Region and Turkey. As a matter of fact, beech wood is one of the most important commercial hardwood species in Southeastern Europe (Skarvelis *et al*., 2013). Beech wood is classified as a medium density hardwood; it is heavy, hard, strong, high in resistance to shock, and highly suitable for steam bending (Bektas *et al*., 2002).

Birch (*Betula pendula*), a hardwood species, is the most significant deciduous tree species in Europe, the Nordic countries, Poland, Belarus and Russia. Birch wood is mainly used for plywood production and for indoor applications due to its low dimensional stability (Hill 2006; Biziks *et al*., 2013). Birch plywood production in Russia has demonstrated constant growth in recent years, producing nearly 3.5 million cubic meters in 2016. This industry is heavily export-oriented, with more than half of the volume being sold to lucrative markets in Europe, North America and the Middle East & North Africa (MENA). The total value of exported Russian birch plywood amounted to almost 1 billion dollars in 2016 (Hanninen, 2017).

The quality and production costs of beech plywood panels are affected by the formation of red heartwood and difficulties in wood preservation and log storage. It was stated that the diameter of the logs used in plywood manufacturing needed to be at least 35 cm (Lutz, 1978). Beech trees in the existing forests in Turkey reach this diameter in 120 years (Toksoy *et al.,* 2006). For birch trees, this growth is slow in the first years and followed by rapid growth. Growth ceases after 50 years (Cakiroglu and Aydin, 2012).

In this study, comparison was made between the economic and technological benefits of the use of birch wood instead of beech wood as a raw material in plywood manufacturing process. For this purpose, some technological properties of plywood manufactured from beech and birch logs were determined and then compared with the values specified in related standards. On the other hand, the quantity of birch and beech logs that can be obtained from the same area in the existing forests of Turkey was determined by using increment and rotation age values. Afterwards, the prices of beech and birch logs were also taken into consideration and the costs of these logs were discussed.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Beech (*Fagus orientalis* Lipsky) logs with 45 cm diameter obtained from the Ordu region, which is located on the north cost of Turkey, and birch logs with 35 cm diameter obtained from Ukraine were used in this study. Veneer sheets with 1.5 mm thickness were obtained by rotary cutting under laboratory conditions after the steaming of beech and birch logs at the temperature of 70 °C - 90 °C for 12 hours. The horizontal opening (distance from the leading edge of pressure bar to a plane extended from the ground surface of the knife) was 85 % of the veneer thickness and the vertical opening was 0.5 mm in the rotary peeling process.

The veneers obtained were dried to 6-8 % moisture content by using a veneer dryer. Five-ply plywood panels with the dimensions of 60 cm x 60 cm and thickness of 7 mm were manufactured. Two types of resins were used as adhesive, melamine-urea formaldehyde (MUF) and urea formaldehyde (UF) resins with 55 % solid content. MUF and UF resin solutions used in plywood manufacturing were composed of 100 parts MUF and UF resins, 30 parts wheat flour and 10 parts NH_4Cl (with 15 % concentration) as hardener, by weight. Technical specifications of UF and MUF resins supplied by the producers of resins are given in Table 1.

The glue mixture was applied at a rate of 160 g per square meter to individual surfaces of veneers with a four-roller glue spreader. Three different plywood drafts were formed for each resin as completely beech veneers in all layers, completely birch veneers in all layers and as

Table 1 Technical specifications of urea formaldehyde and melamine-urea formaldehyde resins
Tablica 1. Tehnička svojstva urea-formaldehidne i melamin-urea-formaldehidne smole

Specifications / *Svojstva*	**Urea Formaldehyde (UF)** *Urea-formaldehidna smola*	**Melamine-Urea Formaldehyde (MUF)** *Melamin-urea-formaldehidna smola*
Solid content / *sadržaj suhe tvari,* %	54-56	54-56
Density / *gustoća,* g/cm^3 *pri* 20 °C	1.22-1.23	1.225-1.240
Viscosity / *viskoznost,* cP·s *pri* 20 °C	100-200	90-150
Gelation time / *vrijeme želiranja,* s	15-25	70-110
Flow rate / *vrijeme istjecanja pri* 20 °C	25-45	20-40
Free formaldehyde / *slobodni formaldehid,* %	max. 0.8	max 0.16
pH, at 20 °C	7.5-8.5	8.5-9.5

mixed panel (beech-birch-beech-birch-beech). Hot press time and temperature were 7 minutes and 110 °C, respectively, while press pressure was 12 kg/cm^2. Two replicate plywood panels were manufactured for each test group. Test samples were conditioned to achieve equilibrium moisture content at 20 °C temperature and 65 % relative humidity prior to testing.

The bonding strength of plywood panels was determined according to EN 314-1 (1998) standard with a universal testing machine. Samples manufactured with MUF and UF resins were tested after immersion in water at 20 °C for 24 h. Twenty-five specimens were used for the evaluation of shear strength tests. Bending strength and modulus of elasticity tests were conducted according to EN 310 (1993) standard on a universal testing machine. Eighteen test samples (9 transverse and 9 longitudinal test pieces) of all test groups were prepared for bending strength and MOE tests and arithmetic mean values of the test results were used.

Multifactor analysis of variance was performed for the statistical evaluation of changes in mechanical properties depending on the wood species and glue types. After multifactor analysis of variance, Student-Newman-Keuls test at the confidence level of 95 % was used to compare the mean values of variance sources.

3 RESULTS
3. REZULTATI

3.1 Mechanical properties of panels
3.1. Mehanička svojstva ploča

The mean values of shear strength, bending strength and modulus of elasticity of plywood panels are given in Table 2, and the results of the multifactor analysis of variance related to these mechanical properties are given in Table 3.

Student-Newman-Keuls test at the confidence level of 95 % was used to compare the mean values of variance sources, and the results of statistical evaluation are given in Table 4.

According to Table 2, the values of mechanical properties of beech plywood panels for UF resin were higher than those obtained for birch and mixed plywood. However, the highest bending strength and modulus of elasticity values for MUF resin were found for birch plywood panels. The results of multifactor analysis of variances also proved that the difference between plywood panels manufactured from beech, birch and mixed veneers was significant. The effect of veneer wood species and glue types on modulus of elasticity and shear strength was significant with error

Table 2 Mean values of bending strength, modulus elasticity and shear strength of beech and birch plywood
Tablica 2. Srednje vrijednosti čvrstoće na savijanje, modula elastičnosti i čvrstoće na smicanje bukove i brezove furnirske ploče

Glue type *Vrsta ljepila*		**Bending strength** *Čvrstoća na savijanje,* N/mm^2			**Modulus of elasticity** *Modul elastičnosti,* N/mm^2			**Shear strength** *Čvrstoća na smicanje*, N/mm^2		
		Beech	Birch	Mixed	Beech	Birch	Mixed	Beech	Birch	Mixed
UF	*X*	104.58	94.34	92.26	7269.6	6044.9	6007.5	3.26	2.89	2.57
	S	5.90	9.90	5.06	313	570	757	0.39	0.35	0.30
MUF	*X*	94.69	100.88	97.41	6899.1	7096.9	6498.4	3.87	3.06	2.96
	S	8.73	10.41	12.86	437	533	465	0.19	0.46	0.38

X: Arithmetic mean values / *X - aritmetička sredina*
S: Standard deviation / *S - standardna devijacija*

Table 3 The effect of sources of variation on bending strength, modulus of elasticity and shear strength of plywood panels
Tablica 3. Utjecaj uzroka odstupanja na čvrstoću na savijanje, modul elastičnosti i čvrstoću na smicanje furnirskih ploča

Mechanical properties *Mehanička svojstva*	**Source of variation** *Uzroci odstupanja*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupnjevi slobode*	**Mean squares** *Srednja vrijednost kvadrata*	**F-value** *F-vrijednost*	**Sig. level** *Stupanj značajnosti*
Bending strength čv*rstoća na savijanje*	Wood species / *vrsta drva*	418.132	2	209.07	2.064	NS
	Glue type / *vrsta ljepila*	9.782	1	9.782	0.097	NS
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	1494.183	2	747.092	7.377	***
Modulus of elasticity *modul elastičnosti*	Wood species / *vrsta drva*	1.27	2	6335558.01	22.508	***
	Glue type / *vrsta ljepila*	4122830.609	1	4122830.609	14.647	***
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	9241163.061	2	4620581.531	16.415	***
Shear strength čv*rstoća na smicanje*	Wood species / *vrsta drva*	17.336	2	8.668	67.881	***
	Glue type / *vrsta ljepila*	5.704	1	5.704	44.668	***
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	1.208	2	0.604	4.730	**

NS: Non-significant / *NS - nije značajno*
***Significant at the 0.001 level / *značajno na razini 0,001*

Table 4 Newman-Keuls table related to the effect of wood species and glue types on the variance sources on bending strength, shear strength and modulus of elasticity of plywood panels ($p \leq 0.01$)
Tablica 4. Newman-Keulsova tablica vezano uz utjecaj vrste drva i vrste ljepila na uzroke odstupanja čvrstoće na savijanje, čvrstoće na smicanje i modula elastičnosti furnirskih ploča ($p \leq 0{,}01$)

Source of variation *Uzroci odstupanja*		***N***	**Shear strength** *Čvrstoća na smicanje,* N/mm²		***N***	**Bending strength** *Čvrstoća na savijanje,* N/mm²		***N***	**Modulus of elasticity** *Modul elastičnosti,* N/mm²	
Wood species *vrsta drva*	Beech	50	3.57	a*	36	99.64	a	36	7084	a
	Birch	50	2.98	b	36	97.61	a	36	6571	b
	Mixed	50	2.76	c	36	94.84	a	36	6253	c
Glue types *vrsta ljepila*	MUF	75	3.30	a	54	97.66	a	54	6831	a
	UF	75	2.91	b	54	97.06	a	54	6441	b

*Different letters indicate statistically significant difference. / **Različita slova označavaju statistički značajnu razliku.*

probabilities of 0.001. However, the effect of wood species and glue types on bending strength was not significant as shown in Table 3.

As can be seen in Table 4, the effects of wood species and glue types on mechanical properties were found statistically significant. The values of shear strength and modulus of elasticity of beech plywood panels were determined higher than those of birch and mixed plywood panels. The reason may lie in the fact that the density of beech wood was higher compared to birch wood. Oven-dry density values of beech (*Fagus orieantalis* Lipsky) and birch (*Betula pendula*) wood were stated as 0.64 g/cm³ and 0.52 g/cm³, respectively (Malkocoglu, 1994; Herajarvi, 2002). It was concluded in the literature that the shear strength of wood increases with increasing density (Chow and Chunsi, 1979; Namara and Waters, 1970). Therefore, it was not a surprising result that the values of shear strength and modulus of elasticity of beech plywood panels were higher than those of birch plywood. Toksoy *et al*. (2006) reported in their studies regarding the use of alder (*Alnus glutinosa* subsp. barbata) wood as an alternative to beech wood that the values of bending strength, modulus of elasticity and shear strength of alder plywood were found as 79 N/mm², 6499 N/mm² and 2.75 N/mm², respectively. Similarly, the values of bending strength, modulus of elasticity and shear strength of plane (*Platanus orientalis*) plywood were found as 70 N/mm², 3960 N/mm² and 1.77 N/mm², respectively (Demirkir *et al.,* 2013). MUF resin was used as adhesive in both studies mentioned above. In the present study, the values of mechanical properties of birch plywood were 101 N/mm², 7096 N/mm² and 3.06 N/mm², respectively. According to these results, birch wood can be stated as a better alternative to beech wood when compared to alder and plane wood.

Also, the MUF-bonded plywood panels generally have higher values of shear strength and modulus of elasticity than those of UF-bonded plywood panel groups. Gindl and Gupta (2002) stated that the treatment of wood with melamine–formaldehyde resin showed a considerable potential to improve mechanical properties. However, as can be seen in Table 4, the effects of wood species and glue types on the bending strength of all groups were not found statistically significant in the present study.

Mean values of shear strength obtained from the samples of all plywood panels manufactured from birch logs were above the limit value (1.0 N/mm²) specified in EN 314-2 (1998) standard. Mean values obtained for bending strength of plywood panels were also higher than the limit values for structural purpose plywood panels (40 N/mm²) specified in DIN 68705-3 (1981). It has been specified in DIN 68792 (2016) that bending strength values parallel to the grain direction of plywood panels, with thicknesses up to 6 mm, need to be at least 75 N/mm², if the panels are used for concrete mould. Modulus of elasticity values of plywood were limited with 8500 N/mm² up to 6 mm thickness and 5000 N/mm² for panels with thickness of 6-12 mm. According to the results, all plywood panels manufactured in this study had satisfactory bonding for indoor applications.

3.2 Economic analysis
3.2. Ekonomska analiza

A few studies of birch plantations in Baltic countries (Liepiņš, 2011) and in naturally regenerated birch stands (Aosaar *et al*., 2016) covering an age range from 15 to 20 years, report birch MAI (Mean Annual Increment) around 10 m³ ha-1 yr-1 (Lutter, 2017). However, the mean annual increment of beech and birch in 1 ha is 2.3 and 3 m³, respectively, in the existing forests in Turkey (State Planning Organization, 2001). When these values are taken into consideration, increment coefficient *X* is found as (1),

$$X = \frac{2.3\ (\text{beech})}{3\ (\text{birch})} = 0.77 \qquad (1)$$

The time required to reach sufficient log diameter for veneer production by rotary peeling is 120 years for beech (Kiris, 2002). Economic studies on birch on fertile forestland and on abandoned agricultural land show that the financial maturity age of birch is around 35 to 40 years (mean 37.5 years), to produce plywood, saw logs and pulpwood (Korjus *et al*., 2011; Tullus *et al*., 2012).

Accordingly, the harvesting time *coefficient Y* is determined as (2),

$$X = \frac{120\ (\text{beech})}{37.5\ (\text{birch})} = 3.2 \qquad (2)$$

The yield is mostly dependent on the log diameter in plywood production. As it was considered that beech and birch trees have the same log diameter at the end of the harvesting season, the productivity coefficient according to log diameter was assumed as *Z*=1 when in-

crement quantity per hectare and the required time to reach sufficient log diameter for veneer production were taken into consideration. The difference between birch and beech was calculated by the following equations.

1 birch = ($X \times Y \times Z$) beech

1 birch = ($0.77 \times 3.2 \times 1$) beech

1 birch = 2.464 beech

Birch was calculated to provide 2.46 times more physical harvesting than beech by considering the present conditions of the forests in Turkey. In addition to this, the prices of birch and beech logs should be evaluated. The price of any product is generally determined by its supply and demand. Changes in supply and demand cause the change in price, too. Therefore, it is very difficult to estimate changes connected with price that include long periods. In addition, the price of any material can change depending on many factors, such as inflation, exchange rate, substitute goods, complement goods, interest and quality (Toksoy *et al*., 2006). The average market price of logs in Turkey was 105 $/m^3$ for birch and 163 $/m^3$ for beech in 2018. When birch logs are used for plywood production instead of beech logs, raw material cost can be reduced at a rate of 35 % according to the market prices.

4 CONCLUSIONS
4. ZAKLJUČAK

Although the use of beech, which is one of the most important wood species, is appropriate for general purpose plywood production in terms of veneer production technology, such production leads to a significant loss in terms of country economy. As known, general purpose plywood does not require high quality properties in the place of use. Suitable technologies should be developed for the use of fast-growing native wood species in general purpose plywood production. It is important to evaluate high-quality beech logs in the furniture industry in terms of ease of processing and technological properties. Birch plywood is produced in some small capacity plywood factories in our region, instead of beech plywood. The present study showed that birch plywood panels are good enough for general purpose use. Birch wood is cheaper than beech wood, and it has suitable density and colour. It has been concluded that the mechanical strength of birch plywood panels was almost the same as that of beech plywood. Therefore, birch wood can be used in all areas where beech wood has been traditionally used. Birch logs are also recommended for plywood production instead of beech logs and this can lead to the decrease in plywood manufacturing costs.

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