ISSN 1819-1894

Asian Journal of Agricultural Research

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

Asian Journal of Agricultural Research 9 (4): 180-188, 2015
ISSN 1819-1894 / DOI: 10.3923/ajar.2015.180.188

Binderless Particleboard from Castor Seed Cake: Effect of Pressing Temperature on Physical and Mechanical Properties

[1,2]Mersi Kurniati, [3]Farah Fahma, [3]I. Amalia Kartika, [3]Titi Candra Sunarti, [3]Khaswar Syamsu, [4]Dede Hermawan, [5]Yukie Saito and [5]Masatoshi Sato

[1]Study Program of Agroindustrial Technology, School of the Graduate Studies,
[2]Department of Physics, FMIPA, Bogor Agricultural University, Darmaga Campus, Bogor, 16680, Indonesia
[3]Department of Agroindustrial Technology, FATETA, Bogor Agricultural University, Darmaga Campus, P.O. Box 220, Bogor, 16002, Indonesia
[4]Department of Forestry Products, FAHUTAN, Bogor Agricultural University, Darmaga Campus, Bogor, 16680, Indonesia
[5]Department of Global Agricultural Sciences, Graduate School of Agricultural and Life Sciences, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan

Corresponding Author: Farah Fahma, Department of Agroindustrial Technology, FATETA, Bogor Agricultural University, Darmaga Campus, P.O. Box 220, Bogor, 16002, Indonesia Tel: +62 251 862 19 74 Fax: +62 251 862 19 74

ABSTRACT

Castor seed cake was used to produce particleboard without synthetic binders. The effect of pressing temperature on the physical and mechanical properties of binderless particleboards was evaluated in this study. Particleboards were manufactured with a target density of 900 kg m^{-3} using pressing temperatures of 150, 160, 170, 180 and 190°C. All particleboards obtained were cohesive, with proteins and fibers acting as binder and reinforcing filler, respectively. With increasing pressing temperature, the modulus of rupture, modulus of elasticity and internal bonding of the particleboards tend to increase while their water absorption and thickness swelling decreased. The best physical and mechanical properties of binderless particleboard from castor seed cake were obtained under pressing temperature of 170°C with modulus of rupture of 3.17 MPa, modulus of elasticity of 244.45 MPa, internal bonding 0.23 MPa, water absorption of 76.54% and thickness swelling of 29.51%.

Key words: Castor seed cake, binderless particleboard, protein, lignocellulosic fibers

INTRODUCTION

Particleboard is a wood-based composite consisting of wood particles or particles of lignocellulosic material bonded together at high temperature and high pressure. The consumption of particleboard was increasing due to the reduction of solid wood supply. It is used widely ranging from building constructions to furniture manufacturing (Nemli and Ozturk, 2006).

The global trend indicates that the marketplace is moving towards using environmental friendly particleboards with reduced or no synthetic resins because of the environmental issues (Baskaran *et al.*, 2012). Manufacturing wood-based materials without using any resins are known as binderless panels, wherein the adhesion is derived from activating chemical components of the board constituents during steam or heat treatment (Okuda and Sato, 2004). Many researchers around the world have studied binderless particleboard form various lignocellulosic materials, such as bagasse pith (Widyorini *et al.*, 2005), bagasse (Mobarak *et al.*, 1982), oil palm fronds (Laemsak and Okuma, 2000), banana bunch (Quintana *et al.*, 2009), oil palm trunk (Hashim *et al.*, 2011), wheat (Khosravi *et al.*, 2011), sun flower whole plant (Evon *et al.*, 2012) and jatropha (Evon *et al.*, 2014).

A previous study carried out by Okuda *et al.* (2006) showed that hemicelluloses and lignin were decomposed during the pressing process. The condensation reactions of lignin contributed to a self-bonding mechanism and the sugar content of the boards decreased with increasing pressing temperature. Another study showed that binderless boards developed from sugar-containing lignocellulosic materials such as sorghum need to be pressed at a temperature of 180°C or higher to achieve satisfactory bonding (Shen, 1986). Salvado *et al.* (2003) tried to maximize the properties of binderless boards using steam-exploded *Miscanthus sinensis* by pressing them at temperatures ranging from 195-245°C and obtained satisfactory results. Furthermore, Hidayat *et al.* (2014) showed that lignin, carbohydrate (cellulose and hemicellulose) and proteins are believed to be natural binders which can be activated under high pressure at elevated temperature for the production of binderless particleboard from jatropha seed cake. Proteins can act as an internal binder inside fiberboards by forming a complex that can improve the cohesion among the fiber surfaces. At the same time, lignocellulosic fibers entanglement also can act like reinforcement (Evon *et al.*, 2012).

Castor (*Ricinus communis* L.) is an oilseed shrub classified into the family Euphorbiaceae and genus Ricinus (Odunsi *et al.*, 2012). It is widely cultivated in most tropical and sub-tropical countries, such as India, China and Brazil, as essential industrial oilseed crop (Barnes *et al.*, 2009). The castor oil can be used for the production of lubricants, paints, soaps and the pharmaceutical industry (Heywood *et al.*, 2007). Since 1942 castor plant was exist in Indonesia and 9000 acres of castor were actually grown in Indonesia producing 3000 t of castor seeds.

Castor seed oil content is high enough (46-55%), consisting of ricinoleic acid (esters of 12-hydroxy-9-octadecenoic acid) (Ogunniyi, 2006). While the castor oil has the potential to be an excellent oil feedstock, large-scale castor utilization will result in huge amounts of husks and seed cakes as by-products. It has been estimated that for every ton of castor oil produces 1.31 t of husks and 1.13 t of castor seed cakes (Lima *et al.*, 2011). With a protein content of 32-48% and high fiber (28-33%), the utilization of castor seed cake has attracted a great deal of interest to develop value-added application such as raw materials in production of binderless particleboard. In addition, a large amount of cake is exhausted as waste, so, it is necessary to find out new utilization. This is an interesting aspect which could be exploited for material applications.

In this study, the effects of pressing temperature on physical and mechanical properties of binderless particleboard produced from castor seed cake were investigated. The morphology of the binderless particleboards obtained was performed by Scanning Electron Microscopy (SEM) to evaluate the change of the protein corpuscles and fibers textures due to degradation process.

MATERIALS AND METHODS

Castor seed cake used in this study was supplied by PT., Bio Greenland Indonesia (biofuel industry). All chemicals and solvent were supplied by Sigma-Aldrich, AppliChem and J.T. Baker, Indonesia.

The small particles of castor seed cake (0.25 μm) were dried at 40-50°C for 24 h to obtain the cake moisture content of 7-8%. The ash, lipid, protein, fiber and carbohydrate contents of castor seed cake were then analyzed using the method based on SNI 01-2891 (1992). Meanwhile the content of cellulose, lignin and hemicelluloses was analyzed based on the method of Van Soest *et al.* (1991).

The castor seed cakes (45 g) were manually loaded into the mats that were formed using a frame of 10×10×0.5 cm. The mats were then pressed in controlled hot press using a pressure of 20 MPa and temperature of 150, 160, 170, 180 and 190°C for 12 min. Target density was 900 kg m^{-3}. Five specimens were coded as CBP-T where T stands for the pressing temperature. Thus CBP-150, for example, signifies castor-binderless-particleboard that was pressed at 150°C. All specimens (CBP-150, CBP-160, CBP-170, CBP-180 and CBP-190) of the binderless particleboards were cut into various test specimens following JIS standard method (JIS-A 5908, 2003) and then conditioned at 30°C for two weeks before analysis.

The physical and mechanical properties of binderless particleboards were characterized by several analyses such as Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bonding (IB), Thickness Swelling (TS) and Water Absorption (WA) based on JIS-A 5908 (2003). The MOR, MOE and IB were conducted using a universal testing machine (Instron 3369). The TS and WA of each sample were measured after soaking in distilled water for 24 h. All determinations were carried out in three repetitions.

The Scanning Electron Microscopy (SEM) (JEOL JSM-6510LA) was used to evaluate the morphology of particleboard obtained. The samples were coated with gold by ion sputter coater and observed with an accelerating voltage 10 kV.

RESULTS AND DISCUSSION

The chemical components of castor seed cake used in this study are presented in Table 1. The big portion of components is protein (32.04%), fibers (33.22%) and lignin (30.84%). It is supposed that those components would strongly contribute for self-bonding of fibers and provide adhesion in binderless particleboards. The binding capacity can be activated by the hydrogen bonding between polar components such as cellulose, starch, lignin and protein, the auto-cross linking reaction between lignin and fat, the protein denaturization, the starch gelatinization and the crystallization of water soluble carbohydrates (Kaliyan and Morey, 2010).

The low fat content (7.72%) of this cake may present the good effect on the particleboard quality, mainly the absence of unpleasant odor. In the case of binderless particleboard production from jatropha seed cake, the cake with high fat content (12%) produced black colored boards and unpleasant odor (Hidayat *et al*., 2014). On the other hand, the presence of moisture in this cake may facilitate the movement of polypeptide chain (protein) and enables to interact with other polymers more easily, as reported by Li *et al.* (2009). In addition, water can act as a binder by increasing the contact area of the particles wherein it may have positive effects on the mechanical and physical properties of the binderless particleboards.

Table 1: Characteristics of castor seed cake

Parameters	Percentage weight on dry basis
Moisture	7.45
Ash	7.52
Protein	32.04
Fat	7.72
Fibers	33.22
Cellulose	18.33
Lignin	30.84
Hemicelluloses	3.85
Carbohydrate (by different)	12.05

Mechanical properties: The effects of pressing temperature on the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE) of binderless particleboard from castor seed cake are shown in Fig. 1a, b, respectively. The MOR and MOE of the binderless particleboards tend to increase with increasing temperature. The binderless particleboard pressed at 170°C had the highest MOR of 3.17 MPa and highest MOE of 244.45 MPa while at higher temperature (>170°C) MOR and MOE decreased. The best MOR of particleboard produced under pressing temperature of 170°C may relate to protein denaturization of cake at around 170-175°C, similar with jatropha seed cake (around 172°C) as reported by Diebel *et al.* (2012). At temperature above 180°C, protein may become partially degraded to be small fragments that no enhanced adhesion ability of fibers in particleboard contribute to decreased MOR.

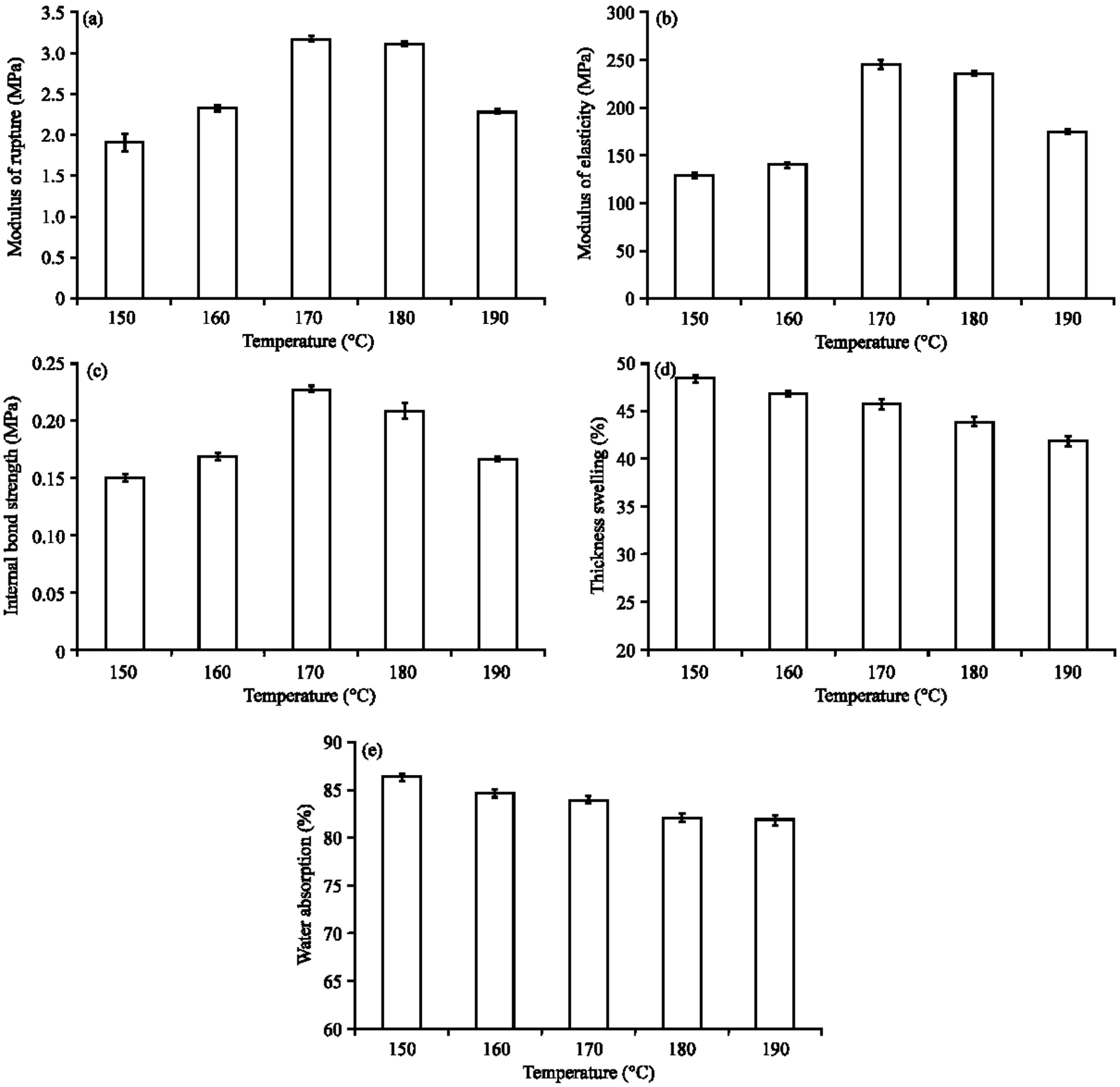

Fig. 1(a-e): (a) Modulus of Rupture (MOR), (b) Modulus of Elasticity (MOE), (c) Internal Bond strength (IB), (d) Thickness Swelling (TS) and (e) Water Absorption (WA) of binderless particleboards made from castor seed cake

The overall average MOR and MOE of the binderless particleboards obtained was found to be lower than the minimum required MOR and MOE as stated by JIS-A 5908 (2003) (8.0 and 2000 MPa, respectively). The low MOR of the binderless panels can be explained by the fact that high pressing temperature is not enough to achieve the strength of the self-bonding through the activation of natural binder (such as protein and fiber) in the particleboard. The bonding mechanism in binderless particleboard without synthetic resin could be due to the presence of natural binder such as protein, hemicelluloses, lignin and cellulose wherein they could be activated at elevated temperature (Evon *et al*., 2014). At pressing temperature applied in this study (150-190°C), protein has been denaturized and hemicelluloses have been degraded. However, it did not allow the activation of lignin (200°C) and cellulose (220°C). It was then not sufficient to create strong bonding between the fibers. On the contrary, at pressing temperature above 200°C lignin and cellulose may be activated but more protein will be degraded. In this study, higher pressing press might be needed to activate the natural binder to reach the high strength of binderless particleboards. At higher pressing press, the activation of natural binder could be allowed by the mechanical adhesion (interlocking by protein penetration through porous fibers surface) and molecular attractive force (Van der Waals forces, hydrogen bonds), as reported by Kumar *et al*. (2002).

The MOE follows the same trend as the MOR. The MOE increased with increasing pressing temperature. The same reason for MOE trend is pressing temperature promoted protein entanglements that enhanced strength. At above 170°C MOE decreased with increasing pressing temperature. Similar tendencies were also reported for binderless particleboard based sunflower whole plant (Evon *et al*., 2010) and sugar cane bagasse (Talavera *et al*., 2007). The partial degradation of protein and hemicelluloses may lead to increase brittleness, associated to the increased rigidity of the fibers.

The inferior strength of the binderless particleboards from castor seed cake may be due to the chemical and physical properties of the castor fibers. The MOR, IB and MOE does not only depend on the bonding strength among fibers but also the individual fibers strength, fibers-protein and fibers geometry (Panyakaew and Fotios, 2011).

Figure 1c exhibits the effects of pressing temperature on the Internal Bonding (IB) of binderless particleboard obtained. Internal bonding test was conducted to determine the interfacial bonding strength between fibers in the boards. The IB is related to the adhesion between fibers (Quintana *et al*., 2009). In general, the IB of binderless particleboards tends to increase with increasing pressing temperature and also follows the same trend as the MOR. At temperature 150 and 160°C, IB of binderless particleboards was lower than that of particleboard pressed at 170°C. This might be due to the optimum of protein activation as natural binder promoted by elevated pressing temperature until 170°C, wherein at this temperature the adhesion between fibers in particleboard achieved the highest value. This adhesion ability decreased while the particleboards were pressed at higher temperature due to degradation of proteins gradually. This phenomenon would be also confirmed by SEM analysis.

Physical properties: The Thickness Swelling (TS) and Water Absorption (WA) of the binderless particleboards produced after 24 h water soaking varies from 41-48% and 80-86%, respectively, are shown in Fig. 1d and e. The TS and WA of the particleboard decreased with increasing pressing temperature. The binderless particleboard pressed at highest temperature has the lowest TS (41.83%) and WA (80.27%). The reduction of WA and TS with increased pressing temperature (150-170°C) can be attributed to a better adhesivity, compatibility and distribution of the protein among the fibers surface.

Based on JIS-A 5908 (2003), none of binderless particleboards obtained satisfies the standard TS requirement, where the particleboards should not have TS more than 12%. The same behavior, higher TS, was also showed by binderless particleboard panels made from oil palm trunk (Hashim *et al.*, 2011).

Morphology of binderless particleboards: The morphology of the binderless particleboards was investigated as a function of pressing temperature. Scanning Electron Micrographs (SEM) of the particleboards manufactured at 150, 160, 170, 180 and 190°C are shown in Fig. 2. The variation

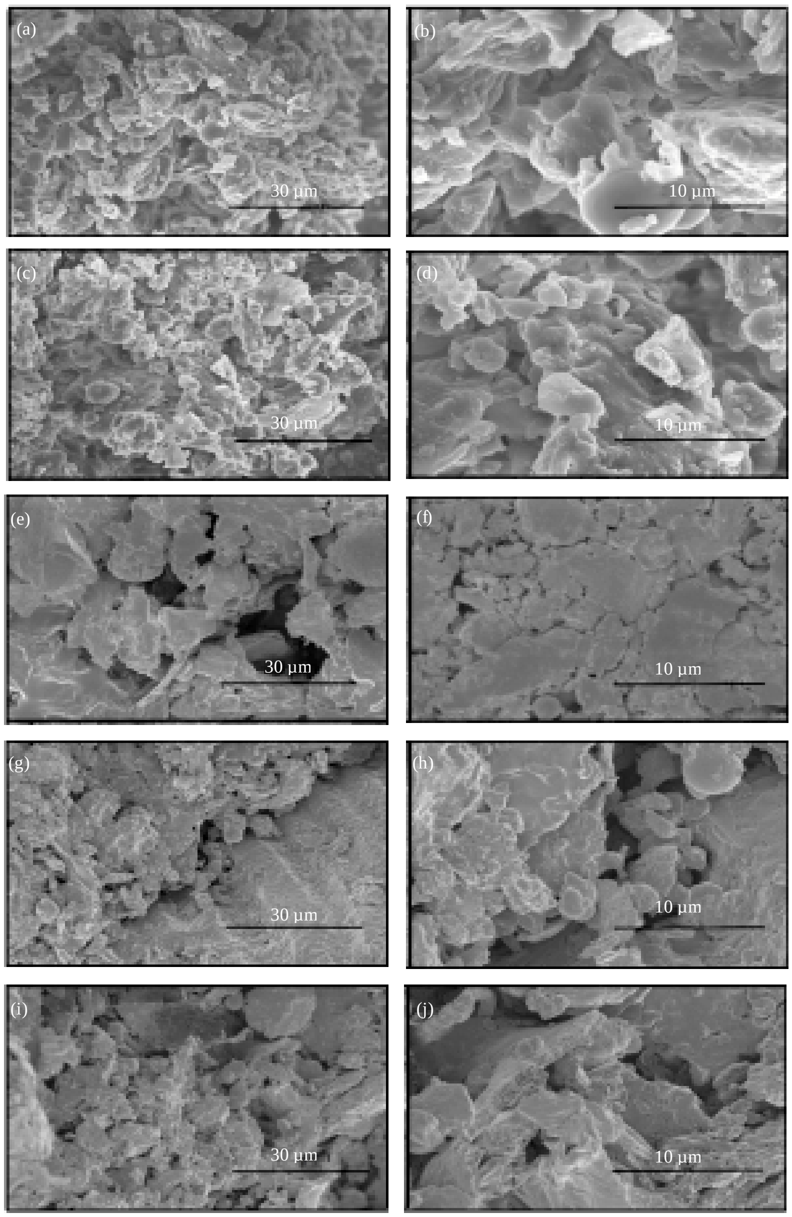

Fig. 2(a-j): SEM images of (a-b) CBP150, (c-d) CBP160, (e-f) CBP170, (g-h) CBP180 and (i-j) CBP190 of pressing temperature resulted in different morphologies which have significant impacts on the particleboard properties. The CBP150 and CBP160 showed similar microstructure (Fig. 2a, c). In these figures, granulated globular protein structure could be seen on the both of particleboards. The 150 and 160°C of pressing temperature did not lead completely denaturization of proteins. Most protein folds into globular domain, as well as protein of castor seed cake (Veeresh and Narayana, 2012). Further higher temperature (170-180°C) has led to improve the denaturization ability of protein and then protein corpuscles of the binderless particleboard disappeared after the treatment temperature and the fibers were embedded in a continuous matrix (Fig. 2e, g). Moreover, proteins chain unfold and entangle with other proteins and new bond arise, causing the texture to change (Gonzalez-Gutierrez *et al.*, 2010). Once the protein has been denatured, then it has the ability to flow onto and into the matrix (fibers) and to form hydrogen bonds with the matrix structure (Frihart, 2005). This surface contact between the protein chains and fibers surface can lead to bonding quality improvement. At pressing temperature above 180°C, the protein became partially degraded. It involved protein aggregation and can occur voids in the protein phase (Mo *et al.*, 1999), resulting reduction in adhesion strength (Fig. 2i, j). The Fig. 2b and d showed that with increasing the magnification, the particleboards pressed by lower pressing temperatures (150 and 160°C) seem to have more void spaces. Consequently, more void spaces could improve tendency to absorb water and increased the thickness swelling on the binderless particleboards. The specific surface area produced a smoother surface and became to be flat when they were pressed at higher temperature 170 and 180°C (Fig. 2e, g) and reduced void spaces (Fig. 2f, h). The smooth surface area due to mechanical interlocking of denaturized protein particles leads to solid bridges between particles (Kaliyan and Morey, 2010).

CONCLUSION

The effect of pressing temperature on physical and mechanical properties of binderless particleboards made from castor seed cake was investigated. Testing results revealed that pressing temperature has an influence on the properties of the binderless particleboards obtained. Generally, the MOR and MO increased with increasing pressing temperature but it was insufficient to meet the JIS standard requirement. Meanwhile internal bonding for all the particleboards exceeded the minimum requirement of the JIS standard. With increasing pressing temperature (150-190°C) the thickness swelling and water absorption of the castor seed cake binderless particleboard decreased and they did not satisfy the minimum requirement of the JIS standard.

ACKNOWLEDGMENT

The authors would like to acknowledge the DIKTI for financial support (Grant of International Research Collaboration and Scientific Publication with contract No. 084/SP2H/PL/Dit.Litabmas/V/2013).

REFERENCES

Barnes, D.J., B.S. Baldwin and D.A. Braasch, 2009. Ricin accumulation and degradation during castor seed development and late germination. Ind. Crops Prod., 30: 254-258.

Baskaran, M., R. Hashim, N. Said, S.M. Raffi and K. Balakrishnan *et al.*, 2012. Properties of binderless particleboard from oil palm trunk with addition of polyhydroxyalkanoates. Composites Part B: Eng., 43: 1109-1116.

Diebel, W., M.M. Reddy, M. Misra and A. Mohanty, 2012. Material property characterization of co-products from biofuel industries: Potential uses in value-added biocomposites. Biomass Bioenergy, 37: 88-96.

Evon, P., V. Vandenbossche, P.Y. Pontalier and L. Rigal, 2010. Thermo-mechanical behaviour of the raffinate resulting from the aqueous extraction of sunflower whole plant in twin-screw extruder: Manufacturing of biodegradable agromaterials by thermo-pressing. Adv. Mater. Res., 112: 63-72.

Evon, P., V. Vandenbossche and L. Rigal, 2012. Manufacturing of renewable and biodegradable fiberboards from cake generated during biorefinery of sunflower whole plant in twin-screw extruder: Influence of thermo-pressing conditions. Polymer Degradation Stability, 97: 1940-1947.

Evon, P., I.A. Kartika and L. Rigal, 2014. New renewable and biodegradable particleboards from jatropha press cakes. J. Renewable Mater., 2: 52-65.

Frihart, C.R., 2005. Handbook of Wood Chemistry and Wood Composites. CRC Press, USA.

Gonzalez-Gutierrez, J., P. Partal, M. Garcia-Morales and C. Gallegos, 2010. Development of highly-transparent protein/starch-based bioplastics. Bioresource Technol., 101: 2007-2013.

Hashim, R., N. Said, J. Lamaming, M. Baskaran and O. Sulaiman *et al*., 2011. Influence of press temperature on the properties of binderless particleboard made from oil palm trunk. Mater. Design, 32: 2520-2525.

Heywood, V.H., R.K. Brummit, A. Culham and O. Soberg, 2007. Flowering Plant Families of the World. Firefly Books, Richmond Hill, Canada, ISBN-13: 978-1554072064, Pages: 424.

Hidayat, H., E.R.P. Keijsers, U. Prijanto, J.E.G. van Dam and H.J. Heeres, 2014. Preparation and properties of binderless boards from *Jatropha curcas* L. seed cake. Ind. Crops Prod., 52: 245-254.

JIS-A 5908, 2003. Particleboards. Japanese Standards Association, Tokyo, Japan.

Kaliyan, N. and R.V. Morey, 2010. Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass. Bioresource Technol., 101: 1082-1090.

Khosravi, S., P. Nordqvist, F. Khabbaz and M. Johansson, 2011. Protein-based adhesives for particleboards effect of application process. Ind. Crops Prod., 34: 1509-1515.

Kumar, R., V. Choudhary, S. Mishra, I.K. Varma and B. Mattiason, 2002. Adhesives and plastics based on soy protein products. Ind. Crops Prod., 16: 155-172.

Laemsak, N. and M. Okuma, 2000. Development of boards made from oil palm frond II. Properties of binderless boards from steam-exploded fibers of oil palm frond. J. Wood Sci., 46: 332-336.

Li, X., Y. Li, Z. Zhong, D. Wang, J.A. Ratto, K.Sheng and X.S. Sun, 2009. Mechanical and water soaking properties of medium density fiberboard with wood fiber and soybean protein adhesive. Bioresour. Technol., 100: 3556-3562.

Lima, R.L., L.S. Severino, L.R. Sampaio, V. Sofiatti, J.A. Gomes and N.E. Beltrao, 2011. Blends of castor meal and castor husks for optimized use as organic fertilizer. Ind. Crops Prod., 33: 364-368.

Mo, X., X.S. Sun and Y. Wang, 1999. Effects of molding temperature and pressure on properties of soy protein polymers. J. Applied Polymer Sci., 73: 2595-2602.

Mobarak, F., Y. Fahmy and H. Augustin, 1982. Binderless lignocellulose composite from bagasse and mechanism of self-bonding. Holzforschung-Int. J. Biol. Chem. Phys. Technol. Wood, 36: 131-136.

Nemli, G. and I. Ozturk, 2006. Influences of some factors on the formaldehyde content of particleboard. Build. Environ., 41: 770-774.

Odunsi, T.A.A., O.S. Olabode and T.K. Ojediran, 2012. Physical and nutrient characterisation of raw and processed castor (*Ricinus communis* L.) seeds in Nigeria. World J. Agric. Sci., 8: 89-95.

Ogunniyi, D.S., 2006. Castor oil: A vital industrial raw material. Bioresour. Technol., 97: 1086-1091.

Okuda, N. and M. Sato, 2004. Manufacture and mechanical properties of binderless boards from kenaf core. J. Wood Sci., 50: 53-61.

Okuda, N., K. Hori and M. Sato, 2006. Chemical changes of kenaf core binderless boards during hot pressing (II): Effects on the binderless board properties. J. Wood Sci., 52: 249-254.

Panyakaew, S. and S. Fotios, 2011. New thermal insulation boards made from coconut husk and bagasse. Energy Build., 43: 1732-1739.

Quintana, G., J. Velasquez, S. Betancourt and P. Ganan, 2009. Binderless fiberboard from steam exploded banana bunch. Ind. Crops Prod., 29: 60-66.

SNI 01-2891, 1992. Food and Beverages Analysis Procedures. Badan Standarisasi Nasional, Jakarta.

Salvado, J., J.A. Velasquez and F. Ferrando, 2003. Binderless fiberboard from steam exploded *Miscanthus sinensis*: Optimization of pressing and pretreatment conditions. Wood Sci. Technol., 37: 279-286.

Shen, K.C., 1986. Process for manufacturing composite products from lignocellulosic materials. US Patents No. 46279 51, September 30, 1986.

Talavera, F.J.F., J.A.S. Gusman, H.G. Richter, R.S. Duenas and J.R. Quirarte, 2007. Effect of production variables on bending properties, water absorption and thickness swelling of bagasse/plastic composite boards. Indus. Crops Prod., 26: 1-7.

Van Soest, P.J., J.B. Robertson and B.A. Lewis, 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci., 74: 3583-3597.

Veeresh, S.J. and J. Narayana, 2012. Assessment of agro-industrial wastes proximate, ultimate, SEM and FTIR analysis for feasibility of solid bio-fuel production. Universal J. Environ. Res. Technol., 2: 575-581.

Widyorini, R., J. Xu, K. Umemura and S. Kawai, 2005. Manufacture and properties of binderless particleboard from bagasse I: Effects of raw material type, storage methods and manufacturing process. J. Wood. Sci., 51: 648-654.