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ORIGINAL PAPER

The potential for using the sycamore (*Platus orientalis*) leaves in manufacturing particleboard

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Abstract Developing value-added products from any underutilized non-woody or woody material could play a critical role in economical development as well as forest resource management of any country. The objective of this research was to evaluate the potential of using the sycamore leaves in production of particleboard. Variable factors were as board density (0.6 and 0.7 g/cm^3), press time (4 and 6 min), and press temperature (140 and 160 °C). Some chemical properties of the sycamore leaves (cellulose, holocellulose, lignin and ash contents, alcohol–benzene solubility, 1 % sodium hydroxide solubility, hot- and cold-water solubility), mechanical (modulus of rupture, modulus of elasticity, and internal bond strength) and physical properties (thickness swelling and water absorption) of the resulting particleboards were determined. Overall results showed that the mechanical properties of all the panels exceed the minimum requirements of European Norm for furniture manufacturing. The mechanical properties of particleboard were improved significantly as board density increased from 0.6 to 0.7 g/cm^3 and press time increased from 4 to 6 min. However, the effect of press temperature was not significant ($P < 0.05$). Conclusively, sycamore leaves, an underutilized waste, can be an alternative raw material for particleboard industry and resulting value-added panels owing to their high mechanical properties and interesting design esthetics could be used for furniture and interior decoration.

Keywords Sycamore leaves · Particleboard · Mechanical properties · Physical properties

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Introduction

Technological progress along with consumer demands and expectations continues to increase demands on global resources, leading to major problem of material availability and environmental sustainability (Faruk et al. 2012). Particleboard industry suffers from raw material shortage and consumption of wood-based panels is continuously increasing (Pirayesh et al. 2013). On the other hand, solid waste management is a significant challenges and growing in many developed and developing countries. Solving old and new challenges will require human ingenuity and creativity and also need an approach that makes better and greater use of renewable resources, increases the resilience and diversity of production systems (FAO 2012). Over the last few decades, biocomposites have been undergoing a remarkable development. A selection of agricultural residues including wheat straw, sugarcane, sunflower seed hull, bamboo, and palm has been successfully used in particleboard manufacturing and is already in the market under different trade names (Ciannamea et al. 2010).

One of the underutilized bio-based resources is tree leaves with the potential of providing a non-food-based market for particleboard industry. The world's total forest area is just over 4 billion hectares or 31 % of the total land area (FAOSTAT 2012). Total biomass yield and the leaf proportion vary with species and varieties. Climate (moisture and solar radiation) and soil fertility are determining factors on productivity (Espinoza et al. 1999). Fresh leaf yields of 40 ton/ha/year (nearly 10 tons of dry matter) have been reported for some species in Costa Rica (Espinoza et al. 1999). In the forest, leaves fall on to the ground and can be both beneficial (become food for numerous soil organisms vital to the forest ecosystem (Campanella et al. 2013) or detrimental [ignition point in wildfires (Ozkaya et al. 2013) and soil metal concentration concerns (Heckman and Kluchinski 1996). Foliage biomass, fuel depth, fuel bulk density, and foliage retention are of important indices in prediction of fire behavior properties in forests (Bilgili 2003). In cities and towns, leaves are predominantly considered a waste; they are collected and burned and in rare cases are composted (Campanella et al. 2013) and in villages usually are used by farmers as a ruminant roughage source for cows (Ozkaya et al. 2013). Only in the United States, there are 30 million tons of leaves that are collected and burned every year (Campanella et al. 2013). In some countries, burning of leaves in populated areas as well as municipal leaf deposal in sanitary landfills are prohibited (Heckman and Kluchinski 1996). They tend to burn slowly and consequently generating large amounts of airborne particulates (fine bits of dust, soot, and other solid materials); they can cause health problems and may also contain hazardous chemicals such as carbon monoxide (Campanella et al. 2013).

The leaves have a waxy epidermal surface layer (Campanella et al. 2013). The hydrophobic layer primarily includes all kind of extractives (wax, inorganic silicon, and fat), which could weaken the compatibility between water-based adhesives and waxy materials (Zheng et al. 2009). Since UF resin is water based, it cannot effectively bond leaves particles to make high-quality particleboard. Because of the similar reason, other water-based adhesives including protein and starch-based adhesives are also not effective to bond grass-based particleboards directly (Zheng et al. 2009). Isocyanates (especially PMDI) are another important chemical group of adhesives used for raw materials that are difficult to glue, like straw, bagasse, rice shells, or sugar cane (Dunky and Pizzi 2002). Indeed, some commercial particleboard plants using agricultural residues almost exclusively use MDI as the adhesive (Papadopoulos and Hague 2003). The cost of PMDI is about 7–10 times higher than that of UF (Zheng et al. 2009). But 4 % of isocyanate gives panels the results which are comparable to those of boards bonded with 8 % of a phenolic resin (Dunky and Pizzi 2002) and 7 % of a phenolic resin gives panels the results which are comparable to those of boards bonded with 10 % of UF (Doosthoseini 2002). Furthermore, MDI needs lower press time than UF does (Doosthoseini 2002). In this article, we explore the development of biocomposites via the use of leaves obtained in the fall season from sycamore trees that now have no usage in Iran. In particular, sycamore leaves (*Platus orientalis*) were use as it is predominant species in the cities of Iran especially the capital. These leaves are a low-cost renewable resource that until now have not been considered for the production of high value applications. The objective of this study is to use sycamore leaves as a raw material for laboratory made one-layer particleboard and to test the mechanical and physical properties of panels to determine whether they have required levels of properties for general uses. In addition, since of the key factors determining panel quality other than raw material and adhesive is process parameters, the effects of board density, press temperature, and press time on the physical and mechanical properties of the resulting particleboard were investigated. This study was carried out in 2011 at Shahid Rajayee Teacher Training University, Iran.

Materials and methods

Leaves obtained in the fall season from sycamore trees (*P. orientalis*) were first cleaned of dirt and impurities and then chopped using a blender (Suny pro-classic food processor) without any treatments. Particles were oven-dried at 100 ± 3 °C to reach the target moisture content (3 %, Pirayesh et al. 2012) then screened with a machine with 3 mm and .5 mm openings, leaving uniformly sized particles. Methylene diphenyl diisocyanate (MDI) with characteristics given in Table 1 was provided from Baspar Shimi, Iran, and used at a level of 4 wt% for manufacturing single-layer particleboards. Particleboard panels were manufactured using standardized procedures that simulated industrial production at the laboratory. The particles were placed in a drum blender and sprayed with MDI for 5 min to obtain a homogenized mixture.

The particles then were pressed into panel mat using a laboratory scale hydraulic hot press. Aluminum foil was applied on the MDI-mat to avoid the adhesive sticking to the hot press plates. The suitable moisture content of the MDI-mat for particleboard manufacturing was adjusted at

Table 1 Properties of the MDI adhesive

Properties	MDI[a]
Solid (%)	100
Density (g/cm^3)	1.273
Viscosity (cps)	300
Gel point (100 °C)	–

[a] Methylene diphenyl diisocyanate

8 % (Abdolzadeh et al. 2011). Since MDI resin contains no water, prior to mat fabrication, some water was added to the leaves particles to obtain the necessary MDI-mat moisture content. Thickness of panels was controlled by stop bars and panels target density was 0.7 g/cm^3. Three panels were produced for each group. The experimental design is shown in Table 2. The panel production parameters were also displayed in Table 3.

Chemical properties of the sycamore leaves were determined and specimens were sampled and prepared according to Tappi T 257 cm (1985) Standard. Holocellulose and cellulose contents were determined according to the chloride method (Wise and Karl 1962). The lignin T 222 cm (1998) and ash T 211 om (1993) contents were also measured. Alcohol–benzene T 204 cm (1997), hot- and cold-water T 207 om (1999), and 1 % NaOH T 212 om (1998) solubility were determined.

Some mechanical properties; modulus of rupture (MOR) (EN 310 1993), modulus of elasticity (MOE) (EN 310 1993), and internal bond strength (IB) (EN 319 1993) and physical properties; thickness swelling (TS) and water absorption (WA) (EN 317 1993) were determined for the produced particleboards. The average of 10 and 20 measurements were reported for mechanical and physical properties, respectively. The data obtained was statistically analyzed using analysis of variance (ANOVA) and Duncan's mean separation tests.

Table 2 Experimental design

Parameter			Abbreviation	Repetition
Density (g/cm^3)	Press time (min)	Press temperature (°C)		
0.6	4	140	A1	3
		160	A2	3
	6	140	A3	3
		160	A4	3
0.7	4	140	A5	3
		160	A6	3
	6	140	A7	3
		160	A8	3

Table 3 Production parameters of particleboards

Parameter	Value
Peak pressure (kg/mm^2)	25
Thickness (mm)	16
Dimensions (mm)	420 × 420
Number of boards for each type	3

Results and discussion

The chemical composition can be helpful in determining properties and end-use of the bioproducts; lignin facilitates reactivity and allows better response to chemical modifications, while higher cellulose content leads to higher stiffness and is most reinforcing component of biomaterials (Campanella et al. 2013). Certain chemical properties of the sycamore leaves and hard/soft woods are listed in Table 4. A comparison between sycamore leaves and softwoods and hardwoods (Pirayesh et al. 2012) indicated that sycamore leaves had the lowest holocellulose (57.3 %) and cellulose (27.4 %) contents. In terms of lignin, sycamore leaves had a little lower content (23 %) compared to hardwoods and softwoods. Ash content, alcohol–benzene solubility, 1 % NaOH solubility, hot- and cold-water solubility of sycamore leaves were much higher than hardwoods and softwoods.

Effect of board density

The main effect of board density is summarized in Table 5 which demonstrates positive effects of board density on mechanical properties ($P < 0.05$). Generally, MOR, MOE, and IB improved with increasing board density from 0.6 to 0.7 g/cm^3 by 6.5, 4.9, and 16.9 %, respectively. Increasing board density can be a way of enhancing the particleboard properties because contact area of particles could be increase and stronger adhesion developed (Doosthoseini 2002). The positive influence of increasing panel density on the mechanical properties has been reported by different researchers (Nemli et al. 2003; Guntekin and Karakus 2008). Physical properties (TS and WA) also improved ($P < 0.05$) by the increasing board density that can be due to low porosity and difficult diffusion at higher board densities (Nemli et al. 2003). Increasing panel density has a preventive effect on water absorption (Doosthoseini and Zarea-Hosseinabadi 2010). More effective usage of adhesive and better gluing by increasing board density can be the reason of improving physical properties by increasing panel density (Nemli et al. 2003; Doosthoseini 2002). The result of physical properties is compatible with pervious researchers (Doosthoseini and Zarea-Hosseinabadi 2010) but is inconsistent with Guntekin and Karakus 2008 and Kalaycioglu and Neml 2006.

Effect of press time

Upon increasing press time, the mean mechanical and physical properties of the panels significantly increased ($P < 0.05$) (Table 5). Panels pressed for 4 min showed lower MOR, MOE, and IB than those pressed for 6 min. Furthermore, panels pressed for 6 min showed lower TS

Table 4 Chemical composition of sycamore leaves (this study) and soft/hardwoods (Pirayesh et al. 2012)

Raw material	Holo-cellulose (%)	Cellulose (%)	Lignin (%)	Ash (%)	Solubility (%)			
					Alcohol-benzene (2/1)	1 % NaOH	Hot water	Cold water
Sycamore leaves	57.3	27.4	23	7.9	14.8	35.7	21.8	19.1
Hardwoods	70–78	45–50	30–35	0.35	2–6	14–20	2–7	4–6
Softwoods	63–70	45–50	25–35	0.35	2–8	9–16	3–6	2–3

Table 5 Effect of density, press time and press temperature on the mechanical and physical properties of the panels

	Value	MOR (Mpa)	MOE (Mpa)	IB (MPa)	WA-2 h (%)	WA-24 h (%)	TS-2 h (%)	TS-24 h (%)
Density (g/cm^3)	0.6	16.09 a	1,987 a	0.59 a	25.44 a	33.84 a	10.83 a	17.35 a
	0.7	17.13 b	2,085 b	0.69 b	23.88 b	32.17 b	9.18 b	15.96 b
Time (min)	4	16.46 a	2,017 a	0.63 a	24.82 a	33.18 a	10.18 a	16.69 a
	6	16.77 b	2,055 b	0.66 b	24.5 b	32.82 b	9.83 b	16.35 b
Temperature (°C)	140	16.67 a	2,032 a	0.64 a	24.59 a	32.98 a	9.97 a	16.55 a
	160	16.56 a	2,040 a	0.65 a	24.73 a	33.02 a	10.04 a	16.49 a

Means with different letter groupings are different ($P \leq 0.05$)

and WA than those pressed press for 4 min. The result may indicate that at 4-min press time, adequate heat is not transferred to the core section of the mat. The results can be attributed to more complete polymerization with longer press time (Yousefi 2009). Besides, with the increase in press time, heat transfers to core layers leading to solid bonds (Maloney 1989). Similar results were also stated by different authors (Yousefi 2009; Tabarsa et al. 2011; Ashori and Nourbakhsh 2008). The highest MOR, MOE, IB, and the lowest TS and WA were belonging to panels with 0.7 g/cm^3 density that pressed for 6 min.

Effect of press temperature

The effect of press temperature on the mechanical and physical properties of the panels was not significant (Table 5). In other words, there is no significant difference between mechanical and physical properties of panels pressed at 140 °C and those pressed at 160 °C ($P < 0.05$). This may indicate that 140 °C is sufficient temperature for complete polymerization of sycamore leaves-based panels bonded with MDI. When bio-based composites are hot-pressed, under high temperature, compressive stresses are imparted to the individual cells resulting in damaged cell walls (Dunky and Pizzi 2002), and this can be one of the reason of decreasing mechanical properties of panels produced under higher temperature. Low necessary hardening temperature and high tolerance against humidity (water proof nature) are of the advantages of MDI over the conventional resin (UF) (Dunky and Pizzi 2002). On the other hand, this can mean at higher press temperature partial degradation of cured resin as well as the leaves structure take place at surface layers of the panels (Salari et al. 2013). Similar results were also stated by Zheng et al. (2009), Kargarfard et al. (2002). The mean values of properties for the 8 treatments are presented in Table 5 to allow a quick comparison of the effects of variables on the panels' properties. MOR values ranged from 15.9 to 17.7 MPa. Besides, MOE values varied from 1,985 to 2,130 MPa and IB values ranged from 0.6 to 0.74 N/mm^2. Based on EN standards, 12.5, 14, and 1,800, 0.28, and 0.40 N/mm^2 are the minimum requirements for modulus of rupture, modulus of elasticity, and internal bond strength of particleboard panels for general uses and furniture manufacturing, respectively (Nemli et al. 2008). Mean values and SD of panels made from sycamore leaves are given Table 6. Using light weight, raw material improves mechanical properties bio-based composites due to high compaction ratio (Tabarsa et al. 2011), and this can be one of the reasons of obtaining high-quality particleboard employing sycamore leaf. On the other hand, there is positive relationship between biomaterial wettability and adhesion (Pirayesh and Khazaeian 2012) and since MDI have excellent wetting behavior (Dunky and Pizzi 2002), the good mechanical properties of sycamore leaves panels made with MDI could be justified.

Mechanical properties of all the panels exceed the minimum requirements of EN standards for furniture manufacturing. 24 h TS of particleboard ranged from 15.3 to 18 % that it is a little higher that the limit of 15 % of EN standard. Employing different treatments of the leaves; anaerobic digestion (Zheng et al. 2009), using silane, dewaxing, or washing of the leaves (Campanella et al. 2013), the properties of sycamore leaves-based panels can be even improved.

Table 6 Mean values and SD of panels made from sycamore leaves

Treatment code	MOR (Mpa)	MOE (Mpa)	IB (MPa)	WA-2 h (%)	WA-24 h (%)	TS-2 h (%)	TS-24 h (%)
A1	15.92 A	1,958 A	0.57 A	25.8 D	34.2 F	11.23 F	18.05 G
	(0.23)	(21.6)	(0.02)	(0.25)	(0.28)	(0.35)	(0.24)
A2	16.05 A	1,991 BC	0.6 B	25.17 C	33.72 E	10.9 E	17.07 E
	(0.14)	(24.6)	(0.02)	(0.32)	(0.19)	(0.25)	(0.31)
A3	16.38 B	2,019 C	0.61 B	24.97 C	33.32 D	10.13 D	16.77 D
	(0.25)	(48.3)	(0.02)	(0.3)	(0.28)	(0.28)	(0.27)
A4	16.03 A	1,979 AB	0.6 B	25.83 D	34.12 F	11.07 EF	17.52 F
	(0.26)	(16.5)	(0.01)	(0.41)	(0.26)	(0.31)	(0.28)
A5	16.63 C	2,021 C	0.63 C	24.28 B	32.72 C	9.68 C	16.12 C
	(0.22)	(24.8)	(0.01)	(0.43)	(0.16)	(0.16)	(0.29)
A6	17.23 E	2,101 DE	0.71 E	24.02 B	32.1 B	8.92 A	15.55 AB
	(0.17)	(24.6)	(0.02)	(0.4)	(0.4)	(0.23)	(0.19)
A7	17.73 F	2,130 E	0.74 F	23.3 A	31.7 A	8.85 A	15.28 A
	(0.16)	(15.7)	(0.01)	(0.26)	(0.23)	(0.19)	(0.29)
A8	16.92 D	2,089 D	0.68 D	23.92 B	32.15 B	9.28 B	15.83 BC
	(0.21)	(17.6)	(0.01)	(0.17)	(0.31)	(0.19)	(0.22)

The numerical value in the parenthesis is SD. Different letters indicate significantly different groups ($P \leq 0.05$)

Conclusion

Composite materials can be successfully made out of sycamore leaves collected in the fall and MDI resin, achieving mechanical properties desired for some applications, such as furniture, interior decoration (partition, wall, and ceiling paneling), and other applications. Board density and press time were the main parameters influencing the physical and mechanical properties of the panels. However, the effect of press temperature on mechanical and physical properties was not significant. Conclusively, mechanical properties of all the panels exceed the minimum requirements of EN standards for furniture manufacturing. Using underutilized wastes like sycamore leaves for manufacturing particleboards could contribute solution of raw material shortage for particleboard industry as well as diminishing environmental problems regarding their burning. Besides, the pressure on forest resources can be decreased and some job opportunities can be created. Furthermore, using leaves in particleboard manufacturing could mean the farmers second income from plantation and alleviate poverty.

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References

Abdolzadeh H, Doosthoseini K, Karimi AN, Enayati AA (2011) The effect of acetylated particle distribution and type of resin on physical and mechanical properties of poplar particleboard. Eur J Wood Prod 69:3–10

Ashori A, Nourbakhsh A (2008) Effect of press cycle time and resin contents on physical and mechanical properties of particleboard panels made from the underutilized low-quality raw materials. Ind Crops Prod 28(2):225–230

Bilgili E (2003) Stand development and fire behavior. For Ecol Manag 179:333–339

Campanella A, Wool RP, Bah M, Fita S, Abuobaid A (2013) Composites from northern red oak (*Quercus robur*) leaves and plant oil-based resins. Appl Polym Sci 127(1):18–26

Ciannamea EM, Stefani PM, Ruseckaite RA (2010) Medium-density particleboards from modified rice husks and soybean protein concentrate-based adhesives. Bioresour Technol 101:818–825

Doosthoseini K (2002) Wood composite materials, manufacturing, applications. vol 1 (Fundamentals). University of Tehran Press, Tehran, Iran (in Persian)

Doosthoseini K, Zarea-Hosseinabadi H (2010) Using Na^{+}MMT nanoclay as secondary filler in plywood manufacturing. J Indian Acad Wood Sci 7(1–2):58–64

Dunky M, Pizzi A (2002) Wood adhesives. In: Chaudhury M, Pocius AV (eds) Adhesive science and engineering: surfaces, chemistry and applications, chap 23. Elsevier, Amsterdam, pp 1039–1103

EN 310 (1993) Wood-based panels, determination of modulus of elasticity in bending and bending strength. European Committee for Standardization, Brussels, Belgium

EN 317 (1993) Particleboards and fiberboards, determination of swelling in thickness after immersion. European Committee for Standardization, Brussels, Belgium

EN 319 (1993) Particleboards and fiberboards, determination of tensile strength perpendicular to plane of the board. European Committee for Standardization, Brussels, Belgium

Espinoza E, Benavides JE, Ferreire P (1999) Evaluación de tres variedades de morera (*Morus alba*) en tres sitios ecológicos de Costa Rica y bajo tres niveles de fertilización. Citado por Benavides, J.E.

FAO (2012) State of the world's forests. Rome. www.fao.org/

FAOSTAT data (2012) http://faostat.fao.org/faostat/. Accessed Dec 2012

Faruk O, Bledzki AK, Fink HP, Sain M (2012) Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci 37:1552–1596

Guntekin E, Karakus B (2008) Feasibility of using eggplant stalks (*Solanum melongena*) in the production of experimental particleboard. Ind Crops Prod 27:354–358

Heckman JR, Kluchinski D (1996) Chemical composite of municipal leaf and hand collected urban leaf litter. Environ Quality 25(2):355–362

Kalaycıoglu H, Neml G (2006) Producing composite particleboard from kenaf (*Hibiscus cannabinus* L.) stalks. Ind Crops Prod 24:177–180

Kargarfard A, Doosthoseini K, Jahan Latibari A, Hoseinzadeh A (2002) The effects of press temperature and press time on heat transfer in particleboard manufacturing. J Res Dev 16:56–65 (in Persian)

Maloney TM (1989) Modern particleboard and dry process fiberboard manufacturing. Miller Freeman Publication, San Francisco

Nemli G, Kırcı H, Serdar B, Ay N (2003) Suitability of kiwi pruning for particleboard manufacturing. Ind Crops Prod 17:39–46

Nemli G, Yildiz S, Gezer ED (2008) The potential for using the needle litter of Scotch pine (*Pinus sylvestris* L.) as a raw material for particleboard manufacturing. Bioresour Technol 99:6054–6058

Ozkaya K, Ayrilmis N, Dizel T, Imirzi HO (2013) Utilization of extract of fresh tree leaves as extender in synthetic adhesives for laminated veneer lumber (LVL). Ind Crops Prod 44:67–70

Papadopoulos AN, Hague JRB (2003) The potential for using Xax (*Linum usitatissimum* L.) shiv as a lignocellulosic raw material for particleboard. Ind Crop Prod 17:143–147

Pirayesh H, Khazaeian A (2012) Using almond (*Prunus amygdalus* L.) shell as a bio-waste resource in wood based composite. Compos Part B 43(3):1475–1479

Pirayesh H, Khazaeian A, Tabarsa T (2012) The potential for using walnut (*Juglans regia* L.) shell as a raw material for wood-based particleboard manufacturing. Compos Part B 43(8):3276–3280

Pirayesh H, Khanjanzadeh H, Salari A (2013) Effect of using walnut/almond shells on the physical, mechanical properties and formaldehyde emission of particleboard. Compos Part B 45:858–863

Salari A, Tabarsa T, Khazaeian A, Saraeian A (2013) Improving some of applied properties of oriented strand board (OSB) made from underutilized low quality paulownia (*Paulownia fortunie*) wood employing nano-SiO2. Ind Crops Prod 42:1–9

T 204 cm (1997) Solvent extractives of wood and pulp. TAPPI Standards

T 257 cm (1985) Sampling and preparing wood for analysis, TAPPI Standards

T 211 om (1993) Ash in wood and pulp. TAPPI Standards

T 212 om (1998) One percent sodium hydroxide solubility of wood and pulp. TAPPI Standards

T 222 om (1998) Acid-insoluble lignin in wood and pulp. TAPPI Standards

T 207 om (1999) Water solubility of wood and pulp. TAPPI Standards

Tabarsa T, Ashori A, Gholamzadeh M (2011) Evaluation of surface roughness and mechanical properties of particleboard panels made from bagasse. Compos Part B 42(5):1330–1335

Wise LE, Karl HL (1962) In: Earl Libby C (ed) Cellulose and hemicellulose in pulp and paper science and technology. Mc Graw Hill Book Co., New York

Yousefi H (2009) Canola straw as a bio-waste resource for medium density fiberboard (MDF) manufacture. Waste Manag 29:2644–2648

Zheng Y, Pan Z, Zhang R, EI-Mashad HM, Pan J, Jenkins BM (2009) Anaerobic digestion of saline creeping wild ryegrass for biogas production and pretreatment of particleboard material. Bioresour Technol 100:1582–1588