Some Chemical Properties of Luffa and Its Suitability for Medium Density Fiberboard (MDF) Production

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This study was conducted to evaluate suitability of luffa (*Luffa cylindrica*) fiber for medium density fiberboard (MDF) production. For the experiment, luffa and commercially manufactured fibers (*Pinus sylvestris* (30%), *Fagus orientalis* Lipsky (35%) and *Quercus robur* L. (35%)) with 11% moisture content were used. Luffa was mixed with commercially manufactured fibers in the following fashion: a layer of luffa fiber (30 g) placed in the middle of the mat, two equidistantly placed layers (60 g) in the mat, three layers (90 g) instead of two in the mat, and homogenously (90 g) dispersed without a district pattern in the mat, respectively. In panel production the only variable tested was the addition of luffa fiber at various weights to the wood fibers. Commercial urea formaldehyde (UF) adhesive was used as a binder. Chemical properties, including holo-, α-cellulose, and contents, alcohol-benzene solubility in dilute alkali (1% NaOH), and hot and cold water solubility, were determined. In addition, some physical and mechanical properties, such as density, thickness swelling (TS), bending strength (BS), modulus of elasticity (MOE), and internal bond (IB) of the panel of MDF were also measured. The chemical composition and solubility of luffa were found to be similar to those of nonwoods in general. Thus, the results suggest that luffa (*Luffa cylindrica* Mill.) fiber can be used as an alternative raw material for MDF manufacturing.

Keywords: Luffa fiber; Luffa cylindrica; MDF; Physical properties; Mechanical properties

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INTRODUCTION

Huge quantities of natural fibers are produced yearly from biomass worldwide. Each source of natural fibers, *e.g.*, cotton, flax, or palm tree, displays its own morphological characteristics and chemical composition. These resources have already been used for several centuries, but their importance is growing in modern society because of the search for sustainable materials.

Luffa (*Luffa cylindrica* Mill.) is a tropical plant belonging to the family Cucurbitaceae. It is widely available in wet and warm climates of the world. *Luffa cylindrica* fibers are commonly found in China, Japan, and other countries in Asia and is quite common in the southern parts of the US. *Luffa cylindrica* fibers are obtained from a subtropical cucurbitaceous plant, which produces a fruit with a fibrous vascular system. Plant size varies in relation to location, ranging from 15 cm to 1 m, or even more than 1 m in certain areas. The chemical composition of luffa fibers depends on several factors, such as plant origin, weather conditions, soil, *etc*. For instance, the cellulose content varies from 55 to 90%, the lignin content is within the range of 10 to 23%, the

hemicelluloses content is around 8 to 22%, extractives amount to nearly 3.2%, and ash makes up 0.4%. The density of luffa is around 0.82 to 0.92 g/cm^3, which is lower than the density of some common natural fibers like sisal (1.26 to 1.45 g/cm^3), hemp (1.48 g/cm^3), coir (1.25 g/cm^3), ramie (1.50 g/cm^3), and cotton (1.51 to 1.60 g/cm^3) (Siqueira *et al.* 2010; Boynard and D'Almeida 2000). According to Boynard *et al.* (2003) the use of luffa fibers in composite material may be very advantageous.

Several researchers have also examined the practicality of using plants other than wood-based materials to produce composite panels, such as bamboo (Rowell and Norimoto 1988), wheat straw (Han *et al.* 1998; Halvarsson *et al.* 2010), kenaf (Grigoriou *et al.* 2000), kiwi prunings (Nemli *et al.* 2003), cotton carpel (Alma *et al.* 2005), sunflower stalks (Bektas *et al.* 2005), agro-based fiberboard (Lee *et al.* 2006), hazelnut husk (Copur *et al.* 2007), hazelnut shell (Copur *et al.* 2008), peanut husk (Akgül and Tozluoğlu 2008), canola straws (Yousefi 2009), sugarcane bagasse (Ashori *et al.* 2009), corn stalks (Akgül *et al.* 2010), corn and cotton stalks (Kargarfard and Jahan-Latibari 2011), and stinging nettle stalks (Akgül 2013).

In this manuscript, the physical properties, mechanical properties, and chemical composition of luffa (*Luffa cylindrica*) panels are investigated with the objective of evaluating the use of this natural material as a source of reinforcement phase in MDF.

EXPERIMENTAL

Materials

Native luffa fibers *(Luffa cylindrica* Mill.) from the Mediterranean region (Hatay) of Turkey were purchased from a local shop. Luffa fibers were separated by hand until fine particulate fibers were obtained. The obtained luffa fibers were cleaned from dirt and dust. Fibers were sheared through a clipper to break them into smaller pieces, and then the product was mixed with commercially manufactured fibers.

The stems and branches of pine (*Pinus sylvestris* L.), beech (*Fagus orientalis* Lipsky), and oak (*Quercus robur* L.), with a diameter of 25-35 cm and a length of 75-100 cm obtained from the Bolu Forest district were used. The commercial size MDF panels were manufactured at Divapan Integrated Wood Company located in Duzce, Turkey.

Methods

The stems and branches of pine (*Pinus sylvestris*), beech (*Fagus orientalis*), and oak (*Quercus robur*) were divided into pieces to make chips with dimensions of 20 × 25 × 5 mm in a chipper. In order to convert the materials into fiber, an Asplund defibrator with 7.8 bar steam pressure at 175 °C was used for 3.5 min. Next, 1% paraffin, 0.8% NH_4Cl (hardener), and 11% urea-formaldehyde (UF) resin were added into the fiber mixture. Materials were mixed for 3 min to achieve a homogenized resin distribution. All of the material was dried at 100 to 110 ^oC until the material reached 11% moisture content. The mats, with 11% average moisture content, were pressed with 38 kg cm^{-2} pressure at 150 °C for 6 min. After cooling, the panels were sanded using 50, 80, and 120 grit sandpapers. Then, the panels were conditioned at 20 ± 2 °C and 65 ± 5% relative humidity until 12% moisture content was reached. The MDF production parameters are presented in Table 1.

Table 1. Production Parameters of MDF Panels

Parameter	Value
Press temperature (°C)	150
Pressing time (min)	6
Press pressure (N/mm^2)	2.4-2.6
Thickness (mm)	18
Specific gravity (g/cm^3)	0.718
Replications for each panel type	2

Five different panel types were employed in the study. The first type was a traditional fiber mat. The second type had a layer of luffa fiber (30 g) placed in the middle of the mat. The third panel type had two equidistantly placed layers (60 g) in the mat (rough panel). The fourth type was similar to the third type, but had three layers (90 g) of luffa fiber instead of two. In the last type of panel, luffa fiber (90 g) was homogenously dispersed without a distinct pattern in the mat.

Twenty experimental panels with dimensions of 480 mm × 480 mm × 18 mm at a target density of 0.718 g/cm^3 for each type of raw material combination were manufactured at Divapan Integrated Wood products Inc. in Duzce, Turkey. Five types of experimental panels with different ratios of unmixed and mixed with commercially manufactured fibers were produced. The raw material formulation for the experimental MDF panels is presented in Table 2.

Table 2. Experimental Design

MDF type[a]	Raw Material	
	Luffa	Pine (30%) + beech and oak (70 wt%)[b]
LoR	-	Traditional fiber mat
LkR	Luffa fiber (90 g) was homogenously dispersed without a distinct pattern in the mat	
L1R	Layer of luffa fiber (30 g) placed in the middle of the mat	
L2R	Two equidistantly placed layers (60 g) in the mat	
L3R	Three layers (90 g) instead of two in the mat	

[a] The density of the boards made from L (Luffa) and I (pine, beech, oak wood) fibers was 0.72 g/cm^3.
[b] Pine 30%, beech (*Fagus orientalis*), and oak (*Quercus robur*) mixture at 70% ratio.

The properties of the urea–formaldehyde used in this study are given in Table 3.

Table 3. Properties of Urea-Formaldehyde Resin

Properties	**Unit**	**Value**
Solids content	%	55 ± 1
Density (20 °C)	g cm^{-3}	1.227
Viscosity (20 °C)	Cps	185
Flowing time (20 °C)	S	25-40
Free formaldehyde (max)	%	0.7
Gel time (100 °C) (10% NH_3SO_4)	s	40-60
Shelf time (20 °C)	day	45
pH	-	7.5-8.5

Specimens for the study were sampled and prepared according to TAPPI T257 cm-02 (2002) for chemical tests. Before the chemical analyses, wood samples were cut to a length of 1 to 2 cm and ground in a Wiley mill to a homogeneous meal. Holocellulose analysis was done according to the Wise sodium chlorite method (Wise and John 1952). Lignin content was determined as acid-insoluble Klason lignin using the TAPPI T222 om-02 (2002) standard method. The traditional method for the quantitative determination of lignin is based on Klason's technique, involving hydrolysis with 72% sulfuric acid. In this procedure, lignin was left as an insoluble residue and was recovered by filtration and gravimetrically determined.

Water-soluble materials in wood include inorganic salts, sugars, polysaccharides, cycloses, cyclitols, and some phenolic substances. Certain materials soluble in water are more or less soluble in many organic solvents. Consequently, the extracts soluble in organic solvents may contain a considerable fraction that is also soluble in water. If the extraction with water is not preceded by extraction with these solvents, a portion of the material removed by water is soluble in the organic solvents. The amount of material dissolved by hot water becomes greater as the time of extraction is increased, and prolonged extraction may dissolve a considerable portion of the wood substance. The water becomes acidic because of hydrolysis of acetyl groups in the wood. The action becomes one of hydrolysis by dilute acid (Browning 1967). The solubility properties were also determined based on the hot water (TAPPI T207 cm-99 1999) method. The ash content of *Luffa cylindrica* was determined according to ASTM E1755 -01 (2007).

TS EN 326-1 (1999) was followed for taking samples from the panels. Each panel was first divided into pieces bigger than 800 × 1600 mm. Then, the sub-samples were taken from them, following the standards mentioned above. Following TS EN 325 (1999), sample thickness and length were measured using a digital micrometer and compass, grading 0.01 mm. Standard testing procedures were also used to determine the density of panels (TS EN 323 1999), 2 and 24 h thickness swelling (TS) (ASTM D-1037-06 1994), and bending strength and modulus of elasticity (MOE) (TS EN-310 2008). ASTM D-1037-06 (1994) was used for internal bond (IB) of panel tests.

Statistical Analysis

The data regarding mechanical tests were expressed as mean ± standard deviation and were analyzed using an analysis of variance (ANOVA) procedure for a completely randomized design. Differences were considered statistically significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

The chemical properties of luffa fibers are given in Table 4. The main chemical components of *Luffa cylindrica* were: holocellulose (84.84%), α-cellulose (62.34%), lignin (14.04%), and ash (0.37%). In addition, solubility of the luffa in alcohol-benzene (0.25%), hot water (3.30%), cold water (4.50%), and 1% NaOH (16.38%) was found.

The chemical properties of luffa were compared with those of conventional raw materials that are utilized in MDF production. Luffa had higher polysaccharides (holocellulose) and α-cellulose contents than most annual plants (Table 5). The results of the study revealed that the solubility of luffa was similar to that of hardwoods in all solutions but alcohol-benzene. However, the lignin content was lower than that of corn

stalks, cotton carpel, cotton stalks, and hazelnut husk. The ash content of luffa, on the other hand, was lower than most annual plants (Table 5).

Table 4. Chemical Properties of Luffa Fibers

Luffa	%*
Cold water solubility	4.50 (0.09)
Hot water solubility	3.30 (0.11)
1% NaOH solubility	16.38 (0.19)
Alcohol-benzene solubility	0.25 (0.04)
Holocellulose	84.84 (0.41)
Lignin	14.04 (0.24)
α-cellulose	62.34 (0.37
Ash	0.37 (0.07)

*Values in parentheses are standard deviation

Table 5. Chemical Composition of Luffa Fibers, Corn Stalks,[a] Cotton Stalks,[b] Cotton Carpel,[c] Cereal Straw,[d] Hazelnut Husk,[e] and Soft/Hardwoods[f]

	Chemical Composition and Solubility %							
Raw Material	Holo-cellulose %	α-cellulose %	Lignin %	Ash %	Alcohol-benzene (2/1)	1% NaOH	Hot water	Cold water
Luffa fibers	84.84	62.34	14.04	0.37	0.25	16.38	3.30	4.50
Corn stalks	67.50	44.05	20.20	8.10	13.0	44.7	18.1	17.4
Cotton stalks	72.20	41.60	19.30	2.40	6.10	42.90	17.8	16.7
Cereal straw	64-71	36-46	12-17	3-12	2-4	38-40	12-17	4-7
Cotton carpel	71.6	31.2	20.5	5.54	6.63	48.6	12.2	8.39
Hazelnut husk	55.1	34.5	35.1	8.22	1.63	50.4	20.9	18.2
Hardwood	70-78	38-50	30-35	0.35	2-6	14-20	2-7	4-6
Softwood	63-70	29-47	25-35	0.35	2-8	9-16	3-6	2-3

[a] Akgul *et al.* 2010; [b] Akgul and Tozluoglu 2009; [c] Alma *et al.* 2005; [d] Eroglu 1988; [e] Copur *et al.* 2007; [f] Fengel and Wegener 1989

Table 6. Physical and Mechanical Properties of MDF Panels Containing Luffa Fiber

MDF type	Density kg/m^3	Thickness swelling (TS) (2 h)	Thickness swelling (TS) (24 h)	Bending strength N/mm²	Modulus of elasticity (MOE) N/mm²	Internal bond (IB) N/mm²
LoR	0.719[a] (0.05)	7.24[a] (0.66)	12.30[a] (2.92)	50.91[a] (1.48)	5495.84[a] (13.06)	0.69[b] (0.01)
LkR	0.717[a] (0.05)	7.62[a] (1.27)	14.55[a] (4.51)	44.05[a] (0.18)	4483.40[a] (6.16)	0.37[a] (0.01)
L1R	0.718[a] (0.05)	8.94[b] (0.48)	18.02[a] (4.08)	25.31[b] (0.61)	2925.38[b] (8.99)	0.41[a] (0.01)
L2R	0.717[a] (0.04)	8.74[b] (0.48)	17.96[a] (4.75)	41.78[a] (0.43)	4400.12[a] (9.05)	0.46[a] (0.01)
L3R	0.721[a] (0.05)	8.76[b] (0.71)	18.80[a] (9.83)	41.87[a] (1.04)	4548.84[a] (12.96)	0.41[a] (0.01)

Homogenous groups: Letters in each column indicate groups that are statistically different according to Duncan's multiple range test at $P < 0.05$
Values in parentheses are standard deviation
Comparisons were between each control and its test

Physical and mechanical properties of MDF panels containing luffa fiber are presented in Table 6. The general finding was that the addition of luffa fiber in panel production decreased the density, bending strength, modulus of elasticity, and internal bond strength and made panels less elastic compared to the panels produced with 100% wood fiber. It can be seen from Table 6 that the mean density of the fiberboards varied from 0.719 to 0.721 kg/m^3, the mean MOE varied from 5495.84 to 4548.84 N/mm^2, the mean IB strength varied from 0.69 to 0.41 N/mm^2, the mean bending strength varied from 50.91 to 41.87 N/mm^2, the mean thickness swelling (2 h) varied from 7.24 to 8.76%, and the mean thickness swelling (24 h) varied from 12.30 to 18.80% for panel type LoR and for panel type L3R, respectively. This finding could be due to insufficient mixing of luffa fibers and adhesives.

It can be seen in Table 6 that the mean thickness swelling percentage of all types of boards showed an increase from 2 to 24 h soaking time in higher values. An increase in the number of luffa layers in the mat caused panels to have a higher mean thickness swelling. The mean TS of panels increased considerably as the number of luffa layers in the mat increased from panel LkR to L3R. For all soaking times, the highest mean swelling percentage was observed from the mat with three layers (90 g), rather than two (panel L3R). All of the fiberboards produced in this study did not meet the minimum required TS value according to TS 64-5 EN 622 (1999) for the 2 and 24 h water immersion time. Utilizing resin-type adhesive and waxes, changing the production parameters, and modifying fiber would have improved the water repellency of the produced panels with luffa fiber.

Standard TS 64-5 EN 622 (1999) recommends a minimum BS value of 20 N/mm^2, a minimum MOE value of 2200 N/mm^2, and a minimum IB strength value of 0.55 N/mm^2 for fiberboards manufactured for general purpose use. The present findings showed that all produced fiberboards met the minimum requirement. However, only panel type LoR (100% wood fiber) met the minimum requirement for IB strength (0.55 N/mm) required by TS 64-5 EN 622 (1999). Decreases in strength and elasticity properties of the MDF were inversely related to the number of layers of luffa in the mat.
The strength properties of the MDF are mainly attributable to the physical and mechanical properties of individual wood fibers, fiber orientation, and the manner in which these components were combined in the structure. The weaker mechanical properties from luffa fiber addition in MDF panels could be explained by the small size of luffa fiber particles in the structure, resulting in a low fiber aspect ratio and ultimately leading to poor physical fiber-to-fiber contact. Groom *et al.* (1999) found similar results with mixtures comprised of various fines contents; there was a negative correlation between the amount of fines in the mixture and the mechanical properties of panels produced.

CONCLUSIONS

1. In order to determine the properties of luffa collected from the Mediterranean region of Turkey, chemical, physical, and mechanical analyses were performed. The results of these analyses showed that it was possible to produce fiberboards utilizing luffa fiber at various percentages as a mixture with the wood fiber.

2. The addition of luffa fiber significantly decreased the hygroscopic and mechanical properties. Although physical and mechanical properties were diminished with the addition of luffa fiber, board mechanical properties fulfilled the requirements of European standards.
3. The results of this study indicated that it was not possible to meet the minimum internal bond strength standard when luffa fiber was added to the mixture.

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