The Performance and Properties of Wood–Polypropylene Panels as Affected by Wood Aqueous Extraction

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Abstract

The manufacturing of wood–polymer composites (WPCs) by compounding wood particles with plastic at temperatures above their melting point may cause thermal degradation of the wood, which can lead to undesirable properties, including odor, discoloration, and degradation of the mechanical properties of the panels. This study was conducted to investigate the effect of a particle pretreatment (cold-water soaking and hot-water extraction) on the performance and properties of WPC panels made of four lignocellulosic materials (LCMs) and polypropylene (PP), 50/50 by weight. Composites filled with pretreated and untreated particles of three wood species and date palm midrib fronds were manufactured using a melt blending technique followed by compression molding. The physical, mechanical, and dimensional stability properties of the WPC panels were evaluated. The results indicated that the four LCMs are significantly different in all chemical constituents. Pretreating the wood particles by either cold or hot water resulted in significant improvements in the compatibility of each wood species with PP, as was observed by an increase in the mechanical properties and by a decrease in the water uptake and thickness swelling of the composite panels. An enhancement in strand color and a decrease in smoke and excessive odor during the compounding process were also observed, which resulted in an enhancement in the performance of the produced panels, particularly for the date palm midrib fronds.

Since the early 1930s, the global consumption of plastics has been drastically increasing, exceeding all expectations relative to other mineral and nonmineral building materials. The use of plastics is highly correlated with their good characteristics and shape control for many products. It is well known that plastics are used in an increasing number of applications due to the ability to control their shape or form; they have been used in food and household product filling, the carpet industry, furniture and pipe components, televisions, computers, and children's toys as well as in other industries. Most plastic is a nonbiodegradable, causing soil fill that affects plant growth and causes erosion (Viksne et al. 2010). These properties make plastics one of the most vital classes of materials. The recovery and reuse of these materials (wood and plastic) may offer a significant opportunity for saving landfill space as well as for reducing our impact on the environment (Bromett et al. 1992).

Wood–polymer composites (WPCs) behave like wood and are workable with conventional woodworking tools. These composites are considered to be environmentally friendly products because they are typically produced from recycled materials, have the possibility of being recycled more than once without a significant loss of product, and are associated with low production costs (Harikumar et al. 1999, Stark 1999). In addition, they are lightweight compared with other wood panels, in particular wood–cement composites. They are highly resistant to moisture, fungi, and insects, and they can be used in different plastic production technologies and applications. There are many applications of WPCs in our daily lives, such as in cars behind the vinyl and carpeting on the doors, consoles, headliners, trunk liners, and seat backs (Youngquist 1995). In addition, many window and door manufacturers are also considering these composites as an alternative to solid wood in clad components.

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The industrial development of WPCs still has many limitations even though the properties and uses of these products have dramatically increased in the past four decades. The three most important limitations are the poor compatibility between the hydrophobic polymers and the hydrophilic wood particles (Bengtsson et al. 2006, Danyadi et al. 2006, Ghasemi and Kord 2009, Kord 2011) and the low thermal stability and high moisture absorption of wood (Devi et al. 2004, Shebani et al. 2008). In the literature, several methods are suggested that can be used to overcome the problem of the poor compatibility between wood fibers and thermoplastics. For example, the pretreatment of fibers and the use of coupling and dispersion agents have been reported (Nasser 2002, Kord 2011).

Extractives, which are nonstructural and have a low molecular weight, are the secondary components of the chemical composition of wood. Generally, based on ovendry weight, they vary from less than 1 to 5 percent but can be up to 30 percent in some extreme cases (Shebani et al. 2008). The amount and composition of extractives differ depending on the solvent used (Sefara and Birkett 2004), and they differ markedly across various parts of the same tree and species (Horvath 2006), harvesting seasons (Zabel and Morrell 1992), and storage times (Silverio et al. 2008). Although wood extractives represent a small percentage of the entire wood composition, they can negatively influence many wood characteristics, such as thermal stability (Shebani et al. 2008), compressive strength (El-Osta et al. 1980), and bending strength (Al-Mefarrej 1985). Wood extractives are also responsible for many challenges in the wood industry in the production of WPCs (Shebani et al. 2008), pulp production and papermaking (Silverio et al. 2008), particleboard (Pan et al. 2007), and wood–cement composites (Moslemi et al. 1983).

The influence of wood extractives on the thermal stability of wood and WPCs has not been extensively studied. Pan et al. (2007) reported that particleboard made from hot-water–treated wood particles had more desirable qualities (higher mechanical properties and dimensional stability) than those made from untreated particles.

Shebani et al. (2008) concluded that the thermal stability of the extracted cellulose from four wood species exhibited a higher thermal stability than the wood itself. The thermal gravimetric analysis and derivatives of the thermal gravimetric curves of the four wood species extracted by hot water, ethanol-cyclohexane, and a combination of both shifted to higher temperatures, implying an improvement in thermal stability with extraction. Nachtigall et al. (2007) suggested that some wood extractives can emit an unpleasant smell during the production of WPCs or may have unfavorable effects on the thermal stability of the final products. The manufacturing of these composites by compounding wood particles with plastic at a temperature above their melting temperature (up to 200°C) may cause a degradation of the wood that can lead to undesirable properties, including odor, discoloration, and a decrease in the mechanical properties of the panels (Nachtigall et al. 2007). To use wood as a filler in the plastic industry, Aref et al. (2013) concluded that particles should be treated by aqueous extraction before being compounded with polypropylene (PP), which enhances the performance of the composites, especially of date palm fronds. Saudi Arabia is a country poor in natural forests, but it has relatively large quantities of other lignocellulosic materials available in the form of agricultural residues from annual crops. Several of these lignocellulosic fibers have been used successfully to produce particleboards (Hegazy and Aref 2010) and to some extent inorganic-bonded boards (Nasser et al. 2011). Few studies have been conducted in Saudi Arabia to produce WPCs or to evaluate the compatibility of some local wood species or agricultural residues for WPC manufacturing (Abu-Shakh and Hamid 2004, Aref et al. 2013).

The objective of this study was to investigate the effects of the pretreatment of wood particles on the properties of WPC panels. WPCs filled with pretreated and untreated particles of three wood species and date palm midrib fronds were manufactured, and their physical, mechanical, and dimensional stability properties were evaluated.

Materials and Methods

Raw materials

Four lignocellulosic materials were used in the current study to manufacture the WPC panels. Two of those were tree prunings of hardwood species (*Tamarix aphylla* and *Conocarpus erectus*), which were planted as urban trees and collected during 2011 from the cities of Damam and Qassim, respectively; branches of *Juniperus procera* trees were selected as a softwood species and collected from the Al-Baha region in the southwest of the kingdom. Date palm midrib fronds were collected from residual deposits in Riyadh city. The characteristics of these materials and their descriptions are listed in Table 1.

PP pellets from the local market (SABIC Company, Riyadh, Saudi Arabia) were used in this work. PP is an injection-molding grade of a PP copolymer with a narrow molecular weight distribution and a high flowability. Some of its properties are listed in Table 2 as provided by the supplier.

Particle preparation

After collecting and air-drying the lignocellulosic materials, they were cut down into 2- to 3-cm-long pieces using a band saw to facilitate grinding into particles and kept in separate polyethylene bags until used. The fragmented materials were then fed through a laboratory-type hammer

Table 1.—Characteristics of the lignocellulosic materials.[a]

Lignocellulosic material	Height (m)	Diam. (cm)	Age (y)	SG	MC (%)[b]	Remarks
Tamarix aphylla	32.2	35.7	30–35	0.638	15.16	Branches without bark
Conocarpus erectus	15.7	11.9	10–12	0.653	6.39	Branches with bark (12%–18%)
Juniperus procera	18.5	28.9	20–25	0.641	6.47	Branches without bark
Phoenix dactylifera	—	—	—	0.141	37.13	Midrib fronds without leaflets

[a] Each value is an average of 10 samples from five trees or 200 date palm fronds. SG = specific gravity; MC = moisture content.
[b] After air-drying and before processing. Date palm required additional drying to decrease the MC.

Table 2.—Physical properties of polypropylene.

Physical properties[a]	Value	ASTM method
Melt index (g/10 min)	25.0	D-1238
Density (g/cm^3)	0.954	D-1505
Vicat softening point (°C)	153	D-1525
Tensile strength at yield (MPa)	36	D-638
Hardness (shore D)	104R	D-2240

[a] As reported by the supplier.

mill using a 5-mm screen. The dimensions of the particles, including the particle length, width, and length-to-width ratio for each, are given in Table 3.

The current investigation used 20-, 40- and 60-mesh screens. The particles that passed through a 0.8-mm sieve (20 mesh) but were retained on a 0.4-mm sieve (40 mesh) were used for the manufacturing of the WPC panels, while the particles that passed through the 0.4-mm sieve (40 mesh) but were caught on a 0.27-mm sieve (60 mesh) were used for chemical analysis.

The specific gravity (SG) and chemical characteristics of the four lignocellulosic materials (LCMs) were determined according to ASTM standards (American Society for Testing and Materials [ASTM] 1989). These standards are used to evaluate the engineering performance of wood-based panels, such as particleboard, medium-density fiberboard, and hardboard. These characteristics include SG (Smith 1956), moisture content (MC), total extractives content (ASTM 1989), solubility in cold and hot water (ASTM 1989), lignin content (ASTM 1989), cellulose content (ASTM 1989), hemicellulose content (Rozmarin and Simionescu 1973), and ash content (ASTM 1989).

Pretreatments of the LCMs

Two aqueous extraction pretreatments were used to enhance the performance and compatibility between the LCM and the PP. These pretreatments were cold- and hot-water extractions. The LCM particles were either soaked in cold water for 48 hours or pretreated by a hot-water extraction for 6 hours, changing the water every 2 hours according to the methods outlined by Moslemi et al. (1983). To avoid the formation of undesirable foams that arise from the wood moisture as well as to avoid any discoloration that may result from charring of the extracted materials, the LCM particles were dried in an oven at 100°C ± 5°C for approximately 24 hours, except in the case of the date palm fronds, which were dried at 80°C ± 5°C for 18 hours.

Composite panel preparation

To reach a targeted WPC panel density of 1.0 g/cm^3, a predetermined amount of the raw materials (LCMs and PP) were weighed based on the wood-to-plastic ratio (50/50 by weight). Compounding of the raw materials was carried out by using a melt-blending technique according to the method of Stark and Matuana (2007) using a twin-screw extruder. The blended material was degassed in an electric oven for 15 to 20 minutes at 200°C to eliminate any moisture traces before compounding. After degassing, the degassed materials were fed into the preheated compounding machine for final compounding. The extruded strands were then cooled in a water bath and pelletized in a pelletizer. No additives were used with the raw materials. The wood–PP mixture was poured into the pressing mold, which consisted of two 300 by 300-mm stainless steel plates (2 mm thick), each of which were covered with a Mylar sheet to facilitate the removal of the panels after pressing and cooling. The mat was consolidated in a Carver hydraulic laboratory press (Model Monarch 2354) to produce panels with final dimensions of 300 by 300 by 10 mm. The WPC panels were hot pressed for 10 minutes, including the closing time, under a pressure of 4.3 MPa at 180°C ± 5°C and cooled to approximately 60°C to 70°C before removal and allowed to cool further with a heavy weight (30 kg). The edges of the panel were trimmed and conditioned at 65% ± 5% relative humidity and 20°C ± 2°C for at least 1 week before testing. Three panels were processed for each material combination.

Resin–particleboard preparation

Three-layer particleboard panels were manufactured using urea-formaldehyde as a binder. For additional details regarding the manufacturing variables and the processing of these panels, see Nasser (2012).

Preparation of the WPC test specimens

To remove the low-density and poor bonding areas of the boards after conditioning the molded panels, each panel was trimmed to dimensions of 25 by 25 cm. A variety of engineering and material properties tests were performed. Each panel was divided into test specimens; some were used to determine the mechanical and physical properties, and others were used to determine the dimensional stability.

Determination of the properties of the WPC panels

Mechanical properties.—Tests of static bending and tensile perpendicular to the panel surface (internal bond [IB]) were carried out at the Department of Chemical Engineering, College of Engineering, King Saud University, using a Hounsfield testing machine (H100 KS). The test specimens were prepared and tested according to ASTM standards (1989) for WPC panels, which has a 50/50 wood-to-plastic ratio by weight with a control of 100% wood (resin–particleboard). Test specimens for bending were 50 mm in width and 250 mm in length (span = 23 cm). Data were collected and used to calculate the modulus of elasticity (MOE) and modulus of rupture (MOR). On

Table 3.—Dimensions and slenderness ratio (L/D) of the particles (20/40 mesh) used for wood–polymer composite panels.[a]

Lignocellulosic material	Length (mm)	Width (mm)	L/D ratio
Conocarpus erectus	3.18 (1.04)	0.86 (0.58)	4.05 (1.61)
Tamarix aphylla	2.62 (0.68)	0.70 (0.16)	3.89 (1.32)
Juniperus procera	2.88 (0.93)	0.70 (0.16)	4.34 (1.80)
Phoenix dactylifera	3.47 (1.22)	0.62 (0.13)	5.89 (2.75)

[a] Values are means (standard deviations) of 90 measured particles.

completion of the bending tests, the SG and MC of the panels were determined according to the ASTM Standard D2395 (ASTM 1989) using the volume by displacement in water and ovendry weight. The IB test is widely utilized in all particleboard research, and the dimensions of the samples were 50 by 50 mm and had the same thickness as a finished panel (approximately 10 mm).

Water uptake and dimensional stability.—Water uptake (WU) and thickness swelling (TS) were carried out based on European standards. Samples of both untreated and treated WPC were soaked in water at room temperature (22°C to 25°C) for 2, 24, 48, 96, 120, and 144 hours. The specimens were then suspended to drain the water for 10 minutes, the excess water was removed, specimens were immediately weighed, and the test board widths and thickness were remeasured. WU is expressed as a percentage of moisture absorbed based on an ovendry weight, and TS is calculated as a percentage of thickness change based on an ovendry thickness.

Statistical analysis

The experimental design was a completely randomized design that was used to investigate the effects of the species, pretreatments, and their interactions. The results were analyzed using the Statistical Analysis System. A Duncan multiple range test was used to detect the differences between the species and pretreatments as well as to detect their interactions.

Results and Discussion

Chemical analysis

The mean values of the chemical constituents of the four LCMs used for the manufacturing of the WPC panels are given in Table 4. These constituents include the total extractives, cellulose, hemicellulose, lignin, and ash contents, and cold- and hot-water solubility.

Statistical analysis indicates that the four species were significantly different in all chemical constituents. As shown in Table 4, *J. procera* had the highest average values of cellulose and lignin contents (47.74% and 35.51%, respectively), while it had the lowest values of hemicellulose (16.75%) and solubility. *Phoenix dactylifera* had the highest average values of extractive and hemicellulose contents (21.43% and 27.86%, respectively) and solubility.

The ash content ranged from 0.9% for *J. procera* to 6.5% for *T. aphylla* (Table 4). The ash content of *T. aphylla* (6.5%) and *P. dactylifera* (5.32%) were higher than most softwoods and hardwoods, which normally do not exceed 2% (Haygreen and Bowyer 1996), but the ash content can reach 5% in some tropical species (Hindi 2001). The same result was reported by Hindi (2001) for *T. aphylla*.

The variation in the chemical constituents of the four species can define the differences in their compatibilities with plastic. These results suggest that pretreatment may be beneficial for enhancing the compatibility of these woods with plastic.

Effect of species on the properties of the WPC panels

The results of the analysis of variance show that except for the MC, the various parameters of the mechanical (MOR, MOE and IB) and physical (SG) properties, and WU and TS after 2 and 24 hours of water soaking the panels significantly changed from one LCM to another.

Table 5 shows the mean values of the mechanical and physical properties of the WPC panels made from each LCM and PP. It is clear from this table that the highest values for MOR, MOE, and IB were obtained for *J. procera,* while the lowest values were recorded for panels made of *P. dactylifera*. The weakness of the WPC panels made from date palm fronds compared with the other LCMs is in disagreement with the findings of Agoudjil et al. (2010), who reported that the surface of the date palm petiole fiber is cylindrical in shape and irregular with many filaments and cells, allowing adhesion between the fibers and the polymer matrix. However, our results do agree with the findings of Al-Khanbashi et al. (2005), who reported that surface modification seems to be essential for purifying and cleaning the surface of the fibers due to a large amount of impurities and the uncompleted growth of fibers, which may result in poor adhesion between the fibers and the matrix. We think that this is the case for the date palm midrib fronds in the current study, which resulted in the lower performance of this wood–PP composite. Comparing the properties of the WPC panels of the four species under investigation with the EN Standards 312-2 and 312-3 (European Committee for Standardization 1996a, 1996b) for particleboard revealed that all of the panels had mechanical properties higher than the requirements for general-purpose interior fitments, load-bearing boards, and heavy-duty load bearing.

The MC of the WPC panels was very low compared with any wood-based composite panels, and it was very homogeneous, ranging from 0.8 percent for *P. dactylifera*

Table 4.—Chemical constituents of the lignocellulosic materials used for wood–polypropylene composite panels.[a]

Lignocellulosic material	% content of:						
	Extractives	Cellulose	Hemicellulose	Lignin	Ash	CWS	HWS
Conocarpus erectus	11.08 C (0.18)	47.41 A (0.30)	22.55 C (0.46)	30.04 B (0.63)	1.86 C (0.02)	7.98 C (0.11)	7.85 C (0.36)
Tamarix aphylla	16.28 B (0.24)	45.49 B (0.30)	25.91 B (0.17)	28.61 C (0.35)	6.49 A (0.11)	12.83 B (0.31)	12.66 B (0.21)
Juniperus procera	10.49 C (0.45)	47.74 A (0.80)	16.75 D (0.72)	35.51 A (0.59)	0.87 D (0.09)	3.55 D (0.30)	3.25 D (0.29)
Phoenix dactylifera	21.43 A (0.69)	44.57 C (0.12)	27.86 A (0.56)	27.57 C (0.48)	5.32 B (0.13)	18.63 A (0.69)	22.79 A (0.69)
Softwood[b]	2–6	45–50	15–35	23–30	0.2–0.5	4–6	2–7
Hardwood[b]	2–8	45–50	20–32	25–34	0.2–0.5	2–3	3–6

[a] Values are means (standard deviations) of five replications. Data are according to the ASTM (1989) procedure, except for hemicellulose content, which is according to Rozmarin and Simionescu (1973). CWS = cold-water solubility; HWS = hot-water solubility. Means with the same letters in a column are not significantly different at the 5 percent level of probability.

[b] According to Haygreen and Bowyer (1996).

Table 5.—Physical and mechanical properties of the wood–polypropylene composite panels.[a]

Lignocellulosic material	Physical properties		Mechanical properties		
	SG	MC (%)	MOR (MPa)	MOE (GPa)	IB (MPa)[b]
Conocarpus erectus	1.01 A (0.006)	0.75 A (0.03)	31.27 C (2.35)	3.24 C (268)	5.69 B (0.73)
Tamarix aphylla	0.96 B (0.011)	0.78 A (0.06)	32.74 B (1.64)	3.65 B (192)	5.16 C (0.75)
Juniperus procera	0.96 B (0.009)	0.89 A (0.01)	34.05 A (3.84)	3.88 A (228)	5.85 A (0.44)
Phoenix dactylifera	0.93 C (0.010)	0.82 A (0.04)	29.42 D (3.51)	3.24 C (633)	4.77 D (0.31)
Requirements[c]	—	—	11.50	—	0.24
Requirements[d]	—	—	13.00	1.60	0.35

[a] Values are means (standard deviaitons) of nine samples. SG was based on ovendry weight and volume at test using the displacement method. Means with the same letters in a column are not significantly different according to Duncan's multiple range test. SG = specific gravity; MC = moisture content; MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond.

[b] The IB samples were surface adhesion breaks and do not represent true IB. The IB will be greater.

[c] For general-purpose use of particleboard according to the EN 312-2 (European Committee for Standardization [CEN] 1996a) standard.

[d] For interior grade–type (including furniture) use of particleboard according to the EN 312-3 (CEN 1996b) standard.

to 0.9 percent for *J. procera* without any significant differences. This means that all specimens were conditioned under control conditions before testing. The SGs of the WPC panels ranged from 0.93 for *P. dactylifera* to 1.01 for *C. erectus*. These values are much lower than those of a mineral-filled thermoplastic system (it is approximately 2.5 g/cm^3; Avella et al. 1998). The SG of a 50 percent (by weight) kenaf–PP composite is approximately 1.07 (Sanadi et al. 1995). More pieces can be made with lignocellulosic fibers compared with the same weight of mineral fibers. This is beneficial because raw materials are purchased by weight, whereas pieces or articles are sold by the number. This could result in a significant material cost savings with a higher-volume and lower-cost commodity plastic matrix (Avella et al. 1998).

The mean values for WU and TS after 2 and 24 hours of water soaking of the WPC panels and that of the resin-bonded particleboard manufactured from the same LCMs are given in Table 6. The values of WPC panels were generally lower than those for the resin-bound particleboard produced from the same LCMs. For example, the WU of the particleboard after soaking in water for 24 hours ranged from 47.5 to 58.6 percent, and these values for the WPC panels ranged from 1.4 to 3.9 percent (Table 6). These values are very low in comparison to those for the particleboard produced from the same LCM, which ranged from 16.8 to 18.0 percent. This means that the WPC panels manufactured from the four LCMs in this study have greater dimensional stability characteristics than purely wood-based composition panels.

The differences in the mechanical properties and dimensional stability characteristics of the WPC panels of the four LCMs may be attributed to variations in their physical, chemical, and anatomical properties as well as to differences in the particle dimensions and their slenderness ratios (Table 3). The role of extractives and hemicelluloses may be the main reasons for the differences between the four LCMs, particularly between *J. procera* and *P. dactylifera*. Additionally, an increase in the lignin content may play a major role in increasing the mechanical properties of the WPC panels due to the lignin being a thermoplastic material. It can be concluded that the bond strength between PP and the particles of *P. dactylifera* is relatively weak due to the higher extractive and hemicellulose contents. These results are in agreement with the trend previously observed in the literature (Nasser 2002, Ashori and Nourbakhsh 2010).

Effect of pretreatment on the properties of WPC panels

The variance analysis results indicate that aside from the MC and SG characteristics, the mechanical and physical properties, as well as the dimensional stability characteristics of the WPC panels, are significantly affected by the pretreatment of the wood particles. The effects of pretreatments (cold-water soaking and hot-water extraction) on the

Table 6.—Dimensional stability properties of the wood–polymer composite (WPC) panels and resin–particleboard (RPB).[a]

Lignocellulosic material	Water uptake (%)				Thickness swelling (%)			
	2 h		24 h		2 h		24 h	
	WPC	RPB	WPC	RPB	WPC	RPB	WPC	RPB
Conocarpus erectus	0.64 C (0.11)	40.45 B (5.3)	2.12 C (0.22)	56.06 B (5.32)	0.64 B (0.13)	14.07 B (1.6)	1.30 B (0.15)	16.30 B (1.3)
Tamarix aphylla	0.82 B (0.27)	24.24 C (4.6)	2.93 B (0.99)	47.48 D (7.2)	0.55 C (0.49)	9.71 D (1.1)	1.20 C (0.79)	16.82 B (2.0)
Juniperus procera	0.38 D (0.11)	44.25 A (3.3)	1.41 D (0.56)	52.62 C (4.2)	0.27 D (0.23)	15.10 A (2.0)	0.60 D (0.53)	17.98 A (1.9)
Phoenix dactylifera	1.16 A (0.48)	40.45 B (4.2)	3.90 A (1.26)	58.55 A (3.9)	0.77 A (0.57)	10.80 C (2.2)	1.80 A (0.77)	18.00 A (1.7)
EN standard	—	—	—	—	—	8	—	15

[a] Values are means (standard deviations) of nine samples. WPC data are from the current study; RPB data are from Nasser (2012). Three-layer particleboard, 50 percent solid content of urea-formaldehyde (8% for core and 10% for surfaces), 1 percent wax emulsion, 0.70 g/cm^3 target density, 150°C for 7-minute press time at 3.0 MPa pressure. Means with the same letters in a column are not significantly different according to Duncan's multiple range test.

Table 7.—Effect of pretreatments on the properties of the wood–polypropylene panels.

						Dimensional stability (%)			
	Physical properties		Mechanical properties			Water uptake		Thickness swelling	
Pretreatments	SG	MC (%)	MOR (MPa)	MOE (GPa)	IB (MPa)	2 h	24 h	2 h	24 h
Untreated	0.95 A (0.002)	0.86 A (0.02)	28.55 C (2.88)	3.14 C (450)	4.71 C (0.40)	1.01 A (0.53)	3.47 A (1.47)	0.93 A (0.45)	1.79 A (0.75)
Cold water	0.96 A (0.010)	0.83 A (0.05)	32.19 B (1.63)	3.48 B (252)	5.48 B (0.50)	0.67 B (0.27)	2.47 B (0.89)	0.29 B (0.19)	1.01 B (0.53)
Hot water	0.96 A (0.009)	0.74 A (0.01)	34.87 A (1.59)	3.89 A (286)	5.91 A (0.63)	0.55 C (0.19)	1.91 C (0.75)	0.35 B (0.23)	0.78 B (0.48)

[a] Values are means (standard deviations) of 12 samples. SG = specific gravity; MC = moisture content; MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond. The IB samples on these panels were surface adhesion breaks and do not represent true IB. The IB will be greater. Means with the same letters in a column are not significantly different according to Duncan's multiple range test.

WPC panels are presented in Table 7. The results show that all of the mechanical properties of the panels are significantly increased, while their WU and TS are significantly decreased after pretreating with an aqueous extraction. The differences between the two pretreatments (cold water and hot water) were significant except in regard to the MC, where no significant differences were observed. Using this pretreatment resulted in an increase in the average MOR value from 28.6 to 34.9 MPa, with an increase of 22.1 percent compared with panels made with untreated wood particles. With hot-water extraction, the MOE and IB values also increased by 23.9 and 25.5 percent, respectively. The WU and TS values were dramatically decreased by both types of pretreatment. For the WA of the WPC panels, there were significant differences between the cold-water and hot-water pretreatments, while those differences were not significant in the TS. Pretreating the wood particles by extraction with hot water showed the greatest enhancement of the properties of the WPC panels compared with those panels made with either cold-water pretreatment or untreated particles.

The percent change of the panel properties due to the pretreatments based on the untreated WPC panels is given in Table 8. These results show that one trend was observed with pretreatment for each LCM: the mechanical properties of WPC panels were increased, while the dimensional stability was decreased. This effect differed according to the type of LCM. The greatest improvement with pretreatment was obtained for panels made from *P. dactylifera* particles pretreated with hot water before compounding with PP (30.9%, 57.5%, and 26.4%, respectively). For the MOR, the greatest increase was recorded for *P. dactylifera,* followed by *C. erectus*. Generally, for all four LCMs used, hot-water extraction had a greater effect than cold-water soaking for all properties. The MOR ranged from 25.1 MPa for untreated *P. dactylifera* to 36.7 MPa for *J. procera* particles treated with hot water. The MOE ranged from 2.5 GPa for untreated *P. dactylifera* to 4.2 GPa for *C. erectus* particles treated with hot water. The highest IB value recorded was for *J. procera* treated with hot water (6.7 MPa), while the lowest value (4.3 MPa) was obtained for untreated *T. aphylla*.

These results show that the extraction of wood particles by either cold or hot water improves the mechanical and physical properties of the WPC panels made from the four LCMs. In addition, using pretreatments with the wood particles resulted in improvements in the strand color, decreases in smoke and excessive odor during the compounding process, and enhanced performance of the panels produced, especially with the date palm midrib fronds. These results can be attributed to the removal of sugars and other water-soluble extractives from the wood, which are highly hydrophilic substances. The removal of these substances may improve the compatibility between the wood and the matrix (Borgin and Corbett 1971). These results are in agreement with the literature (Nasser 2002).

Conclusions

From the results of the current study, the following conclusions may be drawn.

- The physical properties and chemical composition of the woods differed significantly among the four LCMs investigated.
- The highest values of MOR and MOE were obtained for the WPC panels made from *J. procera* (34.05 MPa and 3.88 GPa, respectively).

Table 8.—Percent change of the properties of wood–polypropylene composite due to the pretreatment.[a]

		Mechanical properties			Water uptake		Thickness swelling	
Lignocellulosic material	Pretreatment	MOR	MOE	IB	2 h	24 h	2 h	24 h
Conocarpus erectus	CWE	+15.6	+9.8	+17.2	−9.33	−9.96	−24.39	−23.13
	HWE	+29.6	+17.2	+16.4	−36.00	−14.72	−40.24	33.13
Tamarix aphylla	CWE	+7.0	+4.6	+8.4	−42.9	−28.9	−55.8	−43.5
	HWE	+11.2	+12.5	+20.2	−50.7	−49.1	−88.5	−90.7
Juniperus procera	CWE	+8.9	+5.0	+15.1	−12.5	−22.7	−38.7	−36.8
	HWE	+16.9	+16.6	+25.4	−45.8	−63.1	−61.3	−52.9
Phoenix dactylifera	CWE	+21.4	+28.6	+19.2	−40.6	−30.5	−45.8	−33.1
	HWE	+30.9	+57.5	+26.4	−61.1	−53.4	−13.9	−23.1

[a] Change calculated as a percentage based on untreated wood–polypropylene panel where property decreased (–) or increased (+). Each value is an average of three specimens. CWE is wood particles soaking in cold water for 48 hours. HWE is wood extracted by hot water for 6 hours (Moslemi et al. 1983). MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond. The IB samples on these panels were surface adhesion breaks and do not represent true IB. The IB will be greater.

- The WU and TS of the WPC panels were generally lower than those of resin-bounded particleboard produced from the same species.
- Using pretreatments for the wood particles, either cold- or hot-water extraction, resulted in significant improvements in the compatibility of each wood species with polypropylene, as observed by an increase in both the mechanical properties and the dimensional stability.
- Without pretreatment of date palm frond particles, WPC panels will have undesirable properties.
- For each lignocellulosic material examined, hot-water extraction had a greater effect on all of the WPC properties compared with cold-water soaking.

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