Evaluation of the Use of Vineyard Pruning Biomass (Bobal Variety) in Constructive Bioproducts

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The use of by-products from agricultural and forestry activity, apart from many other environmental benefits, constitutes an alternative source of income, cost reduction, and support for the principles of the circular economy. The bobal grape is a variety of red grape that is cultivated on 65 thousand hectares only in Spain. Periodic maintenance of the crop must be carried out through winter pruning from December to March. The pruning biomass is burned or crushed and incorporated into the soil, producing environmental contamination and disease transmission. The objective of this work was to use the biomass from vineyard residues in the production of binderless particleboards without using any adhesives, thereby obtaining an ecological product that would benefit the environment. In the manufacturing process, the press temperature (130 °C) and pressure (2.6 MPa) were fixed, varying the particle size (<0.25, 0.25 to 1.00, and 1.00 to 2.00), and the pressing time (15, 30, and 45 min). The results showed that by using particles smaller than 0.25 mm and applying 45 min in the hot press, panels were manufactured that are suitable for general use in a dry environment and for the manufacture of furniture according to European standards.

DOI: 10.15376/biores.17.4.6542-6555

Keywords: Panel; Physical; Mechanical and thermal properties; Vitis vinifera

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INTRODUCTION

Building refurbishing and new construction projects must be addressed in the future by using materials with low environmental impact, such as bio-based materials. The use of these materials will help in reducing their global warming potential. Apart from many other environmental benefits, these by-products from agricultural and forestry activity are an alternative source of income and cost reduction while supporting the principles of the circular economy.

Agriculture activity generates large amounts of waste that is not properly managed in terms of the environment and the economy. Beyond reducing and recycling agricultural waste, co-products, and by-products, there are opportunities for new processes that enable innovative uses of such residues. From a technical point of view, these residues offer a wide variety of qualities in their fibers, and, if exploited properly, they can be used in the development of substitute materials for wood with innovative properties.

According to the International Organization of Vine and Wine OIV (Roca 2019), the worldwide area used to produce wine in 2018 was 7.4 million hectares, of which approximately 1 million was in Spain.

The Bobal grape is a variety of red grape, cultivated mainly in the Levante area with a global vineyard area of approximately 65 thousand hectares. It is a large vine, semi-upright, with thick erect and dense shoots and medium budding. Periodic maintenance of the crop must be carried out through winter pruning from December to March. These prunings are burned or crushed and incorporated into the soil, producing environmental contamination and disease transmission.

There are numerous studies on the properties of plant residues: coconut shell (Alavez-Ramírez *et al*. 2012; Kumar and Saha 2022), paper manufacturing waste with corn peel (Lertsutthiwong *et al*. 2008), kenaf fibers (Naik and Kumar 2021; Prabhu *et al*. 2022), cotton stem fibers (Zhou *et al*. 2010; Zhou *et al.* 2020), coconut shell and bagasse (Panyakaew and Fotios 2011), hemp fibers (Chikhi *et al*. 2013; Jiant *et al*. 2019), flax (Jiant *et al*. 2019; Ramesh 2019), giant reed (Ferrández-García *et al*. 2012; Suárez *et al*. 2022), canary palm (Ferrández-García *et al*. 2017), and Washingtonia palm (Ferrández-García *et al*. 2017).

Other authors have investigated the use of vine pruning to manufacture particleboards using urea formaldehyde (UF) resin as an adhesive (Ntalos and Grigoriou 2002), applying a chemical pretreatment to the particles and varying the proportion of UF (Yasar *et al*. 2010), or adding pine particles and UF (Ozen *et al*. 2014; Yeniocak *et al*. 2014).

Most of today's wood adhesives such as UF resins, vinyl acetate resins, and isocyanate-based resins are composed of various materials derived from fossil resources. Wood adhesives have been developed in the petrochemical industry and have excellent performance, good working properties, and low costs. Besides their environmental impact, it is believed that the use of current wood adhesives will inevitably be restricted in the future due to declines in fossil resource reserves. Due to these problems, there is a high interest related to manufacturing formaldehyde-free boards. This interest has led to increased pressure on particleboard producers to stop using these binders. Following these concerns, several studies have been carried out in manufacturing particleboards with natural resins and adhesives, such as proteins, lignins, tannins, glutens, starches, citric acid, *etc*. (El-Wakil *et al*. 2007; Ciannamea *et al*. 2010; Lei *et al*. 2010; Moubarik *et al*. 2010; Wang *et al*. 2011; Ferrández-García *et al*. 2012; Ferrández-García *et al*. 2019; Liu *et al*. 2022).

Current research on plant biomass is focused at obtaining adhesive-free particle boards with different previous treatments, demonstrating the self-union capacity of natural fibers when the glass transition temperature occurs. Today it is feasible to produce particleboards without the addition of adhesives, due to the action of water (solubilization of molecules), temperature, and pressure, which allow the particles to bind with each other. (Lenormand *et al*. 2017). The cell walls of plant particles are mainly composed of a mixture of organic macromolecules (pectins, cellulose, hemicelluloses, lignin, waxes, starch, proteins, aromatic compounds, *etc*.) and a minority of mineral residues, which are often referred to as ash. Therefore, cell walls can be considered as biochemically complex compounds. Cellulose, hemicellulose, and pectin molecules are polysaccharides (carbohydrate polymers) with hydrophilic functions. Water-soluble compounds generally correspond to pectins and small soluble molecules. The proportions of organic macromolecules vary according to the botanical species and the location in the plant. For example, sunflower pith stands out from the others with a proportion of water-soluble compounds greater than 50% (Chabriac *et al*. 2016). The size and the shape of the particles could have a great influence on the properties of boards without adhesives (Widyorini *et* *al*. 2005). Therefore, determining the size range of the particles is an important parameter to improve their bond.

To address the need for new circular materials from the valorization of waste, this study examined particleboards made from vine pruning without using any adhesives to obtain an ecological and biodegradable constructive product.

EXPERIMENTAL

The materials used in the present investigation were residues from the pruning of Bobal wine variety vineyard (Fig. 1) and water from the municipal drinking water network. The prunings were collected from the Orihuela campus of the Miguel Hernandez University. The prunings were dried outside for 6 months and were later shredded in blade mill. The obtained particles were then classified according to their size with a vibrating sieve into three categories: less than 0.25, from 0.25 to 1.00 mm, and from 1.00 to 2.00 mm (Fig. 1). Particles had an approximate moisture content of 8%.

The mat was formed manually with 1.50 kg of particles of each type in a 600 x 400 mm mold, and 10% water was sprayed in relation to the weight of the particles. Finally, the mold was introduced into a hot press with a temperature of 130 °C and a pressure of 2.6 MPa.

Fig. 1. Vine prunnings (above) and particles of size < 0.25 mm (below)

The particleboards were manufactured using 3 particle sizes and 3 pressing times (15, 30, and 45 min). Table 1 shows the manufacturing characteristics of each type of particleboard.

Table 1. Types of Particleboards Manufactured

Particleboard Type	Number of Repetitions	Particle Size (mm)	Temp (min)	Temperature (°C)	Pressure (MPa)
A1	6	< 0.25	15	130	2.6
A2	6	< 0.25	30	130	2.6
A3	6	< 0.25	45	130	2.6
B1	6	0.25 a 1.00	15	130	2.6
B2	6	0.25 a 1.00	30	130	2.6
B3	6	0.25 a 1.00	45	130	2.6
C1	6	1.00 a 2.00	15	130	2.6
C2	6	1.00 a 2.00	30	130	2.6
C3	6	1.00 a 2.00	45	130	2.6

Before proceeding with the tests, the specimens were conditioned in a JP Selecta conservation chamber (model Medilow-L, Barcelona, Spain) for 24 h at a temperature of 20 °C and a relative humidity of 65%.

Moisture content was measured in an Imal laboratory moisture meter (Model UM2000, Modena, Italy). For the water immersion test, a heated tank with a water temperature of 20 °C was used.

The mechanical tests were performed on an Imal universal testing machine (Model IB600, Modena, Italy). Thermal conductivity tests were carried out on a heat flow meter instrument (NETZSCH Instruments Inc., Burlington, MA, USA).

The properties were determined following the European standards established for wood particleboards: density (EN 323 1993), thickness swelling (TS) and water absorption (WA) after 2 and 24 h of immersion in water (EN 317 1993), internal bonding strength (IB) (EN 319 1993), modulus of rupture (MOR), and modulus of elasticity (MOE) (EN 310 1993). Conductivity was determined by the heat flow meter method (EN 12667 2001). The boards were then evaluated according to the European standard (EN 312 2019).

The morphology of the interior of the raw materials was evaluated using a scanning electron microscope (SEM) and elemental analysis (quantitative and semi-quantitative) was performed using energy dispersive X-ray spectroscopy (EDS). Images of fractured cross sections were taken. For these observations, a Zeiss microscope (Model Sigma 300 VP, Jena, Germany) was used.

The standard deviation was obtained from the mean values of the tests and analysis of variance (ANOVA) was performed. Statistical analyses were performed with SPSS v. 28.0. (IBM, Chicago, IL, USA).

RESULTS AND DISCUSSION

Physical Properties

Manufactured particleboards had an approximate thickness of 7 mm. The results of the density, TS, WA, and thermal conductivity are shown in Table 2.

Table 2. Mean Values of Physical and Thermal Properties

Particleboard Type	Density (kg/m³)	TS 2 h (%)	TS 24 h (%)	WA 2 h (%)	WA 24 h (%)	Thermal Conductivity (W/m·K)
A1	1,068.96 (44.16)	25.00 (6.63)	32.42 (4.47)	80.96 (10.99)	87.73 (26,42)	0.0692 (0.0006)
A2	1,156.59 (43.19)	22.24 (6.77)	30.08 (4.78)	46.81 (14.06)	57.42 (11.71)	0.0724 (0.0007)
A3	1,220.37 (85.01)	29.74 (8.25)	36.23 (3.05)	51.80 (9.78)	60.79 (5.70)	0.0725 (0.0009)
B1	871.47 (64.85)	58.21 (13.15)	66.11 (7.22)	163.17 (19.19)	194.96 (8.51)	0.0697 (0.0003)
B2	878.29 (73.42)	61.92 (2.43)	67.11 (3.15)	159,52 (20.00)	173.49 (12.62)	0.0739 (0.0025)
B3	881.54 (68.33)	62.25 (3.12)	68.02 (5.06)	143.86 (14.43)	164.26 (14.87)	0.0697 (0.0008)
C1	938.26 (89.91)	47.18 (7.99)	50.11 (6.35)	109.32 (27.62)	125.25 (24.74)	0.0733 (0.0007)
C2	903.49 (78.64)	48.77 (3.81)	52.92 (2.47)	122.15 (24.85)	128.31 (22.46)	0.0745 (0.0008)
C3	914.28 (65.35)	48.05 (5.36)	52.39 (6.05)	117.88 (12.74)	125.63 (8.31)	0.0751 (0.0020)

TS: thickness swelling; WA: water absorption; (..): standard deviation.

The density of the particleboards ranged between 872 and 1,220 kg/m^3; therefore they could be considered as high-density boards. After performing the analysis of variance (Table 3), it was observed that the density depended on the particle size and not on the time in the press, obtaining higher values with smaller particles. Particle size was the manufacturing variable with the greatest influence in all properties.

The mean values of TS and WA after immersion in water for 2 h and 24 h were high, with a TS 24 h between 30.08% and 68.02% and a WA 24 h between 57.42% and 194.96%. According to the ANOVA (Table 3), these properties depended again on the particle size and not on the pressing time.

In general, the TS of particleboards made from plant fibers is very high. This could be both due to lack of water repellent chemicals in mat mixtures and to high amount of pith. (Ozen *et al*. 2014; Yenionak *et al*. 2014). High mean TS observed in dense particleboards could be also explained by the higher number of water attractive OH groups in the material (Çöpür *et al*. 2007).

These high TS and WA values obtained were probably the result of the high porosity of the particleboard and the lack of use of water-repellent chemicals during panel manufacturing.

Table 3. ANOVA of the Results of the Tests

Factor	Properties	Sum of Squares	d.f.	Half Quadratic	F	p-value
Particle Size	Density (kg/m^3)	770,116.190	2	385,58.095	67.091	<0.010
	TS 24 h (%)	10.547,503	2	5.273,752	212.180	<0.010
	WA 24 h (%)	111,496.241	2	55,748.121	194.760	<0.010
	MOR (N/mm^2)	279.752	2	139.876	62.023	<0.010
	MOE (N/mm^2)	8,593,165.670	2	4,296,582.83	50.597	<0.010
	IB (N/mm^2)	0.546	2	0.273	43.439	<0.010
	Thermal C. (W/m·K)	0.0000250	2	0.0000125	10.406	<0.010
Pressing Time	Density (kg/m^3)	19,017.061	2	9,508.531	0.465	0.631
	TS 24 h (%)	72.457	2	36.229	0.157	0.855
	WA 24 h (%)	2,922.189	2	1,461.095	0.605	0.550
	MOR (N/mm^2)	25.503	2	12.751	1.761	0.182
	MOE (N/mm^2)	1,336,857.371	2	668,428.685	2.942	0.062
	IB (N/mm^2)	0.062	2	0.031	1.967	0.150
	Thermal C. (W/m·K)	0.0000001	2	0.0000001	5.312	0.010

d.f.: degrees of freedom; F: Fisher-Snedecor distribution.

Thermal Conductivity

The results of the thermal conductivity tests are shown in Table 2, with similar values for all types. The thermal conductivity of the experimental panels ranged from 0.0692 to 0.0751 W/m·K. These values, as indicated by the ANOVA of Table 3, depended on the particle size and, to a lesser degree, on the pressing time.

Table 4 shows a comparison of the thermal conductivity values obtained by other authors with other plant fibers. In boards with similar densities to those of this study, similar values are obtained.

The natural materials used commercially as insulation boards (linen, hemp, cotton, *etc*.) and soft wood fiberboards (low-density fiber panels) have better thermal properties than the particleboards obtained in this work. However, these materials have also little mechanical strength and are used as filler or are covered by other more resistant materials. The results obtained with vine particleboards were lower than with wood particleboards. Therefore, these panels could be considered as a good thermal insulation material.

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Table 4. Thermal Conductivity Coefficients Obtained in Tests with Different Organic Fibers

Name	Thermal Conductivity λ (W/m K)	Source
Hemp	0.111	Behzad and Sain (2007)
	0.040 to 0.094	Kymalainen and Sjoberg (2008)
Flax	0.035 to 0.075	Kymalainen and Sjoberg (2008)
	0.042	Alavez-Ramirez *et al*. (2012)
Cotton	0.040 to 0.069	Nicolajsen (2005)
Date palm rachis	0.083	Agoudjil *et al*. (2011)
Rice straw	0.078 to 0.090	Ferrández-García *et al*. (2017b)
Sisal	0.070	Kalaprasad *et al*. (2000)
Sugarcane bagasse	0.075	Liao *et al*. (2016)
Wood particleboards	0.070 to 0.180	EN 13986 (2015)
Wood fiberboards	0.050 to 0.140	EN 13986 (2015)
Vine pruning	0.069 to 0.075	This work

Mechanical Properties

The results of the mechanical tests can be observed in Table 5. MOR values ranged from 3.61 to 11.24 N/mm^2, MOE values from 420 to 1,810 N/mm^2 and IB values from 0.157 to 0.510 N/mm^2. The mechanical properties were highly dependent on the particle size according to the ANOVA in Table 3, resulting in better behaviour with the smaller particle size (type A). For the other two types, no conclusion can be made due to the high deviation of results. It could be that the high porosity observed in type B and C had a negative influence on the self-bonding of the particles.

Table 5. Mean Values of Mechanical Properties

Particleboard Type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
A1	6.82 (0,72)	737.06 (58.50)	0.265 (0.057)
A2	9.25 (0.91)	1438.67 (106.60)	0.362 (0.074)
A3	11.24 (1.54)	1806.34 (48.69)	0.510 (0.032)
B1	3.61 (0.54)	419.60 (59.37)	0.170 (0.024)
B2	4.58 (0.45)	575.85 (193.34)	0.173 (0.043)
B3	4.28 (1.12)	482.17 (164.96)	0.157 (0.041)
C1	4.52 (1.34)	479.48 (130.98)	0.157 (0.059)
C2	4.27 (1.74)	486.29 (197.45)	0.163 (0.097)
C3	4.42 (0.58)	444.72 (19.70)	0.173 (0.020)

MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bonding strength; (..): standard deviation.

Particleboards with the best mechanical behaviour were type A3, manufactured with a particle size of less than 0.25 mm and with 45 min of pressing time.

A comparison between the results obtained in type A3 vine particleboard with the European standards (EN 312 2010) is shown in Table 6. Each grade of the standard specifies the uses any particleboard that achieves the minimum value of MOR, MOE, IB and TS 24 could have. Type A3 be classified as grade P2 and could be use in interiors and in furniture.

Table 6. Type A3 Vine Particleboard Properties and Comparison with EN 312

Fuente	Type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS 24 h (%)
Present work	A3	11.24	1806.04	0.51	36.23
(EN 312 2010) (Thickness from 6 to 13 mm)	Grade P1	10.50	-	0.28	-
	Grade P2	11.00	1800.00	0.40	-
	Grade P3	15.00	2050.00	0.50	17.00

In the manufacturing of particleboards, the particle size is one the most important factors in the assessments carried out by researchers, it was concluded that with a smaller particle size, better properties are obtained (Hegazy and Ahmed 2015), as shown in this work.

Other authors (Boon *et al*. 2013) indicate that by extending the pressing time, better properties are achieved. This statement coincides with the findings of the work, but only for the type with particle size of less than 0.25 mm. In the other two cases was not possible to make that conclusion due to the deviation of results.

The majority of the studies consulted (Pintiaux *et al*. 2015) indicated that in order to manufacture boards without adhesives, high temperatures are needed, higher than 180 ºC. However, in this work, vine particleboards with a press temperature of 130ºC have been obtained that could be used commercially according to the specifications of European standards (EN 312 2010).

SEM Observations and EDS Analysis

Table 7 shows the different chemical elements present in two cross sections from two branches of vine. The highest fractions in weight are carbon and oxygen, which indicates the large proportion of carbohydrates that the material had. This result is in accordance with other studies (Vivin *et al*. 2003).

Table 7. EDS Chemical Composition of Two Cross Sections of Vine Tree

	Section	Chemical Element											
		C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti
Composition (wt%) Dry Material	S1	45.9	49.1	0.89	0.66	0.42	0.35	0.31	0.19	0.36	1.23	0.61	-
	S2	43.5	50.6	1.12	0.58	0.39	0.36	0.15	0.17	0.31	2.08	0.52	0.18

Silicon was one of the elements present and could have play a role in the self-bonding of the particles (Hashim *et al*. 2011), but further research is needed.

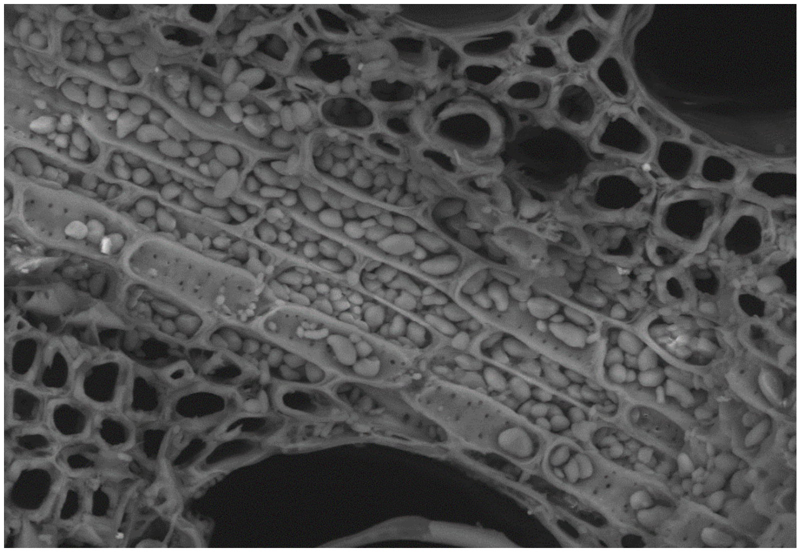

Fig. 2. Micrograph of the cross section of a vine branch

The innermost layer of parenchyma is shown in Fig. 2. It had abundant starch granules, which could have contributed to the self-bonding of the particles (Ferrández-García *et al*. 2019).

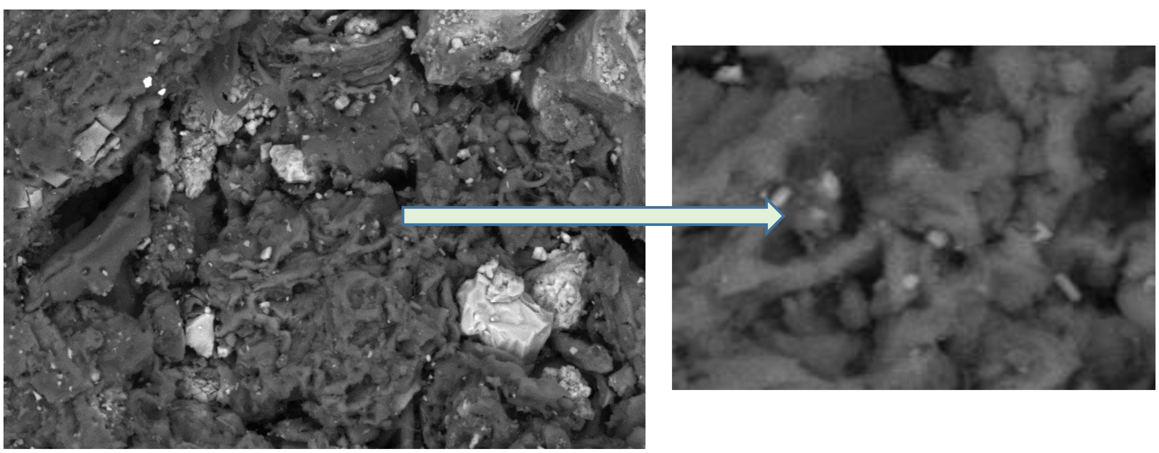

Fig. 3. Micrograph of the cross section of type A1 particleboard. Granules of starch (right).

The micrograph of Fig. 3 shows that in the cross section of one A1 type particleboard there were bonds between the particles and small granules of non-gelled starch. The possible explanations of why starch has not completely gelled could be the lack of water in the preparation of the board, the low temperature of 130 °C applied or that the pressing time of 15 min could have been very short.

In type A particleboards, longer pressing times improved the mechanical properties. It is possible that in this case, longer time in the press increased the gellification of the starch founded in the material. The high porosity observed in type B and C boards, in which the particle size is bigger, does not favor the union of the particles.

CONCLUSIONS

1. It is feasible to manufacture particleboards from vine residues biomass without using any adhesives.
2. The thickness swelling and water absorption values of the particleboards were high. The addition of water-repellent products could improve these parameters.
3. The particle size had a great influence on the properties of the particleboards. The pressing time had influence only when the particle size used is less than 0.25 mm. In the other cases, the deviations do not allow us to affirm the above.
4. In type A particleboards, longer pressing times improved the mechanical properties. It is possible that in this case, longer time in the press increased the gellification of the starch found in the material. Nevertheless, it will be necessary to check in future tests whether the addition of higher amounts of water in the preparation of the board could result in good properties with shorter pressing times.
5. Type A3 particleboard met the minimum requirements to be classified as P2 grade and could be used in furniture, interiors, partition walls and ceilings in dry environments.
6. The experimental vine particleboards had good thermal insulation capacity with an average conductivity of 0.072 W/mK.
7. The valorization of the biomass of the vineyard residues would lead to the manufacturing of an ecological product that would benefit the environment and the circular economy.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Conselleria de Vivienda y Arquitectura Bioclimática de la Generalitat Valenciana of Spain through the program "Plan IRTA", project HBIRT3/2021/7.

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Article submitted: September 5, 2022; Peer review completed: September 24, 2022; Revised version received and accepted: September 29, 2022; Published: October 5, 2022
DOI: 10.15376/biores.17.4.6542-6555