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Evaluation of Some Physico-Mechanical Properties and Formaldehyde Emission of Ecological Chipboards Produced from Annual Residue Plant Stems

Procjena nekih fizičko-mehaničkih svojstava i emisije formaldehida ekoloških ploča iverica proizvedenih od ostataka stabljika jednogodišnjih biljaka

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ABSTRACT • *Urea formaldehyde glue is one of the most preferred glues in the production of wood composite panels. It has many advantages such as economy, effective adhesive power and easy use. However, due to formaldehyde emission, it negatively affects the environment and human health. Formaldehyde emission can cause diseases in the respiratory system depending on the concentration and duration of exposure. In recent years, with legal regulations and increasing consumer awareness, low emission plate production has become inevitable. Therefore, low-emission adhesives, formaldehyde-scavenging chemicals and alternative binders are used to reduce formaldehyde emissions. Many studies have been made on the use of urea formaldehide glue and this topic is still actual. In this study, varying proportions (0, 25, 50, 75 and 100 %) of annual residue plant (ARP) were added to the wood chips used in the production of chipboards to solve these problems. The results showed that in physical properties, with the increase of ARP ratio, water absorption (WA) and thickness swelling (TS) values deteriorated for 2 and 24 hours. In mechanical measurements, the highest figures were obtained from the bending strength (SBS), modulus of elasticity (MOE) and tensile strength perpendicular to the surface (TSP) measurements of the boards produced from 25 % WAP added mixtures. TS EN 120 perforator method was applied to measure the formaldehyde emission in the boards. The test boards can be considered "ecological" since most results of formaldehyde emission (FE) measured on value-added products (WAP) were below the upper limit (8 mg/100g) specified in the E1 (EN 120) standard.*

KEYWORDS: *annual residue plants; physico-mechanical properties; formaldehyde emission; ecological chipboards*

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SAŽETAK • *Urea formaldehidno ljepilo jedno je od najpoželjnijih ljepila u proizvodnji kompozitnih ploča od drva. Ima mnoge prednosti kao što su ekonomičnost, učinkovita moć lijepljenja i jednostavna uporaba. Međutim, zbog emisije formaldehida negativno utječe na okoliš i zdravlje ljudi. Udisanje formaldehida može prouzročiti bolesti dišnog sustava, ovisno o njegovoj koncentraciji i trajanju izloženosti. Posljednjih se godina zbog zakonskih regulativa i sve razvijenije svijesti potrošača teži proizvodnji ploča s niskim emisijama tog plina. Za smanjenje emisije formaldehida upotrebljavaju se ljepila s niskom emisijom, kemikalije za hvatanje formaldehida i alternativna veziva. Objavljene su mnoge studije o upotrebi urea formaldehidnog ljepila, ali tema je i dalje aktualna. Za rješavanje tih problema u ovom su istraživanju drvnoj sječki rabljenoj za proizvodnju iverica dodani različiti udjeli ostataka jednogodišnjih biljaka (ARP): 0, 25, 50, 75 i 100 % Rezultati ispitivanja fizičkih svojstava pokazali su da se s povećanjem omjera ARP-a vrijednosti upijanja vode (WA) i debljinskog bubrenja (TS) tijekom 2 i 24 sata pogoršavaju. Glede mehaničkih svojstava, najveće vrijednosti čvrstoće na savijanje (SBS), modula elastičnosti (MOE) i vlačne čvrstoće okomito na površinu (TSP) dobivene su za ploče proizvedene od smjese s dodatkom 25 % WAP-a. Za mjerenje emisije formaldehida u pločama primijenjena je perforatorska metoda TS EN 120. Ispitane se ploče mogu smatrati "ekološkim" proizvodom jer je većina rezultata emisije formaldehida (FE) izmjerenih na proizvodima s dodatkom WAP-a bila niža od gornje granične vrijednosti (8 mg/100 g) za emisijski razred E1 (EN 120).*

KLJUČNE RIJEČI: *ostatci jednogodišnjih biljaka; fizičko-mehanička svojstva; emisija formaldehida; ekološka ploča iverica*

1 INTRODUCTION
1. UVOD

The inability of renewable natural resources such as forests to meet the increasing demand due to worldwide economic growth and development has created unprecedented needs for recycled forest products from lignocellulosic residues (Bektas *et al.*, 2005; Youngquist *et al.*, 1993). Producing high value-added products (WAP) such as furniture, interior design, and various construction and building materials from WAP, which is not used properly today, is an important activity in terms of economic and environmental awareness. At the same time, the increase in costs, because of the contraction in the supply of wood raw materials, makes the need for alternative raw material sources such as WAP and the research to be carried out even more important. So far, numerous researchers have studied the main properties of particleboard, fiberboard and other lignocellulosic based composite boards produced from different annual plant wastes; some of the studies dealing with waste chestnut bur (Liang *et al.*, 2021), lignocellulosic agro-industrial waste (Martins *et al.*, 2020), agricultural residues (Ferraz *et al.*, 2020), canola straws (Kord *et al.*, 2016), cotton stalks (Nazerian *et al.*, 2016), eggplant stalks (Guntekin and Karakus, 2008), pepper stalks (Guntekin *et al.*, 2008), sunflower stalks (Bektas *et al.*, 2005; Youngquist *et al.*, 1993), wheat straws and corn pith (Wang and Sun, 1998) waste of tea leaves (Yalinkilic *et al.*, 1998) crops residues (Kalaycioglu, 1992) and cob and maize husk (Sampathrajan *et al.*, 1992).

On the other hand, the available annual plant waste in Turkey is estimated to be 142.4 m ton/year (Saka and Yilmaz, 2017). The total amount of annual plants harvested and produced as agricultural waste in Turkey is 37 million tonnes (Guler, 2015). Wheat stalk accounts for the largest part of these annual plant wastes (18 m tonnes), followed by barley stalk (8 m tonnes), cotton stalk (3.5 m tonnes), sunflower stalk (3 m tonnes), corn stalk (2.5 m tonnes), rice stalk (200 tonnes), tobacco stalk (300 tonnes) and lake cane stalk (200 tonnes).

As a result, formaldehyde emission limit (Wang *et al.*, 2017), which is one of the factors that connect this study to the environment, is one of the important health indicators that connects wood-based boards and products to the environment. However, the first study that systematically examined the relationships between wood main chemical components and *FE* was carried out by Schafer and Roffael, (2000) at the beginnings of the 21st century. The results of this research revealed that the *FE* of the main components of wood is very different. As it is known, the two main chemical components of wood are lignin (18-35 %) and holocellulose (65-75 %), which consists of cellulose (40-50 %) and hemicellulose (25-35 %) (Bozkurt and Goker, 1996; Pettersen, 1984).

The starting point of this study is to search for alternative raw material sources that can substitute or add to wood, which is not sufficiently available from worldwide scarce forest resources. While focusing on this point, it was also aimed that the physico-mechanical properties (PMP) and FE values of the materials, to be manufactured from the new raw materials to be tested, would meet the criteria stipulated by the relevant standards. Investigating the FE within the scope of the study and comparing it with the requirements of the relevant standard is particularly important in terms of showing the "environmental sensitivity" of the study.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Preparation of test boards
2.1. Priprema ispitnih ploča

In this study, cotton (*Gossypium hirsitum* L.) stalks (CS), sunflower (*Helianthus annuus* L.) stalks

(SS), wheat (*Triticum aestivum* L.) stalks (WS) and wood chips were used from the annual plant wastes as test materials. The test materials used were provided from the Eastern Mediterranean region. The raw material collected from the field was prepared for flaking after a rough preliminary grading. In this process, particles were screened using a horizontal moving sieve. In the production of single-layer particleboards, chips with average sizes between 3 mm and 1.5 mm were used. After chipping, the chips were dried at 110 °C until they reached an average humidity of 3 %. Urea formaldehyde (UF) glue and 1 % hardener (NH4CL) were added at the rate of 10 % of its dry weight to the dry sawdust prepared in the proportions given in Table 1. For the pressing process, first, the mixing matrix was prepared in 55 cm × 55 cm dimensions and pressed to provide a density of 650 kg/m^3.

Then, the boards which were pressed in the hot press by keeping them at 185 °C under 120 atm pressure for 7 minutes, were taken to the air-conditioning process until they were ready for the tests (Bektas *et al.*, 2005; Ayrilmis, 2010; Guler and Sancar, 2017). During pressing, the press temperature is 185 °C, the press time is 7 minutes after the press is closed, and the press pressure is 4 N/mm^2. Following this, the test boards were subjected to conditioning until they were ready for tests (Bektas *et al.*, 2005; Ayrilmis, 2010; Guler and Sancar, 2017). These conditions were ensured for all the test samples, and a randomly selected sample from the production stages is shown in Figure 1.

2.2 Test procedure
2.2. Provedba ispitivanja

Within the scope of the tests, the *WA* and *TS* values were measured from physical properties according to EN 317 (1993). As for the mechanical properties, static bending strength (*SBS*) EN 310 (1993), modulus of elasticity (*MOE*) EN 310 (1993) and tensile strength perpendicular to the surface (*TSP*) EN 319 (1993) tests were determined in accordance with the relevant standards. Similarly, the formaldehyde emission (*FE*) values of the test boards were determined based on the EN 120 (1996) perforator method included in the BS EN 13986 (2005) standard. As is known, this method measures the formaldehyde content of wood-based panels, which can potentially diffuse under harsh conditions (Costa, 2013). The *FE* values of the samples were briefly measured as follows.

Table 1 Experimental design
Tablica 1. Postavke eksperimenta

Board type *Vrsta ploče*	**Raw materials and mixing ratios, %** *Sirovine i omjeri miješanja, %*			
	WC(*)	CS	SS	WS
A00	100	0	0	0
B25	75	25	0	0
C50	50	50	0	0
D75	25	75	0	0
E00	0	100	0	0
F25	75	0	25	0
G50	50	0	50	0
H75	25	0	75	0
K00	0	0	100	0
L25	75	0	0	25
M50	50	0	0	50
N75	25	0	0	75
P00	0	0	0	100

*Control groups / *kontrolne grupe*

First, completely dry weights of the samples cut in 25×25 mm dimensions from each produced test board were adjusted to be 100 g Myers, (1985). Then, 600 ml of pure toluene was added to them in a 1-liter glass balloon and boiled for 2 hours. After that, the formaldehyde that decomposed after boiling for 2 hours was transferred to distilled water (250 ml) and the solution was completed with pure water to 2 liters. Finally, the formaldehyde in the solution was determined photometrically with the help of a spectrophotometer.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In this section, the physico-mechanical properties (PMP) and formaldehyde emission (*FE*) in the study are evaluated and discussed based on tables and

a) b) c) d)

Figure 1 Production stages of test samples: a) in the field, b) chipping, c) pressing, d) sample
Slika 1. Faze proizvodnje ispitnih uzoraka: a) na terenu, b) usitnjavanje, c) prešanje, d) uzorak

figures formed from the results of ANOVA and DUNCAN's mean separation tests applied to the data obtained in the laboratory. Board density distributions are shown in Figure 2.

As seen in Figure 2, although the density distribution curves of the boards are non-linear, the density values are within certain limits. Since the amount of fiber per unit area in the board varies, the density distribution graphs also vary accordingly. As known, the type of wood used, the production conditions and the amount of chemicals affect the density. When the obtained values were compared with the targeted 650 kg/m^3 density, it was determined that they were in accordance with the 7 % tolerance specified in the TS EN 622-5 (2011) standard.

Likewise, the statistical analysis results of the WA and TS averages of the test boards made from wood chips and annual plant mixtures during the water absorption periods of 2 and 24 hours are presented in Table 2.

Table 2 shows that there was no significant difference between the two-hour *WA* values of the control samples and the board samples produced from cotton and sunflower stalks. However, a significant difference was detected between the 2 hours *WA* values of the wheat stalks and control samples. Compared to the control samples, the best 2-hour *WA* values were measured in cotton stalks, sunflower stalks and wheat stalks, respectively. The highest values in 24-hour *WA* were calculated as 129.6 % and 134.6 % in M50 and N75 group samples with high wheat stalk additives, respectively. These results show that in parallel with the increase in annual plant rate in the board, the 2– and 24-hour water absorption values also deteriorated. Similarly, Kozlowski and Piotrowski (1987) reached TS values of 20 % and 25 % for composite boards made from flax and hemp, respectively. In a study conducted with similar material Bektas *et al.* (2005) noted that the *WA* values of particle boards increased with the increase of sunflower ratio in the board matrix. Buyuksari *et al.* (2010) also proved that the addition of stone pinecone particles positively affected the dimensional stability of the boards. Kalaycioglu (1992), Arslan *et al.* (2007) and Copur *et al.* (2007) confirmed that the use of non-wood lignocellulosic materials in particle board production increases the water absorption values of the produced boards compared to wood.

Analysis of the data in Table 2 revealed the existence of significant differences at the $\rho<0.001$ confidence level between the water absorption values of control group specimens and the water absorption values of group E00, M50, N75 and P00 samples.

Guler *et al.* (2008), Yasar and Icel (2016) revealed that adding annual plants to composite boards increased the thickness increase values of the produced boards compared to wood. At the same time, Bektas *et al.* (2005) determined that in composites produced from sunflower stalks, the TS values of the samples varied depending on the sunflower concentration in the board.

However, the results of water absorption and thickness swelling increment results, including control samples, did not exceed the minimum threshold required by the EN standard EN 312 (2005) for general purpose use and interior equipment. In order to eliminate this negativity regarding water absorption values in composite boards, the use of paraffin is recommended by Ugur (2021).

Table 3 shows the results of ANOVA and Duncan's mean separation analysis applied to the measured data for mechanical properties and formaldehyde emission. It can be seen in the same table that all ANOVA analysis results applied to mechanical properties show significant differences at the ($P<0.05$) level. Also, the test results on the mechanical properties of the test boards produced from annual plants and their mixtures were lower than the control group samples. Again, it was observed that the mechanical properties of the test

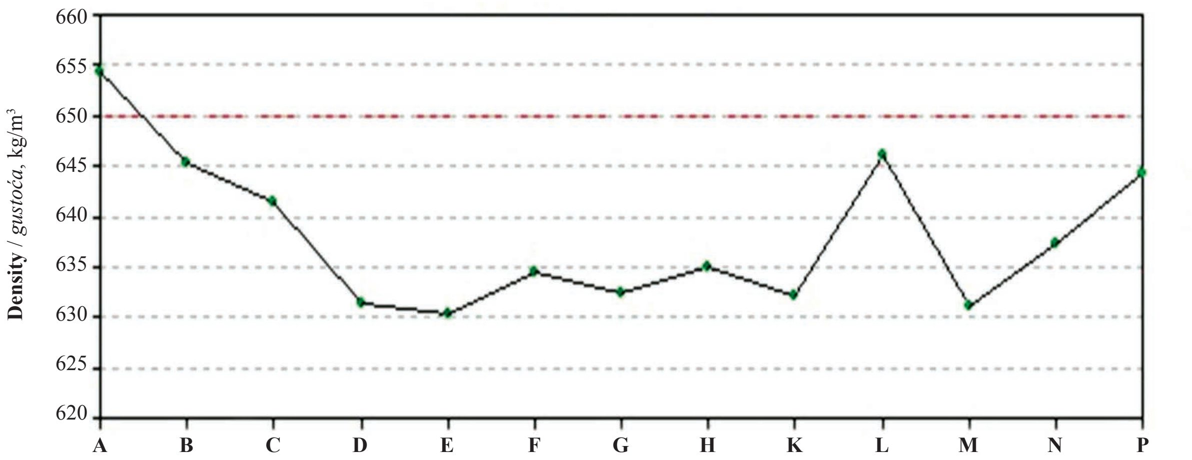

Figure 2 Boards density distribution
Slika 2. Prikaz gustoće ploča

Table 2 Statistical analysis results of water absorption and thickness swelling tests*
Tablica 2. Statistička analiza rezultata ispitivanja apsorpcije vode i debljinskog bubrenja*

Board type *Vrsta ploče*	***ST*, h**	**Water absorption** / *Upijanje vode*			**Thickness swelling** / *Debljinsko bubrenje*		
		Mean, %** *Srednja vrijednost, %***	**Standard deviation** *Standardna devijacija*	***COV*, %**	**Mean, %**** *Srednja vrijednost, %***	**Standard deviation** *Standardna devijacija*	***COV*, %**
A00	2	68.0a	16.10	23.67	19.6a	15.28	72.03
B25	2	71.6a	60.49	84.46	23.5ab	19.42	82.5
C50		72.3a	81.50	112.76	25.1ab	7.7	30.64
D75		76.6ab	64.28	83.94	26.1ab	6.6	25.25
E00		79.0abc	58.88	74.56	27.1abc	4	14.72
F25	2	76.0ab	8.34	10.97	22.5a	14.07	62.43
G50		78.8abc	12.76	16.20	24.1ab	36.98	52.96
H75		83.3abc	38.13	45.76	25.5ab	9.55	37.45
K00		84.2abc	23.52	27.93	26.7abc	21.42	79.93
L25	2	100.6bcd	29.05	28.88	32.0abcd	21.74	67.93
M50		105.1cd	30.56	29.08	34.3abcd	18.28	53.27
N75		115.8d	53.48	46.17	37.7cd	22.23	58.98
P00		116.4d	41.57	35.73	40.3d	20.94	51.91
A00	24	81.9a	26.67	32.53	23.2a	0.98	4.23
B25	24	84.6a	54.97	64.94	28.1ab	0.54	1.93
C50		87.0a	89.12	60.12	29.1ab	2.38	8.16
D75		89.6a	53.87	60.15	31.2abc	2.69	8.61
E00		93.3ab	70.92	75.98	33.9bc	18.89	55.72
F25	24	86.9a	10.86	12.5	27.9ab	9.06	32.45
G50		91.7ab	27.64	30.12	28.1ab	12.16	43.17
H75		93.1ab	50.1	53.78	30.4ab	16.56	62.74
K00		95.6abc	27.01	28.14	32.1abc	16.64	51.84
L25	24	118.9bcd	26.47	22.26	34.7ab	22.44	72.95
M50		120.7cd	30.18	24.99	38.9bc	18.89	55.72
N75		129.6d	44.81	34.56	42.9bc	24.8	68.96
P00		134.6d	36.76	27.3	46.0c	24.69	61.65
P_{SL}		*P<0.001*	-	-	*P<0.09*	-	-

*The number of samples is 30, *ST* – Soaking time, *SL*– Significance level, *COV*– Coefficient of variation, **According to the Duncan Test, there is no significant difference between the mean values represented by the same letters. / **Broj uzoraka je 30, ST – vrijeme potapanja, SL – razina značajnosti, COV – koeficijent varijacije; **prema Duncanovu testu, nema značajne razlike između srednjih vrijednosti označenih istim slovima.*

specimens decreased with the increase of annual plant rate in the panel matrix.

The total group averages of the strength values of the test samples in Table 3 can be listed as follows, from the largest to the smallest: cotton stalks (B25, C50, D75, E00), sunflower stalks (F25, G50, H75, K00) and wheat stalks (L25, M50, N75, P00). In addition, from the results of Duncan's mean separation test in Table 3, it can be said that annual plant properties in general. In terms of the mechanical properties of particle boards, Martins *et al.* (2020) recorded that annual plant waste is lower than eucalyptus wood-based control. Results of some studies on the subject (Ferraz *et al.*, 2020; Onuaguluchi and Banthia, 2016; Hejna *et al.*, 2020; Kashparow *et al.*, 2019; Pickering *et al.*, 2016; Saba *et al.*, 2016; Stokke *et al.*, 2013) indicate that the ratio of chemical components strongly influences the mechanical properties, since cellulose, hemicellulose and lignin in the structure of lignocellulosic material are primarily responsible for the bonding behavior and degradation of natural fibers in composites. According to the findings of Salem and Böhm (2013), the effect of the chemical composition of wood on formaldehyde release is much more important than its physical or anatomical structure. Based on these assumptions, it is stated in the relevant literature that especially cellulose is more effective on the tensile and elastic properties of lignocellulosic materials (Genet *et al.*, 2005; Commandeur and Pyles, 1991; Turmanina, 1965), while the effect of lignin concentrates on compressive and hardness properties (Zhang *et al.*, 2013; Aili *et al.*, 2012; Hathaway and Penny, 1975; Ouyang *et al.*, 2011).

On the other hand, the comparison of the *FE* values measured according to the mixture percentages of the test samples obtained from the composite boards produced from WC-CS, WC-SS and WC-WS mixtures with the relevant standard EN 120 (1996) can be seen in Figure 3. Considering the results of WC-CS mixtures in Fig.3a, it can be seen that the FE values of the A00, B25 and C50 group samples, except for D75 and

Table 3 Test and analysis data of mechanical properties *
Tablica 3. Podatci ispitivanja mehaničkih svojstava i njihova analiza *

Board type *Vrsta ploče*	***SBS*, N/mm²**	***COV*, %**	***MOE*, N/mm²**	***COV*, %**	***TSP*, N/mm²**	***COV*, %**
Means (Standard divisions) / *Srednje vrijednosti (standardne devijacije)***						
A00	18.0 (1.79)a	9.94	4620.8(449.8)a	9.72	0.97(0.20)a	20.70
B25	17.4 (2.36)a	13.53	3773.1(435.8)b	11.56	0.91(0.21)bc	23.69
C50	15.3(0.75)cd	11.95	3757.3(542.3)b	14.44	0.80(0.15)de	19.18
D75	14.4(1.99)d	13.75	3282.2(605.9)c	18.85	0.77(0.18)e	23.41
E00	13.1(1.78)e	13.60	2819.0(418.6)d	14.86	0.55(0.14)f	24.75
F25	17.0(2.14)ab	9.55	3173.2(697.7)c	20.71	0.80(0.11)cd	14.08
G50	16.2(2.46)bc	11.55	2312.7(802.9)e	20.10	0.83(0.13)de	14.86
H75	16.1(2.85)bc	14.23	2023.1(210.4)ef	24.72	0.75(0.14)e	17.25
K00	15.6(1.35)bc	15.70	1800.3(493.3)fg	22.40	0.47(0.10)g	19.32
L25	11.7(1.70)f	15.10	3114.2(909.1)c	25.19	0.35(0.05)h	13.55
M50	7.2(1.06)g	12.50	2265.4(424.8)e	17.75	0.33(0.05)h	12.17
N75	6.6(0.59)h	14.60	1555.41(416.4)g	25.41	0.30(0.02)h	11.16
P00	5.4(0.32)h	7.95	1085.8(406.9)h	29.33	0.29(0.04)h	15.02
P_{SL}	*P<0.000*	-	*P<0.000*	-	*P<0.000*	-
V_{EN}	11.5		1600		0.24	

*The number of samples is 30, BT – Board type, *SBS* – Static bending strength, *MOE* – Modulus of elasticity, *TSP* – Tensile strength perpendicular to the surface, *SL* – Significance level, *COV*– Coefficient of variation (%), EN – Standard value for EN, **According to the Duncan's mean separation test, there is no significant difference between the mean values represented by the same letters.
**Broj uzoraka je 30, BT – vrsta ploče, SBS – statička* čvrstoća *na savijanje, MOE – modul elastičnosti, TSP – vlačna* čvrstoća *okomito na površinu, SL – razina značajnosti, COV – koeficijent varijacije (%), EN – standardna vrijednost za EN; ** prema Duncanovu testu, nema značajne razlike između srednjih vrijednosti označenih istim slovima.*

E00, are below the upper limit specified in EN 120 (1996) (8 mg/100 g). Again, the *FE* values of D75 (75 %) and E00 (100 %) group specimens, which have high CS content, were determined to be higher than other mixture samples. In a study on the subject, Liang *et al.* (2021) remarked that chestnut bark chips effectively reduced *FE* values. Similar results were reported in previous studies (Nemli *et al.*, 2004; Buyuksari *et al.*, 2010). This research stressed that the decrease in *FE* values in the panels may be due to the high amounts of polyphenolic extractives in bark, especially tannins. Similarly, Nemli and Colakoglu (2005) found that the incorporation of mimosa bark particles greatly reduces *FE* values of particleboards.

As for the WC-SS matrixes in Figure 3b, the best result in terms of *FE* was obtained from these mixture samples. All the *FE* values calculated for the samples belonging to F25, G50, H75 and K00 groups were within the limits specified in the EN 120 (1996) standard. Here, it is a remarkable result that the *FE* values (7.2 mg/100 g) of the K00 group samples produced from 100 % SS were below the standard value (8 mg/100 g). For this reason, in areas of use, where environmental sensitivity comes to the fore, composite materials produced from pure SS or WC-SS mixtures in varying proportions may be preferred. Similarly, Martins *et al.* (2020) state that increasing the tannin extract in urea-formaldehyde adhesive reduces free formaldehyde emission in particleboards by 22.5 %. As seen in Figure 3c, *FE* analysis performed for board groups consisting of WC-WS mixtures yielded results similar to the values obtained from WC-CS mixture samples. While the *FE* values of the L25 and M50 group samples (5.1 and 6.0 mg/100 g, respectively) remained below the upper limit required by the relevant standard, the *FE* values of the N75 and P00 groups (8.5 and 9.3 mg/100 g, respectively) exceeded the relevant ultimate value.

It can be thought that this negative result regarding the *FE* value, which occurred in the N75 and P00 groups related to *FE* value, was due to the components of *WS* (Table 2) and their known sensitivity to glue. Shi *et al*. (2006) state that raw materials with lower *FE* values, such as WC, SS and tea leaves, can be added to composite panels to reduce the *FE* values exceeding the standard emissions emitted from high proportions of WS mixtures in the board matrix.

Similar to these findings, Buyuksari *et al*. (2010) determined that formaldehyde emissions were significantly reduced by adding cone particles to composite panels. Besides, the addition of poppy husks into particleboards significantly decreased formaldehyde emission (Keskin *et al*., 2015). Processing conditions of wood-based panels have an important role in reducing board formaldehyde emission, therefore Ismail *et al*. (2006) stated that board formaldehyde emission will decrease with increasing press cycle time.

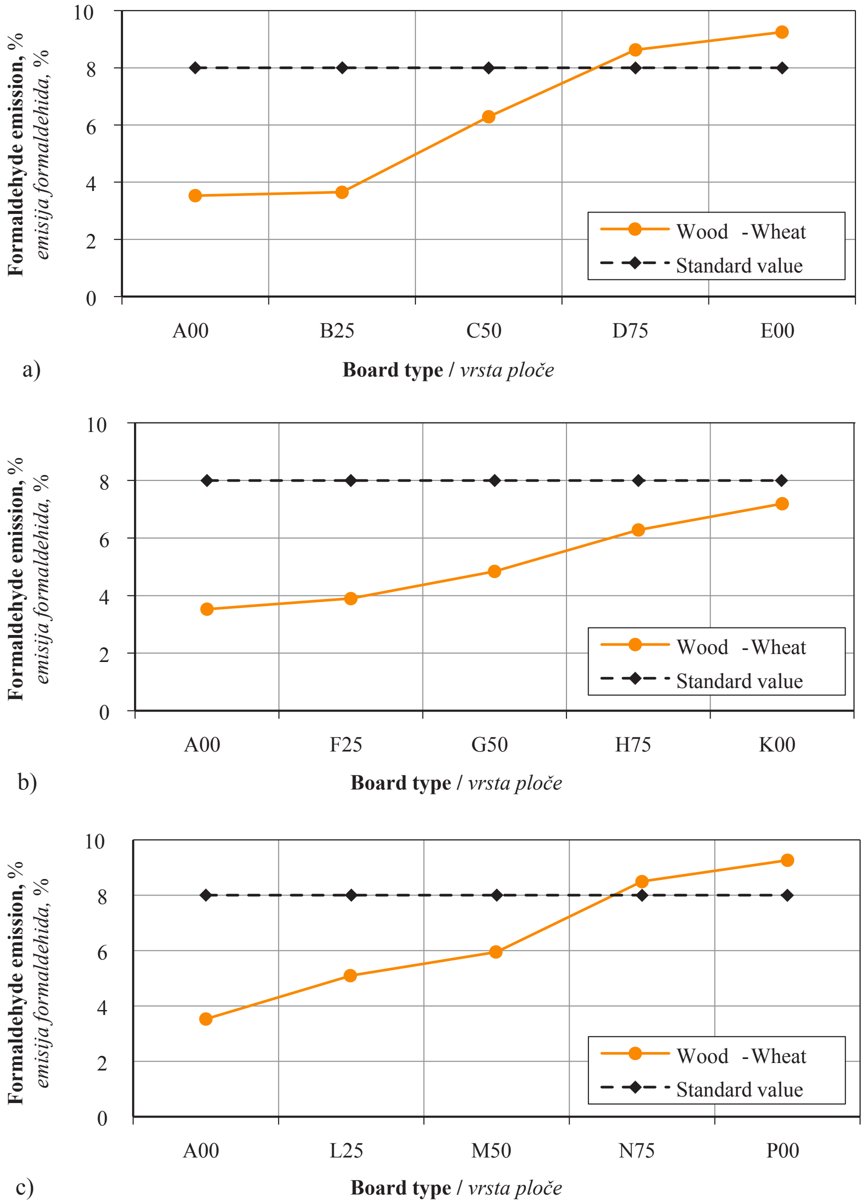

Figure 3 Comparison of formaldehyde emission percentages with the standard value: a) Cotton stalks, b) Sunflower stalks, c) Wheat stalks
Slika 3. Usporedba postotaka emisije formaldehida sa standardnom vrijednošću: a) stabljikâ pamuka, b) stabljikâ suncokreta, c) stabljikâ pšenice

4 CONCLUSIONS
4. ZAKLJUČAK

The main outcomes obtained as a result of the tests and analyses carried out within the scope of this research are summarized below.

In the study, parallel with the increase in the annual plant ratio in the board, 2– and 24-hour water absorption and thickness swelling values worsened and the results could not meet the requirements of the EN 312 (2005).

In mechanical properties, it was also found that the strength values decreased as the WAP ratio in the board matrix increased. Except for the control group (K00: 0.68 N/mm^2), the best mechanical properties in WAP-mixed samples were obtained from B25 group samples with 25 % CS added. Most of the mechanical properties, except tensile strength, met the requirements of the relevant standards.

In terms of ecology, the *FE* values of the test specimens met the requirements of EN 120 (1996), except for the D75 (8.63 %), E00 (9.26 %), N75 (8.50 %) and P00 (9.25 %) groups.

In the light of the data obtained, it can be suggested that the test panels can be used in environmentally sensitive areas where low relative humidity and moderate mechanical strength are required, such as interior design, wooden building partition panels and furniture.

Furthermore, in case annual residue plants (ARP) stalks are not used in industrial areas, the prevention of their inappropriate disposal and destruction, such as incineration and burial, should also be considered an important environmental benefit.

Finally, this study can be an important step for those who want to conduct more advanced level research on this subject and who will produce low-cost ecological building materials.

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