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STRAW OF WHITE MUSTARD (*SINAPIS ALBA*) AS AN ALTERNATIVE RAW MATERIAL IN THE PRODUCTION OF PARTICLE BOARDS RESINATED WITH UF RESIN

Dorota Dukarska, Janina Łęcka, Katarzyna Szafoni
Poznań University of Life Sciences

Abstract. This study evaluated the applicability of particles of white mustard straw as a substitute of wood chips in the manufacture of particle boards, resinated with UF resin. The scope of work included the determination of suitability of mustard straw in the manufacture of particle boards, the manufacture of boards with different proportions of straw and the determination of their basic physico-mechanical properties. Produced single-layer particle boards contained 10, 25, 50, 75 and 100% mustard particles in relation to chip mass. Recorded results indicated that straw of white mustard may constitute a valuable substitute of wood chips in the production of general use particle boards and interior boards, including furniture, used under dry conditions. It was also shown that partial substitution of wood chips with particles of mustard straw in case of boards with density reduced by 30%.

Key words: particle board, mustard straw, substitution

INTRODUCTION

Deficit of wood, its growing prices and concern for the natural environment have resulted in a situation when annual plants and their waste products have become the subject of numerous studies on the search and management of potential substitutes of timber. In view of the chemical composition, morphology and the volume of production, cereal straw is the most promising lignocellulose waste material. However, the primary obstacle for the application of cereal straw in industry, particularly board industry, is the seasonality of harvest, and as a consequence – the impossibility to ensure continuous supplies for the production process. Thus the authors of this study conducted investigations on the production of particle boards with the potential application of waste materials from alternative plants, including herbaceous plants such as evening primrose [Dukarska et al. 2010], and at present white mustard, harvested in the period following

Corresponding author – Adres do korespondencji: Dr inż. Dorota Dukarska, Department of Wood-Based Materials of Poznań University of Life Sciences, Wojska Polskiego 38/42, 60-627 Poznań, Poland, e-mail: ddukar@up.poznan.pl

cereal harvest. Mustard is a spring oil plant, belonging to the family *Brassicaceae*, including also rape, and comprising 120 species, of which 30 are found in Poland in the wild or are grown as crops [Klóska 2007]. Cultivation of mustard is not difficult. The plant yields well on sandy loams rich in calcium. From the technological point of view, the most important part of this plant is its stem, erect, covered with rough hairs, reaching 60 or even 80 cm in height.

White mustard (*Sinapis alba)* due to the wide range of its applications is a multifunctional plant. It is grown in order to obtain seeds, after processing used in the food, cosmetics and pharmaceutical industries (spring sowing, to mid-April), and as a catch crop increasing the biological activity of soil (autumn sowing, to mid-August). Due to its phytosanitary effect, mustard reduces the threat of many diseases and pests of cereals. Thanks to its rapid growth rate and short vegetation period mustard is also used as a nectar flow. Green forage cut before flowering has high nutritive value and may be used as feed for cattle and poultry [Sawicka and Kotiuk 2007]. A review of literature in terms of properties, applicability and growing of mustard has shown that this plant possesses certain advantages facilitating its use as a substitute of timber in the manufacture of particle boards. It is an annual plant with a high yielding potential, rapid growth and a short vegetation period (80-125 days), with high yield of green material, chemical composition comparable e.g. to rape straw [Mishra et al. 2000, Maiti et al. 2007]. It is resistant to changeable atmospheric and soil conditions – it is even said that this crop may be grown in areas where production of rape is costly, it may improve the profitability of oil crop cultivation and the economic situation of farms [Klóska 2007]. It is also essential that mustard is the most consistently yielding spring oil crop, since – as it results from literature – in the course of the last 20 years its yield has not dropped below 10 $dt \cdot ha^{-1}$ [Klóska 2007, Sawicka and Kotiuk 2007]. These advantages, as well as the observed return to natural products on the part of the general public, have resulted in a situation when since 2008 an increase has been observed worldwide in the area cropped to white mustard. According to the FAO report, for many years the biggest producers of white mustard have included Canada (in 2009 the volume of production was 208.3 thousand ton, Nepal – 135.5 thousand ton and Ukraine – 118.2 thousand ton). The volume of mustard production in Poland is difficult to estimate precisely, due to the predominant cultivation of this plant as a catch crop. According to the data of the Main Statistical Office, oil crops, i.e. mustard, sunflower, poppy, apart from rape, cover a total of 24 thousand ha. However, in view of the new prospects for cultivation connected with the development of new cultivars with an improved seed composition [Piętka 2007], we may expect in the nearest years for its production to increase and the scope of its application to be extended.

The aim of this study was to determine the applicability of particles of white mustard straw as a substitute of wood chips in the manufacture of particle boards resinated with urea-formaldehyde resin and to determine the effect of the proportion of mustard straw on its physico-mechanical properties.

MATERIAL AND METHODS

In the manufacture of experimental boards pine chips were used along with particles of white mustard straw, collected in the course of single-stage comminution in a knife shredder. The suitability of mustard straw for manufacturing particleboards was inferred on the basis of analyses of its chemical and fractional composition, as well as dimensional analysis of an average straw sample. The analysis of the chemical composition included determining the content of cellulose with Seifert method, and lignin with Tappi method (T-13 m-54), extraction substances in 96% ethanol with Soxhlet method and the content of mineral substances. Chemical composition of white mustard straw and its comparison to selected lignocellulose materials are given in Table 1. The fraction composition of a mixture of wood chips and particles of white mustard straw, determined on the basis of screening analysis, is presented in Figure 1. Dimensions and parameters of shape for average straw particles and wood chips from the fraction found at the highest proportion in the mixtures are given in Table 2.

Table 1. Chemical composition of white mustard straw and its comparison to selected lignocellulose materials
Tabela 1. Skład chemiczny słomy gorczycy białej i jego porównanie z wybranymi surowcami lignocelulozowymi

Component Składnik	Pine wood[1] Drewno sosny[1]	Rape straw[2] Słoma rzepakowa[2]	Wheat straw[3] Słoma pszeniczna[3]	Mustard straw Słoma gorczycy
Cellulose Celuloza	49.5	37.55	39.3	36.7
Lignin Lignina	27.5	21.30	20.7	21.6
Extraction substances Substancje ekstrakcyjne	5.0	3.76	5.0	3.46
Mineral substances Substancje mineralne	0.5	6.02	5.2	5.6

[1, 3]Kowalczyk et al. [2000] – Kowalczyk i in. [2000].
[2]Dziurka et al. [2005] – Dziurka i in. [2005].

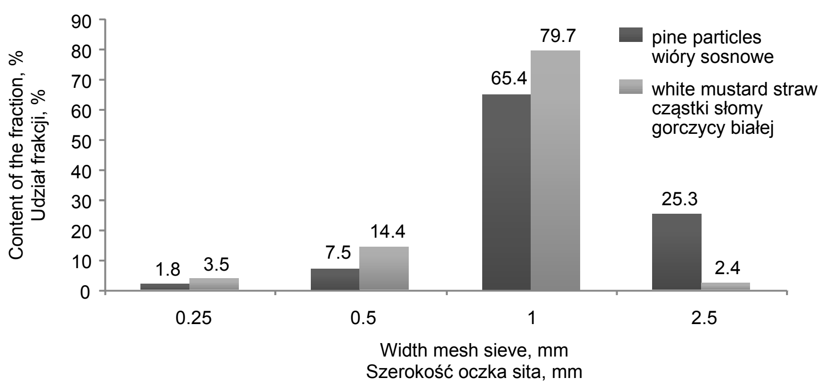

Fig. 1. A fraction composition of a mixture of wood particles and white mustard straw
Rys. 1. Skład frakcyjny mieszaniny wiórów drzewnych oraz cząstek słomy gorczycy białej

Table 2. Dimensional analysis and the shape of average wood chips and particles of white mustard straw
Tabela 2. Analiza wymiarowa oraz kształt przeciętnego wióra drzewnego i cząstki słomy gorczycy białej

Type of lignocellulose material Rodzaj surowca lignocelulozowego	Parameter – Parametr					
	l	a	b	λ	ψ	m
	mm			–		
Wood chips Wiór drzewny	10.3 ±4.61	0.51 ±0.23	1.80 ±0.67	20.09	3.50	5.74
Straw particles Cząstka słomy	9.4 ±2.5	0.34 ±0.08	1.44 ±0.44	27.60	4.21	6.56

l – lenght, a – thickness, b – width, λ – grade of slenderness, ψ – grade of flatness, m – width factor.
l – długość, a – grubość, b – szerokość, λ – stopień smukłości, ψ – stopień płaskości, m – współczynnik szerokości.

Table 3. Properties of UF resin used in testing
Tabela 3. Właściwości żywicy UF stosowanej w badaniach

Type of determination Rodzaj oznaczenia	Unit Jednostka	Value Wartość
Density Gęstość	$g \cdot cm^{-3}$	1.280
No 4 Ford Cup viscosity Lepkość umowna	s	99
Dynamic viscosity Lepkość dynamiczna	mPa·s	494
Apparent dry substance content Zawartość umownej suchej substancji	%	64.5
Miscibility with water Mieszalność z wodą	–	1.4
Gel time at 20°C Czas żelowania w 20°C	h	> 4
Gel time at 100°C Czas żelowania w 100°C	s	63
pH	–	7.85

The applied binding agent was industrial use resin (UF), commonly applied in the particle board industry. Characteristics of the resin are presented in Table 3.

In order to determine properties of boards manufactured with different proportions of mustard straw particles, under laboratory conditions, single-layer particle boards were manufactured at a density of 700 $kg \cdot m^{-3}$ and thickness of 12 mm with a 10, 25, 50, 75 and 100% share of straw. In view of the increase in the interest in the manufacture of lower density materials on the part of board industry it was also decided to investigate within the framework of this study the applicability of white mustard straw in the manufacture of medium heavy particle-straw boards with a density reduced to 600 and 500 kg·m^{-3}. The proportion of straw particles in these boards was determined on the basis of analyses of properties of boards with a density of 700 kg·m^{-3} and it amounted to 25%. Pressing of each type of boards was conducted applying the same parameters, i.e.:

– temperature 200°C
– pressure 2.5 N·mm^{-2}
– pressing time 22 s·mm^{-1} board thickness
– resination rate 12%.

Manufactured boards, after a 7-day conditioning period, were tested in terms of their physical and mechanical properties according to the binding technical standards, i.e.

– bending strength (MOR) and modulus of elasticity at bending (MOE) according to EN 310
– internal bond (IB) according to EN 319
– swelling in thickens after soaking in water for 2h and 24 h (G_t) according to EN 317 and absorbability – also after soaking in water for 2h and 24 h (W_n)
– free formaldehyde content using the perforator test according to EN 120.

RESULTS AND DISCUSSION

Analysis of testing results recorded in the first stage of the study (Table 4) showed that substitution of wood chips with particles of white mustard did not have a significant effect on bending strength or modulus of elasticity of boards. Changes which were observed are only around 6%, max. 15%. The recorded high values of bending strength and modulus of elasticity of manufactured boards meet the requirements of standards

Table 4. Mechanical properties of manufactured boards depending on the share of white mustard straw particles
Tabela 4. Właściwości mechaniczne wytworzonych płyt w zależności od udziału cząstek gorczycy białej

Share of particles Udział cząstek słomy %	Bending strength Wytrzymałość na zginanie		Modulus of elasticity Moduł elastyczności		Internal bond Wytrzymałość na rozciąganie prostopadłe do płaszczyzn płyty	
	N·mm^{-2}					
0	13.2	*1.18**	2 520	*203**	0.85	*0.062**
10	14.4	*0.77*	2 670	*154*	0.82	*0.069*
25	14.7	*1.30*	2 880	*261*	0.68	*0.048*
50	14.7	*1.68*	2 790	*253*	0.59	*0.070*
75	14.8	*1.00*	2 710	*142*	0.46	*0.023*
100	14.5	*0.82*	2 690	*161*	0.29	*0.015*

*Standard deviation.
*Odchylenie standardowe.

EN 312, for P1 general use boards (the required MOR value of 11.5 N·mm^{-2}) as well as P2 interior boards, including furniture (required MOR – 13.0 N·mm^{-2}, MOE – 1800 N·mm^{-2}) used under dry conditions. It is essential from the point of view of the actual evaluation of the effect of the degree of substitution of chips with straw particles on properties of tested boards. Manufactured boards had a single-layer structure, i.e. they were devoid of face layers, which in case of layer boards to a considerable degree determine bending strength of boards and their modulus of elasticity.

However, a different trend is found for the results of internal bond testing. As it had been assumed, an increase in the share of mustard particles in tested boards resulted in a gradual decrease in their internal bond, particularly over a 25% content of mustard in the board. This is caused by the differences in the thickness of straw particles and wood chips, as well as the fact that a mixture of straw particles has a bigger absolute area per a unit of weight, which at the same resination rate reduces the share of area of glue lines, thus reducing the internal bond of boards. Still boards manufactured even at a 100% share of mustard straw particles meet in this respect requirements of standard EN 312, for P1 general use boards used under dry conditions (required 0.28 N·mm^{-2}). Boards with a 75% share of mustard particles meet also the requirements for P2 boards used in interior design, including furniture, also used under dry conditions (required 0.40 N·mm^{-2}).

Water resistance of boards manufactured with the share of mustard particles was determined on the basis of their swelling in thickness and absorbability after 2 and 24 h soaking in water and their results are presented in Table 5. Analyses of these data showed that the dynamics of changes in swelling in thickness and absorbability of tested boards are different, depending on the time of exposure to the action of water. At the initial stage of the study their values were recorded to decrease, particularly for boards manufactured in 100% from mustard waste by 17 and 31%, respectively. Such a behaviour

Table 5. Swelling in thickness and absorbability of manufactured boards after 2 and 24 h soaking in water, depending on the share of white mustard straw particles

Tabela 5. Spęcznienie oraz nasiąkliwość wytworzonych płyt, po 2 i 24 h moczenia w wodzie, w zależności od udziału cząstek słomy gorczycy białej

Share of straw particles Udział cząstek słomy %	Type of test – Rodzaj testu							
	swelling in thicknes spęcznienie na grubość %				absorbability nasiąkliwość %			
	2 h		24 h		2 h		24 h	
0	26.6	*2.22**	35.3	*2.63**	63.0	*3.49**	77.7	*1.75**
10	25.7	*1.94*	34.8	*1.54*	59.8	*3.10*	80.8	*1.62*
25	25.8	*1.57*	36.9	*2.26*	59.4	*4.63*	82.7	*3.06*
50	25.7	*3.10*	42.1	*2.42*	60.1	*6.60*	89.2	*3.38*
75	26.4	*2.76*	46.7	*3.70*	53.3	*4.94*	91.5	*4.04*
100	22.1	*2.43*	52.2	*2.90*	43.5	*3.91*	98.3	*4.36*

*Standard deviation.
*Odchylenie standardowe.

of boards made from mustard under the influence of a short-term action of water may be explained by a lower thickness of straw particles that those of wood chips, which causes an increase in the number of elementary microlayers in the board and at the same time reduces the volume of free spaces, capable of filling with water in such a short time. Samples subjected to 24 h soaking in water showed that with an increase in the share of mustard in the board values of tested parameters were observed to increase. Swelling in thickness of boards made with 100% mustard was by approx. 48% bigger than that in reference boards, while absorbability – by approx. 26%. These changes were caused, analogously as in case of internal bond, by the smaller area of glue lines per unit of straw mass, which additionally at long-term exposure to water are subjected to mechanical destruction and depolymerization as a result of hydrolysis of UF resin bonds.

In the second part of this study particle boards with a density reduced to 500 and 600 $kg \cdot m^{-3}$ were manufactured as well as boards with a 25% substitution of wood chips with mustard waste. Results of testing of their physico-mechanical properties are presented in Tables 6-8. The conducted analysis of data did not show significant changes either in their bending strength or modulus of elasticity (Table 6). The rate of wood chip substitution with mustard straw, adopted in this study for particle boards with a reduced density, resulted consistently in a reduction of internal bond values on average by approx. 20% in relation to particle boards of the same density. Since the value of internal bond co-determines the strength of joints in furniture joints, then from the point of view of the application of such boards in the manufacture of furniture it is essential for the obtained values of internal bond to meet the requirements of standard EN 312 for general use boards used under dry conditions. In case of boards with a density of 600 $kg \cdot m^{-3}$, recorded values also meet the requirements for boards to be used in interior design.

Table 6. Mechanical properties of straw-particle boards depending on density
Tabela 6. Właściwości mechaniczne płyt słomowo-wiórowych w zależności od ich gęstości

Density of boards Gęstość płyt $kg \cdot m^{-3}$	Bending strength Wytrzymałość na zginanie $N \cdot mm^{-2}$				Modulus of elasticity Moduł elastyczności $N \cdot mm^{-2}$				Internal bond Wytrzymałość na rozciąganie prostopadłe do płaszczyzn płyty $N \cdot mm^{-2}$			
	percentage of straw content – procentowy udział słomy											
	0		25		0		25		0		25	
700	13.2	*1.18**	14.7	*1.30**	2 520	*203**	2 880	*261**	0.85	*0.062**	0.68	*0.048**
600	10.6	*0.55*	10.0	*0.63*	2 170	*111*	1 980	*161*	0.65	*0.026*	0.52	*0.039*
500	5.40	*0.84*	5.60	*0.52*	1 240	*171*	1 240	*69*	0.48	*0.012*	0.37	*0.022*

*Standard deviation.
*Odchylenie standardowe.

Analysis of tests on water resistance of straw-particle boards of a reduced density showed that irrespective of the time of soaking in water the manufactured straw-particle boards had higher swelling in thickness values that boards made only from wood chips of the same density (Table 7 and 8). The recorded changes amounted to 30% for boards with a density of 600 $kg \cdot m^{-3}$ and 40% for density of 500 $kg \cdot m^{-3}$. The share of mustard

Table 7. Swelling in thickness of straw-particle boards after 2 and 24 h soaking in water depending on density
Tabela 7. Spęcznienie płyt słomowo-wiórowych po 2 i 24 h moczenia w wodzie w zależności od ich gęstości

Density of boards Gęstość płyt kg·m^{-3}	Swelling in thickness, % – Spęcznienie na grubość, %							
	2 h				24 h			
	percentage of straw content – procentowy udział słomy							
	0		25		0		25	
700	26.6	*2.22**	25.8	*1.57**	35.3	*2.63**	36.9	*2.26**
600	22.7	*1.29*	30.6	*0.94*	31.6	*1.35*	39.4	*0.93*
500	20.0	*1.84*	28.5	*1.58*	25.9	*2.10*	35.5	*1.79*

*Standard deviation.
*Odchylenie standardowe.

Table 8. Absorbability of straw-particle boards after 2 and 24 h soaking in water depending on density
Tabela 8. Nasiąkliwość płyt słomowo-wiórowych po 2 i 24 h moczenia w wodzie w zależności od ich gęstości

Density of boards Gęstość płyt kg·m^{-3}	Absorbability, % – Nasiąkliwość, %							
	2 h				24 h			
	percentage of straw content – procentowy udział słomy							
	0		25		0		25	
700	63.0	*3.49**	59.4	*4.63**	77.7	*1.75**	82.7	*3.06**
600	76.7	*2.86*	88.9	*1.96*	96.4	*2.67*	108	*1.71*
500	95.9	*2.59*	106	*3.19*	109	*2.05*	126	*2.58*

*Standard deviation.
*Odchylenie standardowe.

particles in the manufactured boards also resulted in an increase in absorbability of boards, determined after 2 and 24 h soaking in water, on average of 10-15%.

Measurement of free formaldehyde content, irrespective of the adopted manufacture conditions of particle boards, both those with and without the share of mustard straw particles, did not show significant changes. Although no formaldehyde bonding agent was applied in this study, the recorded results of the perforator test amounting to 3.9-5.2 mg $CH_2O \cdot 100$ g d.m. boards^{-1} qualifying the manufactured boards to hygiene class E1.

CONCLUSIONS

Based on the conducted tests it may be stated that in particle boards resinated with UF resin:

- substitution of wood chips with particles of white mustard straw in the manufacture of particle boards results in a reduction of internal bond of boards and their water resistance at long-term exposure to water, being the higher, the bigger the share of straw particle is;
- boards manufactured in 100% from mustard straw particles exhibit strength properties required for general use boards used under dry conditions, while boards with a 75% share of mustard straw particles also meet the requirements of standards concerning boards under in interior design, including furniture;
- substitution of wood chips with mustard straw particles at 25% makes it possible to manufacture boards with a density reduced to 600 and 500 $kg \cdot m^{-3}$ with the maintenance of strength adequate for general use boards used under dry conditions;
- substitution of wood chips with particles of mustard straw does not affect the hygienic standard of particle boards;
- straw of white mustard may constitute a valuable substitute for wood chips in the manufacture of medium-heavy particle boards resinated with UF resin.

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SŁOMA GORCZYCY BIAŁEJ (*SINAPIS ALBA*) JAKO ALTERNATYWNY SUROWIEC W PRODUKCJI PŁYT WIÓROWYCH ZAKLEJONYCH ŻYWICĄ UF

Streszczenie. W pracy oceniono możliwości zastosowania cząstek słomy gorczycy białej jako substytutu wiórów drzewnych w procesie wytwarzania płyt wiórowych, zaklejonych żywicą UF. Zakres prac obejmował określenie przydatności słomy gorczycy do wytwarzania płyt wiórowych, wytworzenie płyt z różnym udziałem słomy oraz określenie ich podstawowych właściwości fizykomechanicznych. Wytworzone płyty wiórowe o strukturze jednowarstwowej zawierały 10, 25, 50, 75 i 100% cząstek gorczycy w stosunku do masy wiórów. Uzyskane wyniki badań pozwoliły stwierdzić, iż słoma gorczycy białej może być wartościowym substytutem wiórów drzewnych w produkcji płyt wiórowych ogólnego przeznaczenia oraz do wyposażeń wnętrz łącznie z meblami, użytkowanych w warunkach suchych. Wykazano również, iż istnieje możliwość częściowej substytucji wiórów drzewnych cząstkami słomy gorczycy w płytach o gęstości obniżonej o 30%.

Słowa kluczowe: płyta wiórowa, słoma gorczycy, substytucja

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