Oriented Strand Board Production from Water-Treated Date Palm Fronds

Said Hegazy,[a,b] Khaled Ahmed,[a,c] and Salim Hiziroglu [d]*

The objective of this work was to evaluate some of the important physical and mechanical properties of experimental oriented strandboard panels manufactured from four different cultivars of date palm (*Phoenix dactylifera*) fronds. Currently date fronds are considered as waste and under-utilized. Open burning and landfill are common practices for such resources. Therefore experimental panels were manufactured from strands washed with water to determine the effect of such treatment on panel properties. Bending characteristics, internal bond strength, thickness swelling, water absorption, and linear expansion along and across the grain orientations of the samples were tested. Based on the findings in this work, the internal bond strength values of the samples were found to be satisfactory. However, the samples manufactured from water-soaked strands had lower mechanical and physical properties as compared to those made from unwashed material. Water treatment also adversely influenced dimensional stability, namely thickness swelling, water absorption, and linear expansion of the samples. It appears that untreated date palm fronds as underutilized resource show promise sustainable raw material for the manufacture of oriented strandboard panels, but further research is required to maximize their potential.

Keywords: Date palm fronds; Oriented strandboard; Washed and unwashed materials

Contact information: a: Chair of Dates Industry and Technology, College of Food and Agricultural Sciences, King Saud University Riyadh, 11451 Saudi Arabia; b: Agricultural Research Center, Forestry Research Department, Horticulture Research Institute, Giza, Cairo, Egypt; c: Agricultural Engineering Institution, Giza, Egypt; d: Department of Natural Resource Ecology & Management, Oklahoma State University, Stillwater, Oklahoma 74078-USA;
** Corresponding author: salim.hiziroglu@okstate.edu*

INTRODUCTION

Oriented strandboard (OSB), a structural composite panel, is one of the world's most commonly used engineered wood-based panel products in residential construction. Oriented strandboard was first produced in Canada in 1964 but did not achieve solid market status until the mid-1980s (Hiziroglu 2006). More efficient technologies and environmentally friendly methods grew among forest product companies and engineered wood composite products such as OSB began to gain a more important role in the world market. Between 1990 and 1997, the total number of OSB mills increased by more than 50%. Today, the total annual OSB production in North America is approximately 20 million m^3, with 20 companies manufacturing OSB in the United States, Canada, and Europe (Hiziroglu 2006). Given the decline in plywood manufacturing in many countries due to limited large log supply and escalating environmental concerns, forecasters anticipate that OSB production will continue to increase, having achieved a main market share of structural wood composite panels in of the North America and Europe.

Oriented strand board is typically manufactured from fast-growing small tree species, including, *e.g.*, Southern pine and aspen in North America. It is composed of multi-layered panels made from strands of wood, with approximate dimensions of 15 to 25 mm width, 75 to 150 mm length, and 0.3 to 0.7 mm thickness, bonded together with an exterior adhesive under pressure and heat. In general, a simple design of spinning disks is used to form the mat having flakes. Strands of face and core layers of a typical mat are oriented opposite of each other, similar to grain orientation of veneer in plywood manufacture. They are then sequentially dropped on the conveyor belt so that the mechanical properties of the panels can be enhanced.

Wood has played an important role in this process of manufacturing constructional engineered panel-based products such as OSB, as well as laminated veneer lumber (LVL) and parallel strand lumber (PSL). However, due to depletions in natural and plantation forestland, the cost of wood has been increasing globally. Emerging, low cost, more sustainable alternative raw material supplies for structural panel production include low quality trees as well as waste from lumber manufacture and non-wood based agricultural products.

In countries that have very limited wood resources, such as Saudi Arabia and surrounding states, non-wood lignocellulosic fiber resources such as indigenous date palm provide potentially ideal alternative raw materials through which to manufacture structural value-added panel products. Date palm (*Phoenix dactylifera*) is the most important agricultural crop in Saudi Arabia. It grows 20 to 24 m in height, forming a clump with several stems from a single root system, with an average age of 150 years. Worldwide, there are approximately 105 million palm trees, covering an area of 800,000 ha (Al-Jurf *et al.* 1998; Al-Khalifah and Khan 2006; Agoudjila *et al.* 2011). On average, 13 leaves and 7 bunches *per* date palm can be cut annually. The annual amount of date palm recovered material is estimated to exceed 1,200,000 tons of fronds, 410,000 tons of leaves, and 300,000 tons of bunches. In Saudi Arabia alone, approximately 100,000 tons of date palm fronds and 15,000 tons of date palm leaves are produced per year (Al-Sulaiman 2002; Al-Sulaiman 2003).

It is estimated that there are 62 million date trees in the Middle East and North Africa (Al-Jurf *et al.* 1998). The arid climate of Middle Eastern countries is ideal for date plantations. As such, Saudi Arabia maintains seven million tons of date production in the region (Agoudjila *et al.* 2011). Four of the many date palm cultivars, most common in Saudi Arabia are barhi, saqie, khalas, and sukkary. To improve the quality of dates, palm trees are pruned annually to eliminate broken leaves. Unfortunately, however, this biomass of broken leaves is currently either landfilled or burned in the field rather than repurposed as a raw material to manufacture any value-added products. Not only does this biomass, when left in the field, lead to wildfire, but it also adversely influences the ecological balance in the region (Al-Sulaiman 2003).

Bagasse, sugarcane, bamboo, oil palm trunks, and kenaf have been successfully used as raw materials through which to produce different types of experimental composite panels in past investigations (Chow 1974; Smith 1976; Nemli *et al.* 2001; Kriker *et al.* 2008; Hashim *et al.* 2010). Anatomical structure of date palm is quite similar to oil palm (Loh *et al.* 2010). Oil palm (*Elaeis guineensis*) is produced for oil production from its fruit bunches. The trees become old and do not produce oil after 20 to 30 years. Consequently, significant amount of biomass from the trunks and fronds are created in harvesting sites in South East Asian countries, primarily Malaysia and Indonesia (Loh *et al.* 2008; Hashim *et al.* 2010, 2011). Since oil palm is a monocotyledonous species, it does not have cambium, secondary growth, ray cells, branches, and knots similar to date palm (Shaari et al 1991).

Oil palm fronds' average fiber length and diameter are 0.59 mm and 19.6 microns, respectively (Bakar *et al*. 2008). Overall, fronds have a substantial amount of parenchyma cells, with about 4.5% extractives and 20.5% lignin; these quantities are comparable values to those of date palm (Khalil *et al.* 2006; Bakar *et al.* 2008)

Research on bamboo-based OSB has been promising (Lee *et al.* 1996; Febrianto *et al.* 2012). A previous study determined physical and mechanical properties of OSB panels manufactured from three different lengths of bamboo strands treated with water and acetic anhydrides solutions which resulted in satisfactory values (Febrianto *et al.* 2012). Other investigations in this area also evaluated various characteristics of OSB manufactured from bamboo, concluding that bamboo can effectively be used as raw material to manufacture OSB panels with accepted properties (Van der Lugt *et al.* 2005; Sumardi *et al.* 2010).

Research to date on the use of date palm fronds with rich fiber content in the manufacture of particleboard panels has indicated that the material demonstrates satisfactory mechanical and physical characteristics (Iskanderani 2008, 2009; Hegazy and Aref 2010). However, there has been little research to date on the properties of structural panels, including OSB, produced from different cultivars of date fronds as a function of their treatment with water. Therefore, the objective of this work was to determine both the physical and mechanical properties of OSB samples made from frond strands of barhi, sukkari, khalas, and sukkary cultivars of date palms washed with water. Findings from this study may enable further exploration of this currently underutilized species as a sustainable, alternative raw material for structural value-added panel products such as OSB, with the added benefit of simultaneously addressing the major ecological problem of date palm waste biomass faced by Saudi Arabia.

EXPERIMENTAL

Materials and Methods

Fronds of four date palm cultivars barhi, saqui, khalas, and sukkari were collected from date palm farms in Al-Kharj, located 100 km east of Riyadh, Saudi Arabia. Leaflets were mechanically cut from the stalks of the fronds using a commercially manufactured stripper machine. Next, the frond stalks were reduced into sections of 10 to 15 cm length, before conversion into strands in a laboratory disk type strander with a thickness of 0.070 cm and a width ranging from 1.25 to 2.0 cm. Strands were washed by soaking in water at a temperature of 80 °C for 20 h. Higher temperature and longer time span of treatment were avoided for possible over modification of chemical structure of the strands.

They were rinsed and dried with unwashed control material in an oven at a temperature of 90 ºC for several days to a moisture content of 3%. Both the washed and unwashed control strands were sprayed with phenol formaldehyde adhesive at a rate of 10%, based on the dry weight of the raw material, for 15 to 20 min in a rotary drum type blender equipped with a pneumatic spray gun. One percent wax and hardener were also added in the panels. Mixed strands were oriented through a forming box with dimensions of 50 cm by 50 cm, having spacers with uniform distance, so that strands were oriented and laid parallel in one direction on the press caul. Figure 1 illustrates unpressed mats made from unwashed and washed strands.

In the following step, the mats were prepressed for 2 min before they were compressed in a computer controlled Carver press with a temperature of 170 °C and a pressure of 4 MPa for 6 min. The mats were compressed to a nominal thickness of 13 mm at two density levels, 0.65 and 0.75 g/cm^3. A total of 64 panels, namely 2-treatment x 4-cultivar x 2-density x 4-replicitaion were manufactured for the experiments. All panels were conditioned for two weeks in a climate cabinet with a relative humidity of 65% and temperature of 20 °C prior to being cut into samples for the physical and mechanical tests.

The mechanical and physical test specimens for modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), linear expansion (LE), thickness swelling (TS), and water absorption (WA) were prepared based on ASTM standards (ASTM D1037-99 1999). An Instron testing system equipped with a 5,000-kg capacity load cell was used for the mechanical tests. Bending tests were carried out along and across strand direction of the samples.

Linear expansion samples with dimensions of 15 cm by 5.1 cm were cut from each panel and exposed to a relative humidity of 90% and a temperature of 20 °C until they reached equilibrium moisture content. The length of each sample across and along the machine direction was measured at an accuracy of 0.02 mm at the initial and final conditions to determine the linear expansion of the samples. Fifteen cm by fifteen cm samples were also used to obtain 2 h and 24 h thickness swelling and water absorption values for the specimens after soaking them in distilled water. The thickness and weight of the samples were measured at accuracy levels of 0.02 mm and 0.1 g, respectively. Test results were evaluated by analysis of variance (ANOVA) and least significant difference (LSD), employing SAS computer software (SAS Institute, Cary, NC, 2000).

Unwashed strands Washed strands

Fig. 1. Unpressed mats from two types of materials

RESULTS AND DISCUSSION

Table 1 displays the average results of mechanical and physical properties of the samples manufactured from the raw material of four date palm cultivars.

The highest MOE and MOR values, 3,486 and 27,426 MPa, respectively, were found for the panels along-the-strand direction that were manufactured from unwashed material of the bahri cultivar at 0.75 g/cm^3. On the other hand, the lowest corresponding values were 1,769 and 8,986 MPa, respectively, for panels made from the sukkari cultivar at 0.65 g/cm^3.

For all material types, bending properties of the species were significantly lower across-the-strand direction than the along-the-strand direction, as expected at 95% confidence level. For example, the panels had a MOE value of 2,412.2 MPa in the along-the-strand direction, which is 5.05 times higher than the across-the-strand test value. Overall bending characteristics of the specimens followed the similar trend.

It also appears that washing the strands adversely influenced both MOE and MOR values of the samples made from all four types of cultivars. Prior research has demonstrated that some of the extractives and starch content of the raw material are eliminated due to the washing process, which reduces the bending strength of the panels. In a past study, particleboard panels manufactured from washed date particles also showed similar findings (Hegazy and Aref 2010). Overall panels manufactured from the bahri cultivar had the highest bending properties among the others cultivars. Four different cultivars used to make the samples did not show any significant difference from each other in term of their bending properties. Typical commercially manufactured OSB panels have MOE and MOR values within the range of 4,827 to 8,275 MPa and 20.7 to 27.6 MPa, respectively (ANSI 1999).

In this study, panels made from unwashed strands of the bahri and sukkari cultivars resulted in comparable MOR values to the above requirements. However, most of the samples had relatively lower bending properties and the panels had further reduced values after the washing process of the raw material. Lower bending properties of the samples made in this work could be related to significant amount of parenchyma cells and non-fibrous structure of the raw material. Having more parenchyma cells and non-fibrous anatomy of fronds results in a non-homogeneous glue line between strands. It appears that properties of the samples were adversely influenced by this fact. Hashim *et al.* (2010) and Wazzan (2005) also revealed such findings in a past investigation related to composite panels manufactured from oil palm fronds.

Internal bond strength values of the samples ranged from 0.67 MPa to 3.62 MPa. In contrast to MOE and MOR properties, all of the samples satisfied IB values listed in ANSI standards (ANSI 1999). Higher IB values of the panels could possibly be related to the homogeneous mixture of vascular bundles with other anatomical structures of the date palm fronds. As with the bending properties, all of the samples made from water-treated particles resulted in lower IB values, given that water reduced the extractive content in the raw material.

It is clear that the dimensional stability values of the panels were not satisfactory. Thickness swelling as a result of 24 h water soaking ranged from 30% to 100%. Water absorption, along with linear expansion of the samples manufactured from all four cultivars, did not show any significant difference from each other, having substantially higher values than those of typical commercially manufactured particleboard. It seems that the starch content of the raw material is the main source of low dimensional stability of the panels, which is in agreement with a previous investigation (Hegazy and Aref 2010).

Table 1. Physical and Mechanical Properties of the Samples

Cultivar	Water Treatment	Density (g/cm^3)	MOR (MPa)	MOR⊥ (MPa)	MOE (MPa)	MOE⊥ (MPa)	IB (MPa)	Dimensional Stability					
								2-h TS (%)	2-h WA (%)	24-h TS (%)	24-h WA (%)	LE (%)	LE ⊥ (%)
Barhi	Washed	0.65	17.307 (1.681)	2.687 (0.430)	2590.9 (100.92)	373.5 (52.85)	1.24 (0.1)	40.02 (1.7)	64.16 (2.10)	48.27 (4.7)	90.3 (1.0)	0.03 (0.02)	0.64 (0.07)
		0.75	20.669 (2.545)	3,363 (1.319)	2493.1 (201.2)	508.2 (57.9)	1.9 (0.3)	25.38 (0.5)	35.98 (3.0)	41.51 (0.8)	73.3 (3.9)	0.04 (0.01)	0.52 (0.04)
	Unwashed	0.65	19.809 (2.65)	7.22 (0.213)	2825.3 (102.1)	722.9 (113.3)	1.93 (0.18)	15.5 (1.2)	32.04 (2.9)	23.84 (1.1)	64.6 (1.2)	0.02 (0.00)	0.33 (0.01)
		0.75	27.426 (1.49)	4.319 (0.246)	3486.0 (186.2)	536.4 (31.5)	2.1 (0.28)	18.7 (0.7)	27.89 (0.5)	31.63 (0.9)	61.4 (0.9)	0.02 (0.00)	0.24 (0.04)
Khalas	Washed	0.65	11.672 (0.587)	3.591 (0.642)	2063.9 (185.13)	409.4 (57.7)	1.96 (0.31)	29.9 (1.2)	60.79 (0.9)	33.50 (2.0)	80.3 (0.4)	0.05 (0.01)	0.20 (0.02)
		0.75	14.650 (1.44)	3.525 (0.310)	2293.3 (109.7)	481.5 (50.4)	1.11 (0.23)	37.54 (4.6)	57.88 (8.2)	47.60 (5.7)	81.5 (3.7)	0.05 (0.01)	0.31 (0.02)
	Unwashed	0.65	11.765 (1.048)	3.598 (0.535)	2029.9 (28.8)	449.5 (46.6)	1.41 (0.32)	20.8 (0.8)	40.73 (2.9)	31.22 (3.1)	68.4 (2.7)	0.03 (0.02)	0.40 (0.01)
		0.75	14.512 (0.635)	4.789 (0.152)	2597.6 (136.9)	676.3 (73.9)	1.86 (0.16)	24.9 (3.9)	41.90 (7.7)	36.20 (0.9)	71.4 (3.3)	0.01 (0.00)	0.33 (0.07)
Saqie	Washed	0.65	8.986 (1.728)	4.247 (0.136)	1769.48 (183.7)	477.3 (30.5)	1.94 (0.09)	33.0 (2.6)	52.94 (0.8)	41.57 (0.8)	84.09 (1.1)	0.05 (0.01)	0.42 (0.04)
		0.75	17.017 (1.904)	3.956 (0.509)	2851.8 (192.4)	498.3 (75.4)	1.3 (0.21)	39.11 (2.5)	66.53 (1.2)	47.53 (3.5)	90.08 (0.6)	0.02 (0.02)	0.49 (0.06)
	Unwashed	0.65	15.372 (1.495)	5.466 (0.629)	2414.2 (163.7)	519.8 (43.6)	1.97 (0.24)	10.90 (3.1)	19.45 (5.7)	20.22 (2.2)	51.41 (11.4)	0.03 (0.01)	0.39 (0.05)
		0.75	17.561 (1.516)	5.731 (0.507)	2928.7 (137.6)	699.5 (48.4)	2.1 (0.26)	13.40 (1.2)	21.84 (3.1)	24.06 (1.1)	53..06 (3.7)	0.02 (0.01)	0.44 (0.03)
Sukkari	Washed	0.65	12,361 (1.092)	4.460 (0.736)	1989.48 (84.3)	532.8 (34.9)	1.65 (0.31)	27.41 (2.5)	39.01 (4.6)	39.67 (1.1)	78.10 (2.6)	0.06 (0.01)	0.42 (0.02)
		0.75	14.856 (1.277)	5.349 (0.736)	2837.6 (176.9)	559.2 (34.9)	1.97 (0.26)	24.7 (2.7)	30.72 (2.29)	42.36 (0.7)	74.12 (3.9)	0.04 (0.02)	0.48 (0.03)
	Unwashed	0.65	14.141 (2.024)	5.345 (0.646)	2611.1 (106.6)	559.2 (85.1)	1.89 (0.28)	21.99 (1.4)	39.65 (1.3)	33.75 (1.3)	74.58 (1.4)	0.03 (0.01)	0.42 (0.07)
		0.75	21.492 (1.84)	5.735 (0.409)	3324.7 (181.1)	613.95 (40.9)	1.95 (0.16)	26.11 (0.9)	51.10 (1.1)	35.62 (0.4)	79.59 (0.4)	0.02 (0.01)	0.35 (0.02)
L.S.D			1.903	0.670	172.5	70.9	0.25	4.77	7.61	4.26	6.89	0.015	0.049

** Numbers in parentheses are standard deviation values*

CONCLUSIONS

1. This study demonstrated that raw material from date palm fronds, which is a significant source of biomass in the Saudi Arabian region that is currently posing environmental problems due to disposal practices, has potential as a sustainable resource in the manufacture of experimental OSB panels.
2. Although the internal bond strength values of the samples were found to be satisfactory, the bending properties of this material need to be improved by using different approaches, including better resin distribution or modification of strand size.
3. No significant differences were found between the mechanical properties of the panels manufactured from the three date palm cultivars (barhi, sagai, and sukkary).
4. Water treatment of the raw material adversely influenced all properties of the samples.

ACKNOWLEDGMENTS

This study was supported by NSTIP strategic technologies program number (11-AGR 1745-02) in the Kingdom of Saudi Arabia.

REFERENCES CITED

Agoudjila, B., Benchabane, A., Boudenne, A., Ibos, L., and Fois, M. (2011). "Renewable materials to reduce building heat loss: Characterization of date palm wood," *Energy and Buildings* 43, 491-497. DOI:10.1016/j.enbuid.2010.10.014.

Al-Khalifah, N. S., and Khan, P. R. (2006). "Plant water relations and productivity of date palm (*Phoenix dactylifera* L.) cultivars," *Arab Gulf Journal of Scientific Research* 24(I), 30-34.

Al-Jurf, R. S., Ahmed, F. A., Allam, I. A., and Abdel-Rehman, H. H. (1998). "Development of new building material using date palm fronds: Final report," KACST ARP-6-141.

Al-Sulaiman, F. A. (2002). "Mechanical properties of date palm fiber reinforced composites," *Applied Composite Materials* 9(6), 369-377. DOI:

Al-Sulaiman, F. A. (2003). "Date palm fiber reinforced composite as a new insulating material," *International Journal of Energy Research* 27(14), 1293-1297.

ANSI A208.1 (1999). "Particleboard," American National Standards Institute, Washington, DC.

ASTM D 1037-06a (2006). "Standard test methods for evaluating properties of wood-base fiber and particle panel materials," ASTM International, West Conshohocken, PA.

Bakar, E.S.., Sahri,M.H., and H'ng,P.S. (2008). "Anatomical characteristics and utilization of oil palm wood. The formation of wood in Tropical Forest Trees: A Challenge from the Perspective of Functional Wood Anatomy," T. Nobuchi and M. H. Sahri (eds.), University Putra Malaysia Press, Selangor Malaysia, pp: 161-180. ISBN 978-967-5026-12-6.

Chow, P. (1974). "Dry form composite board from selected agricultural residues," World Consultation on Wood Based Panels, Food and Agriculture Organization of the United Nations, New Delhi, India presented at the 4th Int. Conf. on production engineering and design for development, PEDD '74.

Febrianto, F., Hidayet, W., Bakar, E. S., Kwon, G. J., Kwon, J. H., Hong, S. I., and Kim N. H. (2012). "Properties of oriented standboard made from Betung bamboo (*Dendrocalamus asper* Becker ex Hyne)," *Wood Science and Technology* 46, 53-62. DOI:10.1007/s 00226-010-0385-8

Hashim, R., Saari, N., Sulaiman, O., Sugimoto, T., Hiziroglu, S., Sato, M., and Tanaka, R. (2010). "Effect of particle geometry on the properties of binderless particleboard manufactured from oil palm trunk," *Materials and Design* 31(9), 4251-4257.

Hashim, R., Aidawati, W. N., Sulaiman, O., Kawamura, F., Hiziroglu, S., Sato, M., Sugimoto, T., Seng, T. G., and Tanaka, R. (2011). "Characterization of raw materials and manufactured binderless particleboard from oil palm biomass," *Materials and Design* 32 (1), 246-254. DOI:10.1016/j.matdes.2010.05.059.

Hegazy, S., and Aref, I. (2010). "Suitability of some fast growing trees and date palm fronds for particleboard production," *Forest Products Journal* 60(7/8), 599-604. DOI:

Hiziroglu, S. (2006). "Oriented strandboard as a building material," Oklahoma State University Extension Fact Sheet, FAPC -146, Food and Agricultural Products Research Center.

Iskanderani, F. I. (2008). "Physical properties of particleboard panels manufactured from *Phoenix dactylifera*- L (date palm) mid rib chips using urea-formaldehyde binder," *International Journal of Polymeric Materials* 57(10), 979-995. DOI:10.1080/00914030080217 74074.

Iskanderani, F. I. (2009). "Influence of process variables on the bending strength of particleboard produced from Arabian date palm mid-rib chips," *International Journal of Polymeric Materials* 58(1-3), 49-60. DOI:10.1080/0091.4030490277752.

Khalil, H. P. S., Alwani, M. S., and Omar, A. K. M. (2006). "Chemical composition, anatomy, lignin distribution, and cell wall structure of Malaysian plant waste fibers" *Bioresources* 1(2), 220-232.

Kriker, A., Bali, B., Debicki, G., Bouziane, M., and Chabannet, M. (2008). "Durability of date palm fibers and their use as reinforcement in hot dry climates," *Cement & Concrete Composites* 30(7), 639-648. DOI:10.1016j.cemconcomp.2007.11.006.

Lee, A. N., Bai, X., and Peralta, P. N. (1996). "Physical and mechanical properties of strandboard made from moso bamboo," *Forest Products Journal* 47(2), 111-119.

Loh, Y. F., Paridah, M. T., Hoong,T. B., Bakar, E. S., Hamdan, H., and Anis, M. (2010). "Properties enhancement of oil palm plywood through veneer pretreatment with low molecular weight phenol-formaldehyde resin," *Journal of Adhesion Sci.and Tech*. 24, 1729-1738.

Nemli, G., Kalaycıoğlu, H., and Alp, T. (2001). "Suitability of date (*Phoenix dactyliferia*) branches for particleboard production," *Holz als Roh- und Werkstoff* 59(6), 411-412.

Shari, K., Khoo, K. C., and Ali Mohd, A. R. M. (1991). "Oil palm stem utilization: Review of research," ISSN:0126-8198 Research Pamphlet No: 107, 120 pp.

SAS Institute (2000). *SAS User's Guide: Statistics*, SAS Institute Inc., Cary, NC.

Smith Jr., W. W. (1976). "History and description of current (Bagasse Fiberboard) operations of tablopan (de Venezuela, S.A.)," *TAPPI C.A.* Rept. 67, 87.

Van der Lugt, P., van den Dobbelsteen, A. A. J. F., and Janssen, J. J. A. (2005). "An Environmentally economic and practical assessment of bamboo as a building material for supporting structures," *Construction and Building Materials* 20(9), 648-65. DOI:10.1016/j.conbuildmat.2005.02.023

Sumardi, I., Suzuki, S., and Onn, K. (2010). "Some important properties of strand board manufactured from bamboo," *Forest Products Journal* 56(6), 59-63.

Wazzan, A. A. (2005). "Effect of fiber orientation on the mechanical properties and fracture characteristics of date palm fiber reinforced composites," *International Journal of Polymeric Materials* 54(3), 213-225. DOI: 10-1080/0091 4030390246379.

Article submitted: September 5, 2014; Peer review completed: November 9, 2014; Revised version received and accepted: November 13, 2014; Published: November 21, 2014.