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## PROPERTIES OF PARTICLEBOARDS WITH THE PARTICIPATION OF HEMP AND VINE PARTICLES IN THE CORE LAYER – PART II: OPTIMISATION OF THE COMPOSITION

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### ABSTRACT

Volarization of agro-industrial residues into value-added materials such as particleboards will increase the utilisation of natural bio-resources and support the transition to a circular economy.

In the first part of the publication, research was presented regarding the effect of the content of vine, hemp and wood particles in the core layer of three-layered particleboards on the properties of these panels. It was established that the variation in the content of vine and hemp particles does not affect the waterproof properties.

The present part represents the results of the optimisation of the core layer of the panels, given their mechanical properties. Data are delivered with accompanying analysis regarding the screw withdrawal resistance of particleboards. This property is of primary importance in using particleboards as a structural element in furniture production.

As a result of the conducted research, it was established that the panels fabricated with a core layer entirely of hemp particles have the best exploitation properties. It was also found that when using vine particles for the core layer of particleboards, their content is not recommended to be over 30%.

**Key words:** particleboards, vine particles, hemp particles, mechanical properties, optimisation.

### INTRODUCTION

Due to agro-industrial activity, significant amounts of lignocellulosic residual mass remain. Unfortunately, this mass is generally burned (Mohanty, A. K. et al. 2018; Auriga, R. et al. 2021). Given the transition to a circular economy and the maximum utilisation of natural resources, it is necessary usage of this mass for the fabrication of products with added value (Grigorov, R. et al. 2020; Auriga, R. et al. 2022, Pędzik, M. et al. 2022 a; Pędzik, M. et al. 2022 b). A possible utilisation of agro-industrial residues is their use as an alternative raw material in the production of particleboards (Réh, R. and Vrtielka, J. 2013; Kallakas, H. et al. 2018; Ferrandez-Villena M, et al. 2020; Zvirgzds, K. et al. 2022; Lee, S. H. et al. 2022).

In the first part of the study, the effect of the content of hemp and vine particles on the properties of three-layered particleboards was determined. It was found that the varied participation of hemp and vine particles in the core layer of the panels does not have a particular effect on their waterproof properties. It was found that, on the contrary, the increase in the content of hemp particles leads to an increase (improvement) in the mechanical properties of the panels (Grigorov, R. et al. 2022). However, the optimal composition to achieve maximum values for these mechanical properties has not been established.

Screw withdrawal resistance of the panels is an essential property given the applicability of these materials in structural elements in the production of furniture (Chen, Y. et al.

2016; Jivkov, V. and Elenska-Valchanova, D. 2019; Jivkov, V. and Petrova, B. 2020; Antov, P et al. 2020). Therefore, the variation of this property due to the change in the composition of particleboards is of interest.

### MATERIALS AND METHODS

For the study, eight particleboards with different hemp, vine and wood content in the core layer were produced under laboratory conditions. The corresponding panels were marked as follows: Panel type A (100% vine particles), Panel type B (80% vine and 20 % hemp particles), Panel type C (60% vine and 40% hemp particles), Panel type D (40% vine and 60% hemp particles), Panel type E (20% vine and 80% hemp particles), Panel type F (100% hemp particles) and REF (100% wood particles). A detailed description of the methods for the fabrication of particleboards can be found in Grigorov et al., 2022.

The properties of the panels were determined by EN 310 (modulus of elasticity and bending strength), EN 319 (internal bond strength), and EN 320 (screw withdrawal resistance). Eight specimens were used for each test.

Simplex lattice plans were used to deduce the regression models. These plans are particularly suitable in the study of mixtures, such as, in this case, the core layer of three-layer particleboards (Box, G. E. P. and Jenkins, G. M. 1970; Vuchkov, I. and Stoianov, St. 1980). The inferred model is chosen to be of the first degree, in which case the general form of the regression model is as follows:

$$\hat{Y} = b_1x_1 + b_2x_2 + b_3x_3, \quad (1)$$

where:  $\hat{Y}$  – the predicted value for the given property;

$x_1, x_2, x_3$  – components of the mixture (in this case, vine, hemp and wood particles);

$b_1, b_2, b_3$  – regression coefficients.

The optimisation was performed by stepwise regression with 1000 iterations. For this purpose, specialised software QStatLab, version 6.0, was used.

### RESULTS AND DISCUSSION

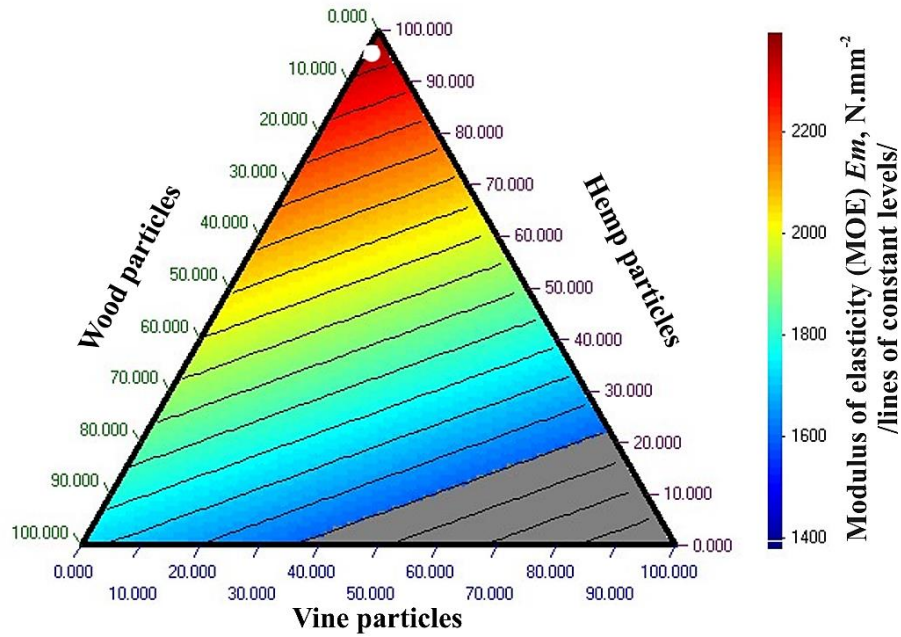
The regression models for the individual properties (modulus of elasticity, bending strength, internal bond strength, screw withdrawal resistance – face and screw withdrawal resistance – edge) of particleboards are presented in tabular form in Table 1.

**Table 1: Regression models for the effect of the composition on the properties of tree-layered particleboards**

Regression coefficient	Property	$b_1$	$b_2$	$b_3$	$F_{cal}$	$F_{(0.05; 2; 4)}$
	Modulus of elasticity (MOE)	13.799	23.711	17.220	54.929	6.944
	Bending strength (MOR)	0.073	0.130	0.080	31.306	6.944
	Internal bond strength	0.0034	0.0055	0.0033	24.725	6.944
	Screw withdrawal resistance – face	0.511	0.635	0.365	235.860	6.944
	Screw withdrawal resistance – edge	0.323	0.422	0.198	106.887	6.944

Variation of modulus of elasticity (MOE) depending on the composition of the

core layer of particleboards is presented in Fig. 1.



**Figure 1: Effect of the composition of the core layer on the modulus of elasticity of the panels (MOE) (grey zone represents MOE values below the requirements for P2 -panels)**

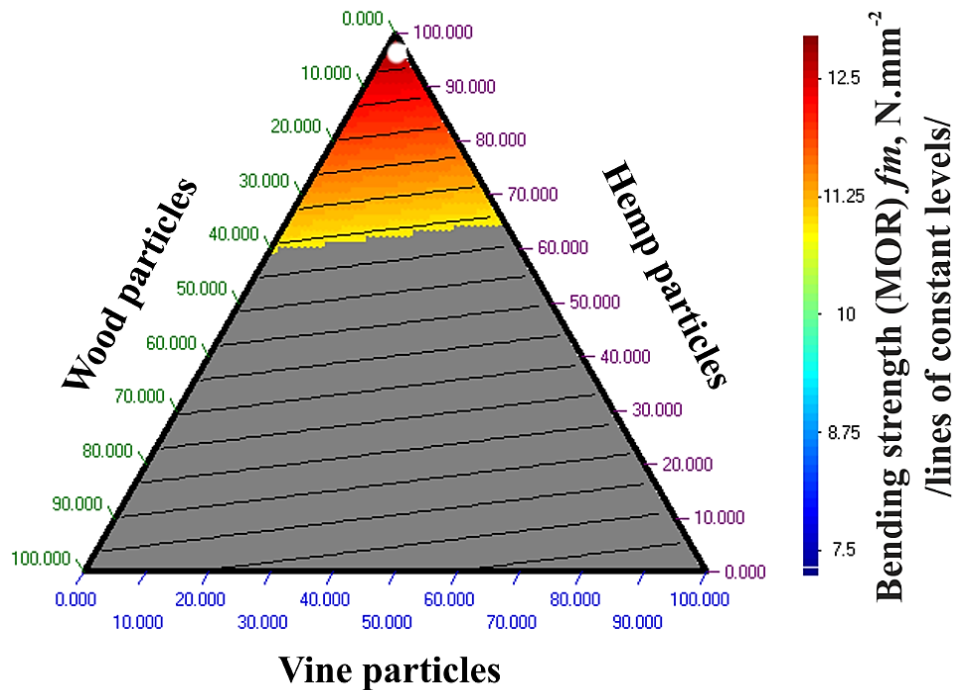
As seen from the "composition-property" diagram for MOE, as the content of hemp particles in the core layer increases, an increase in the MOE is established.

Panels could meet the MOE requirement for particleboards type P2 (interior furnishings, including furniture, for use in a dry environment) –  $1600 \text{ N.mm}^{-2}$  if the content of vine particles does not exceed 38%, as in this case, the content of wood or hemp particles should be at least 62%. The deterioration of the modulus of elasticity of particleboards with an increase of vine particles could be explained by the higher bulk density of this type of raw material and hence the lower compres-

sion ratio. That is also confirmed by the research of Auriga, R. et al. 2022 and Grigorov, R. et al. 2020. The referred studies also noted a decrease in this property with an increase in the content of vine particles.

Conversely, due to the low bulk density of the hemp particles, the MOE of particleboards improves as they increase in the core layer composition. The property's maximum value of  $2316 \text{ N.mm}^{-2}$  is obtained with a core layer composed entirely of hemp particles.

In a graphic form, the panels' bending strength, depending on the composition of their core layer, is presented in Fig. 2.



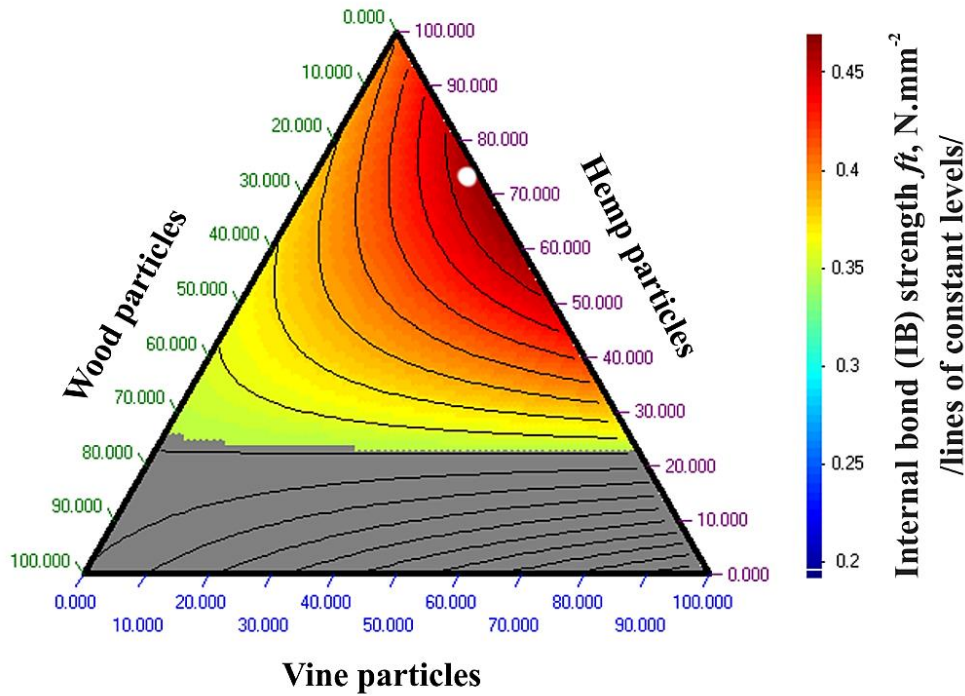
**Figure 2: Effect of the composition of the core layer on the bending strength of the panels (MOP) (the grey zone represents MOR values below the requirements for P2 -panels)**

From the "composition-property" diagram for the MOR of the panels, it can be seen that to achieve the requirements for this property for particleboards type P2, the content of vine particles in the core layer should not exceed 30%. Accordingly, in this case, the content of hemp or wood particles should be at least 70%. That should again be explained by the high bulk density of the hemp particles and the decreasing compression ratio when their amount increases.

Again here, as with MOE, increasing the content of hemp particles in the core layer in-

creases the MOR of the panels. The maximum bending strength of  $13.24 \text{ N.mm}^{-2}$  is when the core layer is composed entirely of hemp particles. The established regularities for improving the bending strength of the panels with increasing hemp particle content are also consistent with the results obtained by Réh, R. and Vrtielka, J. 2013, as well as by Zvirgzds, K. et al. 2022, Auriga, R. et al. 2022.

The variation of internal bond (IB) strength depending on the composition of the core layer is shown in Fig. 3.



**Figure 3: Effect of the composition of the core layer on the IB strength of the panels (grey zone represents IB strength values below the requirements for P2 – panels)**

It is clear from the graph that to achieve the requirement of  $0.45 \text{ N.mm}^{-2}$  for particleboards type P2, the content of vine particles in the core layer should be at most 75%, and accordingly, the hemp or wood particles should be at least 25%. Again, an explanation should be sought here with the reduced compression ratio with an increase in the content of vine particles in the core layer and reduced contact areas between the particles, which correspondingly reduced the number of adhesion areas and connections.

Interestingly, the property's maximum value is obtained with a core layer composed of 70% hemp and 30% vine particles. Here

an explanation can be given with the better mechanical properties of the vine particles, as their amount of up to 30% does not lead to a significant decrease in the compression ratio. The difference between the influence of the composition of the core layer in this property and the other two mechanical properties is that the failure zone is in the core layer. In MOE and MOR, it is in the face layers of the panels. Here, the vine particles' good strength plays a more significant role.

The variation of screw withdrawal resistance on the face of the particleboards is presented in Fig. 4.

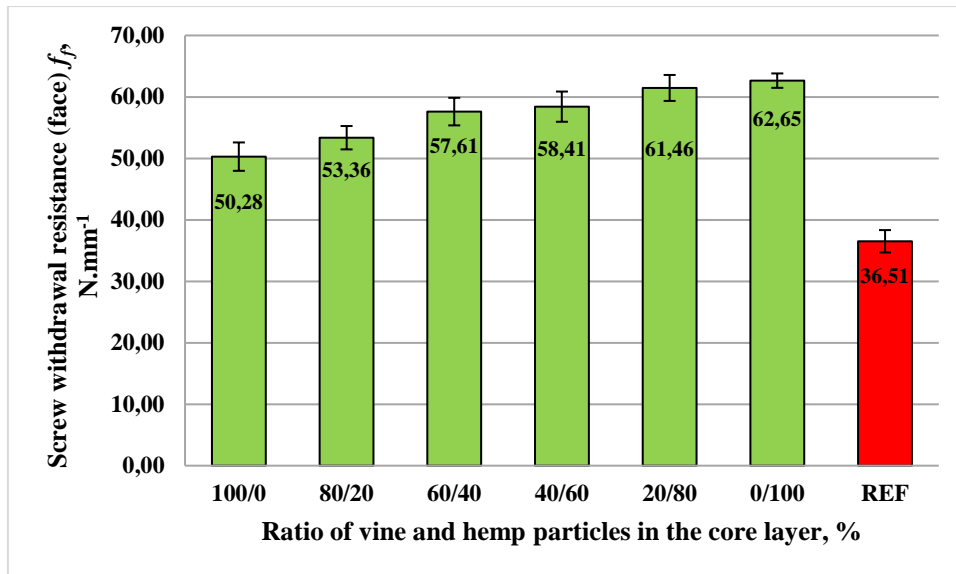


Figure 4: Variation of the screw withdrawal resistance – face (error bars represent the standard deviation)

With an increase in the content of hemp particles at the expense of the content of vine particles in the core layer of panels, an increase in screw withdrawal resistance by 1.25 times is observed. That is explained by hemp

particles' significantly lower bulk density than the bulk density of vine particles. The "composition-property" graphs also confirm that in Fig. 5.

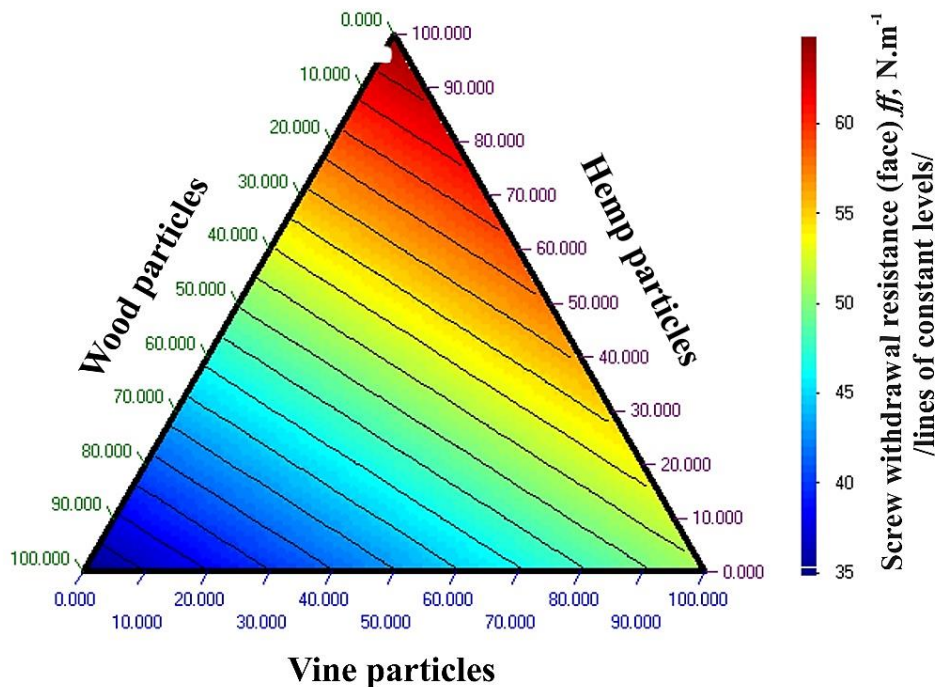


Figure 5: Effect of the composition of the core layer on the screw withdrawal resistance (face) of the panels

Interestingly is the fact that with a core layer of vine particles, the panels have a 1.38 higher screw withdrawal resistance – face than particleboards composed of a core layer of wood particles. The screw withdrawal resistance (face) is 1.72 times higher than the wood particle panels for boards with a core layer of only hemp particles. That should be

explained by the higher compression coefficient when using hemp particles and by the better mechanical strength of the vine compared to wood particles.

The variation of screw withdrawal resistance on the edge of the particleboards is presented in Fig. 6

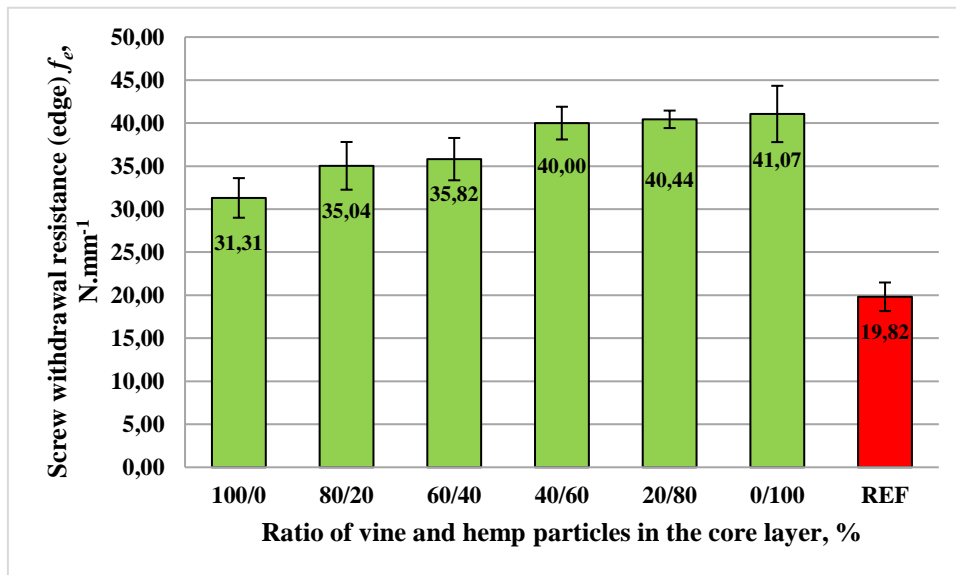
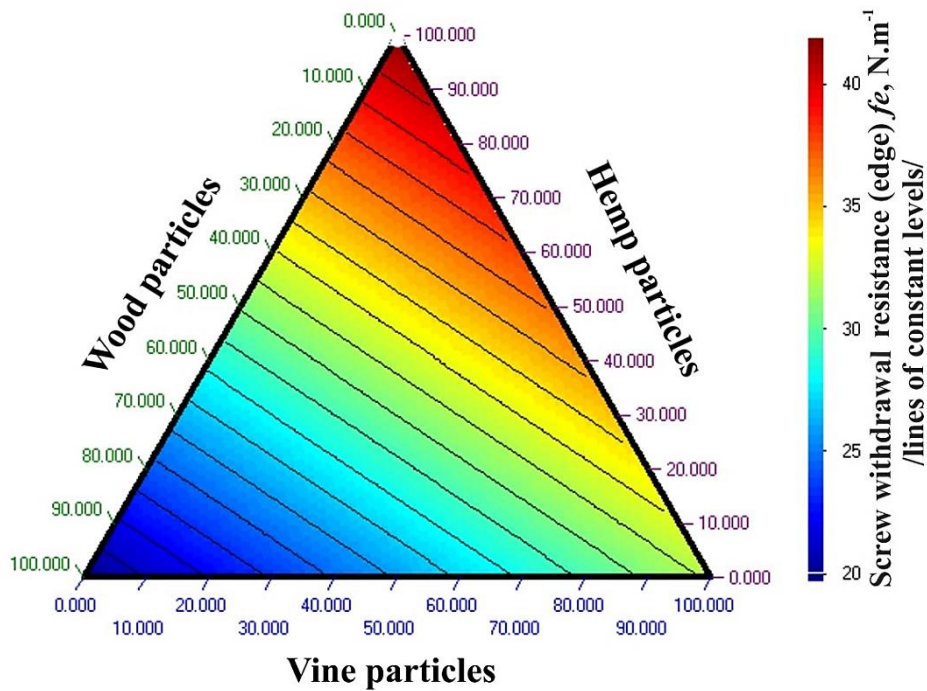


Figure 6: Variation of the screw withdrawal resistance – edge (error bars represent the standard deviation)

The data for screw withdrawal resistance perpendicular to the edge of the panels repeat to a significant extent the picture obtained for the property perpendicular to the face of the panels. However, for this property, the difference between the strength of particleboard with a core layer entirely of

vine particles and that with only hemp particles is smaller – 1.31 times. The results show a much better (high) screw withdrawal resistance (edge) when using vine and hemp particles than wood particles in the core layer. The maximum value for the property of 41.07 N.m<sup>-1</sup> is obtained with a core layer entirely made of hemp particles, Fig. 7.



**Figure 7: Effect of the composition of the core layer on the screw withdrawal resistance (edge) of the panels**

Better by 1.56 times for screw withdrawal resistance (edge), with a core layer of vine particles compared to wood particles alone, which should be due to the higher strength of vine particles compared to wood (Ferrandez-Villena M. et al. 2020; Auriga, R. et al. 2022). While when using hemp particles, in addition to the good strength of this material, a high compression ratio is also achieved (Réh, R. and Vrtielka, J. 2013; Kallakas, H. et al. 2018; Zvirgzds, K. et al. 2022). That leads to a significantly better screw withdrawal resistance than the panels obtained with a core layer of wood particles.

## CONCLUSIONS

As a result of the study, it was found that hemp and vine particles can successfully be used as an alternative to wood raw material source for the core layer of particleboards. However, it was established that when vine particles were used in the core layer of the panels, there was a deterioration in the MOE

and MOR. That is due to the high bulk density and the correspondingly low compression ratio of the vine particles. Therefore, using this kind of alternative raw material source should be considered for the face layers of the panels where the compression ratio is higher. It was determined that if vine particles are used in the core layer of particleboards, their amount should not exceed 30%. However, due to the good mechanical characteristics of vine particles, their participation of up to 30% in the core layer leads to improvement in the IB strength of particleboards.

Regarding the hemp particles, this alternative raw material source was highly suitable for the core layer of particleboards. Because of the high compression ratio, the particleboards fabricated with a core layer only of hemp particles have the best properties.

It should also be noted that particleboards with a core layer of hemp and vine particles have screw withdrawal resistance

significantly exceeding that of panels produced with a core layer of wood particles. That makes these alternative raw materials highly suitable for particleboards designed for furniture manufacturing.

### ACKNOWLEDGEMENTS

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**Conflicts of Interest:** The authors declare no conflict of interest.

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