Feasibility of Using Waste Sweet Bay Wood (*Laurus nobilis* L.) in Particleboard Production

Hikmet Yazici *

Turkey holds a 95% market share of global sweet bay (*Laurus nobilis* L.) leaf trade, and it has 25 leaf processing and manufacturing facilities with different capacities. In this study, the usability of waste sweet bay wood (BW) that was removed from bay leaf processing plants was studied. For this purpose, three-layer particleboards were produced by mixing industrial chips (IC) and waste sweet bay wood chips (BWC) at a mixture rate of 0%, 25%, 50%, 75%, and 100%. For panel production, urea formaldehyde adhesive (UF) was used in 10% of the surface layers and in 8% of the middle layer based on dry chip weight. Some mechanical properties, such as bending strength (BS), modulus of elasticity in bending (MOE), internal bond strength (IB) of the test panels, thickness swelling (TS), and water absorption (WA) amounts, were determined. The results showed that all panel groups except group C (25% BWC + 75% IC) met the general purpose panel class (P1) requirements for use in dry conditions according to TS EN 312 (2012). In addition, group A panels (100% BWC) met the requirements of P2 class for the MOE and BS, and group E panels (75% BWC + 25% IC) met the P3 standards. The results showed that BWC could be used to produce particleboard for general purposes, including furniture.

Keywords: Laurus nobilis; Particleboard; Waste wood; Mechanical properties; Thickness swelling; Bending strength

*Contact information: Design Department, Interior Design Program, Zonguldak Bülent Ecevit University, Çaycuma Vocational School, Çaycuma 67900 Turkey; *Corresponding author: hikmet.yazici@beun.edu.tr*

INTRODUCTION

Particleboard is a wood-based material produced by the gluing of wood particles and other lignocellulosic raw materials. It is widely used worldwide for structural purposes, flooring systems, and furniture (Youngquist 1999; İstek *et al.* 2017a, 2019). As the demand for various wood panel products has increased due to recent increases in population, the effort to find alternative raw mateiral sources remains an important issue because wood raw material obtained directly from forests is insufficient. To solve the raw material problem and meet the future demand for wood-based products, industrial residues, non-wood materials, agricultural residues, fast growing trees, and underutilized wood species are being used (Nasser 2012; Fiorelli *et al.* 2012; Dos Santos *et al.* 2014; Yano *et al.* 2020). In addition, the emergence of a significant amount of waste that can be reused or recycled due to forestry industry practices has also focused on this area, and the conversion of wood waste into usable products has been studied for decades (Clausen 2000; Khedari *et al.* 2004; Dos Santos *et al.* 2014; Zayed *et al.* 2015; Kurt 2020). Today, agricultural and other lignocellulosic wastes are generally burned, disposed of, or used to obtain energy. All of these methods can cause soil and air pollution, and environmental damage is caused by carbon emissions. In addition, an important raw material source disappears before it turns into a value-added product (Nazerian *et al.* 2016; Sugahara *et al.* 2019). Particleboard is an important wood-based material that can be produced using low-quality materials. The production process, using the entire wood raw material with its parts, including bark and needles, results a value-added product. Thus, environmental and economic benefits are obtained (Maloney 1993; Cai *et al.* 2004).

Studies related to finding alternative raw materials were examined to produce wood-based boards. In particular, studies on grain, wheat straw, and corn stalk (Han *et al.* 1998; Wang and Sun 2002; Mo *et al.* 2003; Halvarsson *et al.* 2008), tea plant and red pine wood (Nemli and Kalaycıoğlu 1997; Filiz *et al.* 2011), sunflower stems (Khristova *et al.* 1998; Guler *et al.* 2006; Meinlschmidt *et al.* 2008), castor stalks (Grigoriou and Ntalos 2001), peanut husks and shells (Batalla *et al.* 2005; Akgül and Tozluoğlu 2008; Guler *et al.* 2008), almond shells (Gürü *et al.* 2006), horticultural, tomato, and eggplant stalk wastes (Arslan 2008; Guntekin and Karakuş 2008; Guntekin *et al*. 2009), rice husk (Tansey 1995; Ciannamea *et al.* 2010), cotton stalk and watermelon (El-Mously *et al.* 1999; Guler and Ozen 2004; Alma *et al.* 2005; Mohamed and Nasser 2008), hazelnut husks (Çöpür *et al.* 2007), rhododendron (Akgül and Çamlibel 2008), palm, palm leaves, and palm branches (El-Mously *et al.* 1993; Lin *et al.* 2008; Hegazy and Aref 2010), baggase (Xu *et al.* 2009), linen chips (flax shiv) (Papadopoulos *et al.* 2003), kenaf (Grigoriou *et al.* 2000; Xu *et al.* 2003), grape vine (Ntalos and Grigoriou 2002), and bamboo chips and wastes (Papadopoulos and Hague 2004; Laemlaksakul 2010; Valarelli *et. al* 2014), acai fruit (de Lima Mesquita *et al*. 2018), apple and plum orchard pruning (Kowaluk *et al*. 2019) and sugarcane bagasse, Pinus taeda particles and Malva fibres (Silva *et al.* 2018) were reviewed. These studies on wood-based composites showed that the panel properties are mostly suitable for general purposes (Kalaycioglu *et al.* 2005; Guler *et al.* 2006; Pan *et al.* 2007; Bardak *et al.* 2010; García-Ortuño *et al.* 2011; Guler and Büyüksari 2011; Juliana *et al.* 2012; Topbaşlı and Sevinçli 2017; Guler and Beram 2018; Guler and Yaşar 2018). However, these alternative raw materials also have some disadvantages. In particular, annual plants take up a lot of space, and the panels produced from such materials may have low dimensional stability and inadequate mechanical properties (Iswanto *et al.* 2014). However, some mechanical properties of particleboards can be improved by using chemical additives, such as organosilanes (Onat *et al.* 2014).

Mediterranean sweet bay (*Laurus nobilis* L.) is the most important medicinal aromatic plant in Turkey, and it has an important place in foreign trade (Gökmen 1973; Kayacık 1977; Guler and Basaran 2003; Kurt *et al.* 2016). Bay oil and bay fruits are used in the food, beverage, pharmaceutical, chemical, and cosmetic industries (Özer 1987; Yazıcı 2002). Bay leaves are usually dried and exported. According to the 2012 to 2015 year export data from Turkey, exporting 46,154 tons of bay leaves generated 134 million US$ of income (Turkish General Directorate of Forestry, 2016). The increasing market demands of bay leaves in the world in recent years have enabled private companies to adopt bay leaf production using advanced technologies. There are 25 different facilities in Turkey that operate as bay leaf drying and processing plants. The total processing capacity of the plants is 115,000 tons/year of wet branches. When the installed capacity of businesses across Turkey is considered, approximately 46,000 tons/y of dry sweet bay wood is added to the country's total industrial waste. Most of this bay wood waste is used for energy recovery by burning. Turkey has a thriving forest products industry and major investment in the wood-based panels industry. It ranks first in Europe and globally for particleboard and fiberboard (medium-density fiberboard) production amounts (İstek *et al.* 2017b; İstek *et al.* 2018a; Kurt and Karayılmazlar 2019). In addition, research on the use of different lignocellulosic materials is ongoing in Turkey to meet the increasing need for raw materials. From this perspective, the detection, amount, and evaluation of lignocellulosic industrial wastes are extremely important. Wood raw material with high evaluability is the basis for the continued development of bay processing production plants. In addition, it is important that their capacity constantly increases.

In this study, the possibility of using bay wood obtained from a bay leaf processing and production facility as an industrial waste in the production of particleboard was investigated. For this purpose, some physical and mechanical properties of the particleboards produced from softwood and hardwood chips readily obtained from bay wood and particleboard plants were determined. The obtained values were compared with the requirements of standards, and the suitability of the panels was determined.

EXPERIMENTAL

Materials

In this study, bay wood waste chips (BWC) obtained from a local supplier (Defne Bitkisel Limited Company, Zonguldak, Turkey) and industrial chips (IC) (Kastamonu Integrated Particleboard Factory, Kastamonu, Turkey) supplied from the particleboard plant and consisting of softwood-hardwood wood chips were used as wood-based raw materials. A urea formaldehyde adhesive (UF) with a 65% solid content was used as the adhesive (Kastamonu Integrated Particleboard Factory, Kastamonu, Turkey). Formaldehyde glue's pH is 8.20 in E1 emission class, its density is 1265g /cm^3, gel time is 54 seconds, and flow time (viscosity) is 41 vis.min. In Table 1, the average values of sweet bay (*Laurus nobilis* L.) and some softwood (SW)-hardwood (HW) main chemical components are shown.

Table 1. Chemical Composition (%) of *Laurus nobilis* L. and Some SW-HW Wood

	***Laurus nobilis* L.**			**SW**	**HW**
Wood Components	Yazıcı 2002		Yasar *et al.* 2016	Usta 1989; Kirci 1991; Kirci *et al.* 2002, 2010	Tank 1978; Kirci 1987; Akgül and Kırcı 2002; Gulsoy 2003
	Wood	Bark	Wood	Wood	Wood
Amount of Holocellulose	71.7	60.7	73.26	71.83	73.37
Amount of Cellulose	44.0	31.5	53.59	53.6	47.67
Amount of α-cellulose	-	-	43.28	48.5	45.5
Amount of Lignin	23.2	29.7	21.19	27.2	22.4

The average density of IC used as raw material is 620 kg/m^3, and the average density of BWC is 610 kg /m^3. The bulk densities of the particles were calculated according to TS EN ISO 17828 (2016) standard methods. Bulk density was 224/146 kg/m^3 for IC and 255/229 kg m^3 for BWC values correspond to face/core layer respectively.

Methods

A traditional three-layer particleboard production method was used to produce test panels. Forty percent of the total chip amount was used in the surface layers (bottom-top), and 60% was used in the middle layer. The panel thickness was 16 mm, and the target density was 600 kg /m^3. It is produced in the size of 400 * 400 mm, and after the edges were removed, it remained 360 * 360 mm. The UF glue was applied as 8% for the middle layer and 10% for the surface layers based on dry weight of chips, and the hot-press conditions were set to 180 °C, 16 to 18 MPa specific press pressure, and 5 min press duration. The mixing ratios were determined in proportion to the raw material weight, and they were used in this way in order to determine the effect of BWC addition on the panel properties and the optimum usage ratio (Table 2). In addition, it was considered as sufficient to produce 3 boards for each experimental group to ensure homogeneous distribution in determining the board properties. BWC was used as shelled and the bark ratio in the total BWC raw material is 8%.

Table 2. Mixing Ratio of Experimental Groups

Experimental Group	Code	BWC (%)	IC (%)
A	%100 BWC	100	0
B	%100 IC	0	100
C	%25BWC + %75IC	25	75
D	%50BWC + %50IC	50	50
E	%75BWC + %25IC	75	25

Preparation of wood raw material

For production of the test panels, the sweet bay wood that was provided in small pieces from the bay leaf production facility was largely free of foreign materials and large pieces unsuitable for flaking. Then, it was passed through a laboratory scale chipper and made suitable for screening and classification. In the production of the three-layer particleboard, a sieving and classification process was performed to obtain surface layers and middle-layer chips.

Fig. 1. The middle and surface layer chips: a: BWC (Surface), b: BWC (Medium), c: IC (Surface), and d: IC (Medium)

Chips that passed through a 9-mm screen but failed to pass through a 2.36-mm screen were used in the middle layer, and chips that passed through a 2.36-mm screen but failed to pass through a 1-mm screen were used as the surface layers (Fig. 1). In contrast, industrial chips were not subjected to any screening process because it was ready for production as supplied. Then, the chips were dried at 103 °C for an average of 2 h, which allowed the moisture content to reach the 1% to 3% range.

Production of test panels

The middle layer and surface layer chips of a suitable moisture content were taken to the rotary drum mixer to be glued with the help of a spray gun. After the gluing process, the specified amount of chips was placed in the mold with three layers, and a hot press (SSP 180; Cemil Usta, İstanbul, Turkey) was applied after pre-pressing. The panel produced by the hot press was kept in the laboratory environment on the shelves to be cooled (Fig. 2a). The distribution of sweet bay wood (BWC) in board sections can be seen in Fig. 2b.

Fig. 2. a: Experimental boards, b: BWC distributions in different sections: 1: %100 BWC, 2: %100 IC: 3: %25BWC + %75IC, 4: %50BWC + %50IC, 5: %75BWC + %25IC

Determination of panel properties

After the test panels were conditioned 20 ± 2 °C at 65 ± 5% RH for 2 weeks conditions, the physical properties of moisture (*r*), density (*d*), and water absorption (WA) at 2 h and 24 h and thickness swelling (TS) were determined. In addition, bending strength (BS), modulus of elasticity (MOE), and internal bonding perpendicular to the surface (IB) were determined. In addition, formaldehyde emission of test boards were determined according to the TS EN ISO 12460-5 (2016) perforator method. The experiments were conducted in accordance with the standards given in Table 3. Fifteen measurements were carried out for each experiment as 5 per board. In addition, the experimental results were evaluated by one-way analysis of variance (ANOVA) in the SPSS program (Version 16, IBM Corp., Redmond, NY, USA), and the differences between the groups were determined by Duncan's homogeneity test. Findings related to physical and mechanical properties were evaluated according to TS EN 312 (2012).

Table 3. Test Standards for Physical and Mechanical Properties

Properties	Test Standard
Moisture	TS EN 322 (1999)
Density	TS EN 323 (1999)
Water absorption and thickness swelling	TS EN 317 (1999)
Bending strength and modulus of elasticity	TS EN 310 (1999)
Internal bonding	TS EN 319 (1999)
Preparation of test samples	TS EN 326 (1999)
Particleboard specifications	TS EN 312 (2012)

RESULTS AND DISCUSSION

Physical Properties

The average values and standard deviation values of several physical properties of test panels produced with different rates of bay wood waste chips and industrial wood chip mixtures are shown in Table 4. According to Table 4, the moisture content values of all panel groups complied with TS EN 312 (2012). When the target density value (600 kg/m^3) was taken into consideration, the values obtained were within the 10% tolerance limit specified by TS EN 312 (2012). In addition, there was no statistically significant difference in density value between the panel groups. İstek and Sıradağ (2013) stated that density changes up to 10% in particleboards have no significant effect on board properties.

Table 4. Some Physical Properties of Test Panels

Group	Content	*r* (%)	*d* (kg/m^3)	2 h TS (%)	24 h TS (%)	2 h WA (%)	24 h WA (%)
A	%100 BWC	5.35 ± 0.07**b**	650 ± 45**a**	51.21 ± 3.16**d**	57.07 ± 3.96**d**	83.20 ± 4.62**b**	105.60 ± 4.09**c**
B	%100 IC	5.34 ± 0.15**b**	640 ± 50**a**	33.75 ± 2.93**a**	36.40 ± 3.23**a**	87.59 ± 5.04**c**	98.43 ± 4.86**a**
C	%25BWC + %75IC	5.21 ± 0.13**a**	640 ± 43**a**	42.87 ± 5.76**b**	46.54 ± 5.70**b**	84.61 ± 4.11**bc**	99.59 ± 4.36**a**
D	%50BWC + %50IC	5.16 ± 0.09**a**	650 ± 42**a**	45.95 ± 3.32**c**	50.88 ± 3.70**c**	87.42 ± 3.13**c**	103.41 ± 3.91**bc**
E	%75BWC + %25IC	5.00 ± 0.15**a**	630 ± 47**a**	41.78 ± 2.95**b**	46.42 ± 4.29**b**	78.01 ± 4.79**a**	100.58 ± 4.36**ab**
±: Standard deviation; Means followed by the same letters (a, b, and c) in the same column are not significantly ($p < 0.05$) different							

Examination of the TS values of the panel groups showed that there was a similar order for 2 h and 24 h. The lowest TS values of group B panels for 2 h and 24 h were 33.8% and 36.4%, respectively. For group A panels, the highest TS values were 51.2% and 57.1%, respectively. In addition, there was no statistically significant difference in TS between groups C and E for 2 h and 24 h. Unlike TS, WA values were not similar for 2 h and 24 h, and the lowest values were seen on group E (78.0%) and group B (98.4%) panels for 2 h and 24 h, respectively. A statistically significant difference was found between the E group panels and the other groups for the highest values for 2 h WA. The 2 h and 24 h TS rates of the panel groups are shown in Fig. 3.

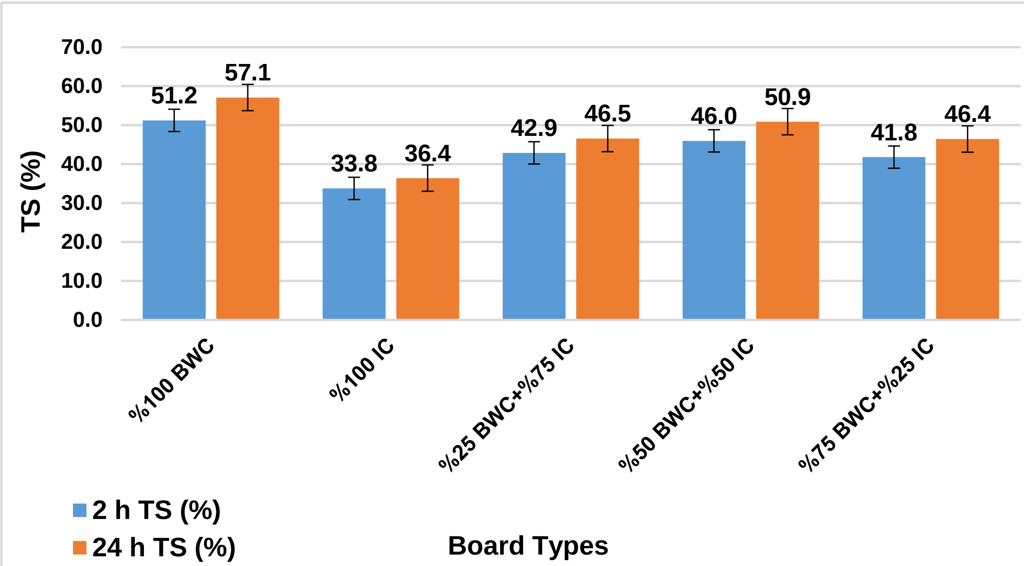

Fig. 3. Thickness swelling at 2 h and 24 h

Figure 3 shows that there was a nonlinear increase in the rate of BWC usage and 2 h and 24 h TS rates. Two h TS values were between 33.8% and 51.2%, and 24 h TS values ranged from 36.4% to 57.1%. The 24-h TS values obtained did not meet the standard value specified for non-load bearing boards used in humid conditions (TS EN 312 2012). However, as there is no requirement for TS value in boards used for general purposes (P1) and interior applications (P2) in dry conditions, the boards are suitable for general purposes. In addition, the dimensional stability of the boards will increase with the use of a water repellent additive, such as paraffin. Analysis of the dimensional stability properties of the panel groups according to BWC and IC usage rates revealed that the high usage rate of IC for TS showed a positive effect, and lower WA results were obtained with the use of BWC. Because BWC chips were obtained from a laboratory environment, they were shorter and thicker than the IC chips. This may have prevented the homogeneous gluing of chips, especially in experimental groups where BWC and IC were used as a mixture. This situation may have affected the amount of water they took into their structure. However, owning to the lignin in the bark structure, it has a water repellent effect and BWC barks have a higher lignin content than wood. It is considered that different consequences occur when BWC barks are not homogeneously distributed on board layers. The decrease in TS value in 75% BWC + 25% IC, which has the lowest density among the board groups, may be explained by the high porosity and the lack of bark presence. The obtained WA and TS values were higher than the standard values and results obtained in similar studies in the literature. This may be a result of not using a water repellent additive in the production of test panels, as well as the amount of glue used, chip geometry and other factors in the production of panels. In addition, other studies have reported that density affects dimensional stability (Zheng *et al.* 2005; Barboutis and Philippou 2007; Nazerian *et al.* 2011; İstek *et al.* 2018b).

Mechanical Properties

The average values and the standard deviation values for some mechanical properties and formaldehyde emission of test panels are shown in Table 5.

Table 5. Mechanical Properties and Formaldehyde Emission of the Test Boards

Group	Content	BS (N/mm²)	MOE (N/mm²)	IB (N/mm²)	Formaldehyde emission (mg/100g)
A	%100 BWC	10.2 ± 1.5**a**	1936 ± 144**bc**	0.35 ± 0.16**b**	1.77
B	%100 IC	11.0 ± 1.1**a**	1621 ± 155**a**	0.24 ± 0.54**a**	3.31
C	%25BWC + %75IC	10.9 ± 2.0**a**	1708 ± 211**ab**	0.20 ± 0.71**a**	4.30
D	%50BWC + %50IC	10.2 ± 1.7**a**	1732 ± 235**ab**	0.26 ± 0.20**a**	2.54
E	%75BWC + %25IC	10.3 ± 2.9**a**	2067 ± 174**c**	0.35 ± 0.84**b**	2.42
Board Class	**Requirements for TS EN 312 (2012)**				
P1		10	*	0.24	E1:≤8
P2		11	1600	0.35	E2≥30
P3		14	1950	0.45	
±: Standard deviation Means followed with the same letters (a, b, and c) in the same column are not significantly ($p < 0.05$) different. * : No value specified P1: General purpose boards used in dry conditions; P2: Indoor equipment (including furniture) boards used in dry conditions; P3: Non-load-bearing boards used in humid conditions					

Table 5 shows that there was no statistically significant difference between the BS values of the panel groups. In addition, all experimental groups for BS met the P1 standard of TS EN 312 (2012). The highest and lowest MOE values were 2070 N/mm^2 and 1620 N/mm^2, which were in group E and group B, respectively. In addition, the value obtained from the E group met the P3 panel class requirement, and all the experimental groups met the MOE requirements of P2 class panels (TS EN 312 2012). The IB values of the experimental groups ranged from 0.20 N/mm² to 0.35 N/mm². The highest IB value was obtained in group A and group E groups (0.35 N/mm²), and the lowest value was found in group C (0.20 N/mm²). However, there was no statistically significant difference between groups B, C, and D. According to TS EN 312 (2012), the results obtained from the A and E experimental groups met the P2 standard, and the B and D groups met the required values for the P1 panel class. The IB value of the group C panels was below the required value (TS EN 312 (2012). In general, the mechanical properties observed were in line with the literature. However, many factors, such as density, bark presence, chip geometry, and distribution, affect the physical and mechanical properties (Nemli 2003; Pan *et al.* 2007; Özlüsoylu and İstek 2018; İstek *et al.* 2020). In this study, there were significant differences between some panel densities, and the fact that some BWC was used in bark form may have affected the mechanical properties. It is thought that the amount of lignin in the bark may affect the mechanical properties (Guler and Yaşar 2018; Kowaluk *et al.* 2019). In addition, in terms of chip geometry, the BWC obtained with a laboratory-type chipper had a different structure than ready-made IC (Nasser 2012). In addition, in different studies, the amount of wood components, such as cellulose, α-cellulose, and lignin, has been found to affect certain physical and mechanical properties (Zayed *et al.* 2015; Guler and Yaşar 2018). Since formaldehyde emission is mainly related to glue type and amount of use, it has been determined that there were no significant differences between the groups, except 25% BWC + 75% IC, with increasing BWC usage rate and a decrease in formaldehyde emission. It is also stated that different wood type (Demirkır et al. 2011) and wood pH (Çolak and Çolakoğlu 2004) and the waiting time of the boards have an effect on the formaldehyde emission (Sıradağ 2020).

CONCLUSIONS

1. The moisture and density values of the test panels complied with TS EN 312 (2012).
2. The thickness swelling (TS) values obtained for 100% waste sweet bay wood chips (BWC) showed statistically significant improvement with the use of 75% BWC + 25%. In addition, although TS and water absorption (WA) values were higher than the standard values and similar studies in the literature, the panels produced were suitable for general purposes.
3. All groups except group P (25% BWC + 75%) met the P1 panel class requirement, and group A (100% BWC) and group E (75% BWC + 25 %IC) met the required value for the P2 panel class. For modulus of elasticity (MOE), the E group (75% BWC + 25 % IC) also met the P3 panel class requirement.
4. The results showed that BWC could be used in the production of particleboards, and the obtained panels were suitable for general purposes, including furniture. In addition, the 75% BWC + 25% usage rate was the most suitable in terms of physical and mechanical properties.
5. Through utilizing BWC, which is considered a waste product, in the production of particleboard, a value-added product was obtained that both saved primary wood raw material and provided an environmental benefit. In addition, the continued increase in number and capacity of bay leaf production facilities in Turkey will contribute to the continued use of BWC as raw material.

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