Asian Journal of Plant Sciences

ISSN 1682-3974

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2016.42.55

Review Article
Agricultural Waste Fibers Towards Sustainability and Advanced Utilization: A Review

[1]Rudi Dungani, [2]Myrtha Karina, [3]Subyakto, [4]A. Sulaeman, [5]Dede Hermawan and [1]A. Hadiyane

[1]School of Life Sciences and Technology, Institut Teknologi Bandung, Indonesia
[2]Research Center for Chemistry, Indonesian Institute of Sciences (LIPI), Indonesia
[3]Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI), Indonesia
[4]Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Indonesia
[5]Faculty of Forestry, Bogor Agricultural University, Indonesia

Abstract
The agricultural waste fibers are of notable economic and cultural significance all over the world are used for building materials, as a decorative product and as a versatile raw product. Agricultural waste fibers also have significant potential in composite due to its high strength, environmentally friendly nature, low cost, availability and sustainability. The agricultural waste is one of the most important problems that must be resolved for the conservation of global environment. The potential properties of agricultural waste fibers have sparked a lot of research to use these fibers as a material to replace man-made fibers for safe and environmentally friendly product. Agricultural waste is seen as one potential source of renewable energy. Their availability is obtained from oil palm plantations and some other agricultural industry such as rice husk, rice straw, sugarcane, pineapple, banana and coconut. Agricultural waste produces large amounts of biomass that are classified as natural fibers which until now only 10% are used as alternative raw materials for several industry, such as biocomposites, automotive component, biomedical and others.

Key words: Biomass, natural fibers, agricultural waste, biocomposites, isolation fiber, sustainability

Received: December 03, 2015 Accepted: February 09, 2016 Published: March 15, 2016

Citation: Rudi Dungani, Myrtha Karina, Subyakto, A. Sulaeman, Dede Hermawan and A. Hadiyane, 2016. Agricultural waste fibers towards sustainability and advanced utilization: A review. Asian J. Plant Sci., 15: 42-55.

Corresponding Author: Rudi Dungani, School of Life Sciences and Technology, Institut Teknologi Bandung, Indonesia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Plenty of wastes is produced due to the increase activity in the modern agricultural sector, represents a tremendous threat to the environment. Meanwhile, declining supply of raw material causing concern and in this context the natural fiber can be seen as a good alternative material for the local timber industry to produce value added product, such as biocomposites. Utilization of natural fiber, especially agricultural waste fiber needs further development as a long term strategy to develop the tremendous wealth of natural plant fiber that are currently under utilised. Agriculture waste can be obtained from plant such as oil palm, bagasse, corn stalks, coir, bamboo, pineapple, banana as well as rice husk which extracted on their part of plant (stem, leaf, seed, fruit, stalk and grass/reed) (Jawaid and Abdul Khalil, 2011).

The main fiber wastes produced from the activity of agriculture is called as Cellulose Fibers (CF) and is of potential as reinforcing materials due to abundantly available, low weight, renewable, degradable, cheaper and low abrasive property. These biomass waste possess several interesting specific properties (Joshi *et al*., 2004; Kalia *et al*., 2009, 2011a; Jawaid and Abdul Khalil, 2011). Agricultural waste is the most abundant form of natural fiber (Doree, 1947) and applied in many spheres of modern industry. However, cellulose fiber is found in combination with other materials such as lignin, hemicelluloses and pectin called as composites (Pickering, 2008). These materials varies with the different types of fibers, growing and harvesting conditions of plant (Saheb and Jog, 1999; Li *et al*., 2007). Therefore, the isolation of cellulose fiber from agriculture waste needs intensive treatment. There are various methods for preparing fibers from cellulose fibers such as chemical treatment (Fahma *et al*., 2010; Nazir *et al*., 2013; Siddiqui *et al*., 2011), mechanical treatment (Abdul Khalil *et al*., 2014) and chemo-mechanical treatment (Jonoobi *et al*., 2011; Fatah *et al*., 2014). They reported that the acid to fiber ratio and treatment time has main effects on isolation and properties of the cellulosic fiber.

Cellulose Fibers from palm pressed fibres have been used as fuel (Arami-Niya *et al*., 2010). The corn husk has also been used for biodegradable film (Norashikin and Ibrahim, 2009), heat insulator from coconut fibers (Yuhazri *et al*., 2011), rice husk ash and coconut fibers in concrete (Domke, 2012). Natural Fibers from banana's tree as fillers into polymers composites (Albinante *et al*., 2014). Rice straw and bagasse fiber used as writing and printing papers (Karim *et al*., 2010). In addition, oil palm fronds, bamboo fibers, coconut fibers, rice-husks and sugar cane-dregs to make cement boards (Hermawan *et al*., 2001, 2002). In the past few years, several of studies have reported natural fibers as a reinforcing agent in biocomposite thermoplastic and thermoset matrices. Coir, banana and sisal of agricultural wastes can be used as reinforced polymer composites for commercial use (Sapuan *et al*., 2003; Yang *et al*., 2006; Sakthivel and Ramesh, 2013; Abdul Khalil *et al*., 2013; Namvar *et al*., 2014). The aim of this review is to describe the selected cellulose fiber from different agriculture waste on various of properties and its applicability towards sustainable and advanced utilization. Besides, isolation treatment of celullosic fiber technique will be compared and application of agricultural waste fibers is briefly be discussed.

OVERVIEW OF WASTE AS GREEN POTENTIAL FROM BIOMASS

Dealing with the growing demand for the renewable resources, agricultural and plantation wastes are considered as the promising and the suitable material. Biomass material is one of the important sources of alternative material for the production of biocomposite products (Abdul Khalil *et al*., 2010b; Abba *et al*., 2013; Namvar *et al*., 2014; Ogah *et al*., 2014). An increasing global awareness about environmental issues is acting as the driving force behind the utilisation of biomass material as valuable products.

Table 1 summarizes the general promising agricultural product resources and its country origin.

Table 1: Agricultural products as a potential natural fiber resources

	Production (million tonnes)											
Countries	Banana	Coconut	Pineapple	Sugarcane	Rice	Oil palm fruit	Jute	Kenaf	Flax	Sisal	Abaca	Kapok
Brazil	6.90	2.82	2.48	0.739	11.76	1.34	26.71	14.20	0.71	0.25	1.20	na
China	10.55	0.250	1.00	125.54	203.29	0.670	0.17	0.08	0.47	0.15	0.65	0.06
India	24.87	11.93	1.46	341.20	159.20	na	1.98	0.12	0.22	0.21	na	na
Indonesia	6.19	18.30	1.78	33.70	71.28	120.00	0.007	4.35	na	0.03	0.05	0.03
Malaysia	0.335	0.605	0.334	0.830	2.63	100.00	0.002	0.01	na	na	na	0.008
Philippine	9.23	15.35	2.40	31.87	18.44	0.473	0.002	na	0.002	na	0.08	na
Thailand	1.65	1.01	2.65	100.10	38.79	12.81	0.06	1.30	0.01	0.003	na	0.07
USA	0.008	na	0.180	27.91	8.63	na	na	na	0.004	na	na	na
Vietnam	1.56	1.31	0.540	20.08	44.04	na	0.02	8.20	na	0.01	0.01	0.003

Source: FAO (2014), na: Not available

Assuming that 40% of the production is available as waste and at least 10% of the waste by weight can be obtained as fiber, millions of metric tons of fibers are available every year and the amount will increases annually. These wastes could be the potential resources for reinforcing materials in bio-composite applications. The utilization of such resources will not only provide the sustainable and less expensive material but at the same time will contribute the waste d isposal management as well as overcoming the environmental problems. However, various factors affect the fiber quality, such plant growth, harvesting stage and fiber extraction process (Dittenber and GangaRao, 2012). Therefore, good understanding of the fundamental properties of agricultural waste fiber is of indispensable.

The development of agricultural industry waste biomass through intensified use of non-conventional raw materials such as oil palm, coconut, pineapple and bagasse were technically and economically feasible. They can play an important supplementary role, especially in the form of fibers (Dungani *et al*., 2014). The agricultural waste material was identified as suitable for the production of paper, composites and engineered material. There are several non-wood fiber sources other than those of agricultural residue origin. Tropical region is endowed with rich biomass fibre resources, in respect of diversity as well as abundance. Malaysia and Indonesia are the world largest producer of agricultural industry waste especially oil palm (Abdul Khalil *et al*., 2010a).

FUNDAMENTAL PROPERTIES OF VARIOUS AGRICULTURAL WASTE FIBERS

To evaluate various agricultural waste properties many studies have been on its isolation and characterization (Kalia *et al*., 2011a; Abdul Khalil *et al*., 2008; Thomas *et al*., 2011; Hemmasi *et al*., 2011; Venkateshwaran *et al*., 2012; Driemeier *et al*., 2012; Nguong *et al*., 2013). Physical, mechanical and chemical properties of various agricultural waste were examined to assess their suitability for various application. The fundamental properties will not only help in open up a new avenue for these fibers but also emphasize the importance of natural fibers from agricultural waste as future material.

Structure and chemical composition: From inner to outer part, the structure of a natural fibre cell consist of primary and secondary cell wall, lumen and middle lamella (Kalia *et al*., 2011b). The cell wall are embedded in a hemicellulose-lignin matrix (Alberts *et al*., 2002; Thomas *et al*., 2011). The basic three structure of natural fiber of the plant raw materials are presented in Fig. 1.

Hemicellulose found in the natural fibers is believed to be a compatibilizer between cellulose and lignin (Thomas *et al*., 2011). The cell wall in a fiber is not a homogenous membrane (Akil *et al*., 2011). Each fiber has a complex, layered structure consisting of a thin primary wall which is the first layer deposited during cell growth encircling a secondary wall. The secondary wall is made up of three layers and the thick middle

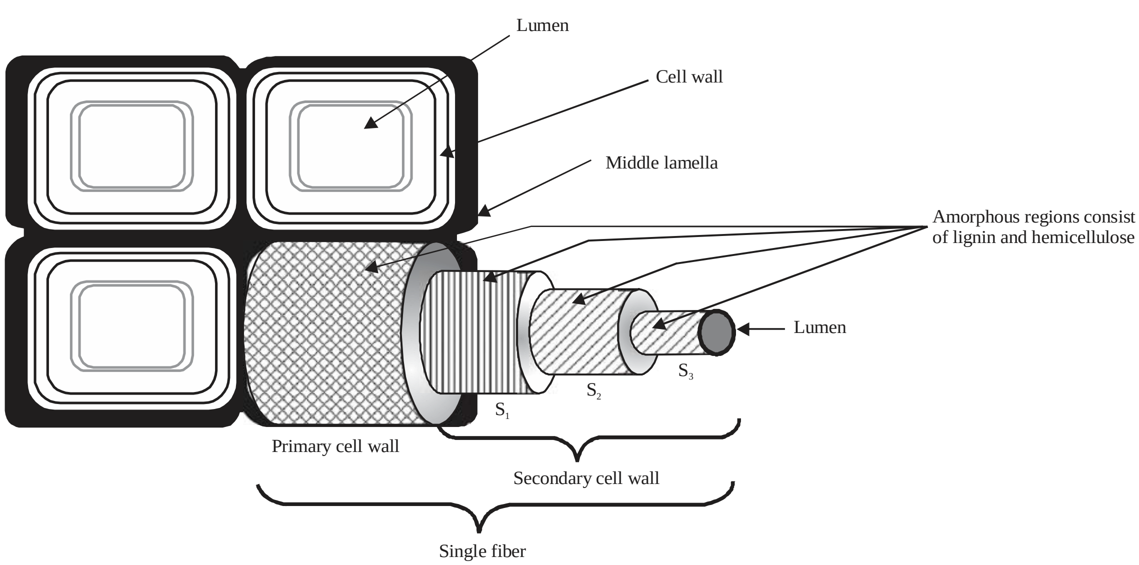

Fig. 1: Sceme of the basic three structure of natural fiber of the plant raw materials

layer determines the mechanical properties of the fiber. The middle layer consists of a series of helically wound cellular microfibrils formed from long chain cellulose molecules (Rowell *et al*., 2000).

The agricultural waste fibers have high variability in properties and depend on fiber structure, fiber cell dimensions, microfibril angle and chemical composition (Rowell *et al*., 2000; Osorio *et al*., 2010). The fiber length and width is very important in natural fibers based fiber composites as it gives an indication of possible strength properties (Rowell *et al*., 2000). The fiber characteristics of agricultural waste indicate a wide range of fiber length, width and thickness. The dimensions of some common agricultural waste fibers are shown in Table 2.

Plant fiber is a complex natural composite consisting of various different chemical substance and mainly composed of cellulose, hemicellulose and lignin with minor amount of pectin (Azwa *et al*., 2013). Due to its main chemical composition, plant fibers are also called as cellulosic or lignocellulosic fibers (Siqueira *et al*., 2009). Those constituents are scattered through out the cell wall of which consists of primary and secondary wall. The portion of these chemicals in cell wall layer is affected by the fiber origin, climate condition during cultivation, the extraction method (Rowell *et al*., 2000; Batra, 1985; Bledzki and Gassan, 1999) and influences the fiber properties chemically and physically. Table 3 shows the chemical composition of several agro waste fibers.

Physical and mechanical properties: Physical and mechanical properties of fiber are highly depends on the growing condition, extraction methods, chemical composition and its ratio (Cristaldi *et al*., 2010; Huang *et al*., 2012). Table 4 summarizes the physical and mechanical properties of several agro waste fibers.

Thickness of middle layer of the secondary cell walls determines the mechanical properties of fiber as well (John and Thomas, 2008; Azwa *et al*., 2013). Excellent mechanical properties such as tensile strength and Young's modulus was reported due to the better orientation of crystalline cellulose which is caused by the high water absorb capability (Thygesen *et al*., 2007). High mechanical property is also shown by the fiber with higher degree of polymerization of cellulose and longer of cell length (Methacanon *et al*., 2010; John and Thomas, 2008). Fiber with higher cellulose content is reported possess better tensile strength and Young's modulus (Reddy and Yang, 2005, 2006). Mechanical property of fiber was also due to the microfibrillar angles. High strength

Table 2: Dimension of selected agricultural waste fibers

Types of fiber	Fiber length (mm)	Width fiber (µm)	Fibril angle (degrees)	References
Oil palm	0.33-50.31	8.30-20.50	40-46	Abdul Khalil *et al.* (2008)
Sugarcane	1.22-1.59	19.35-20.96	10-40	Hemmasi *et al.* (2011) and Driemeier *et al.* (2012)
Banana	0.90-4.00	80.00-250.00	9-13	Alwani *et al.* (2015)
Coconut (coir)	0.30-1.00	92.00-314.00	39-49	Alwani *et al.* (2015) and Setyanto *et al.* (2013)
Corn stalks	0.50-1.50	10.00-20.00	33-39	Nguong *et al.* (2013)
Pineapple	3.00-9.00	20.00-80.00	10-15	Alwani *et al.* (2015)
Rice straw	0.40-3.40	4.00-16.00	31-35	Venkateshwaran *et al.* (2012)
Jute	3.00-3.50	60.00-110	7-9	Gassan *et al.* (2001)
Kenaf	0.66-082	17.70-26.70	5-10	Ververis *et al.* (2004) and Thiruchitrambalam *et al.* (2012)
Flax	0.20-1.40	0.04-0.62	6-10	Gassan *et al.* (2001)
Sisal	0.85-1.00	100-300	10-25	Gassan *et al.* (2001) and Vijayalakshmi *et al.* (2014)
Abaca	2.00-4.00	150-260	6-7	Shibata *et al.* (2002, 2003)
Kapok	2.00-3.00	14.1-18.9	7.3-8.7	Huang and Lim (2006)

Table 3: Chemical composition of selected agricultural waste fibers

Types of fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	References
Oil palm	44.20-49.60	18.30-33.54	17.30-26.51	Abdul-Khalil *et al.* (2007) and Lu *et al.* (2006)
Sugarcane	55.60-57.40	23.90-24.50	24.35-26.30	Wahlang *et al.* (2012) and Hemmasi *et al.* (2011)
Banana	60.25-65.21	48.20-59.2	5.55-10.35	Preethi and Murthy (2013)
Coconut (coir)	36.62-43.21	0.15-0.25	41.23-45.33	Satyanarayana *et al.* (2009)
Corn stalks	38.33-40.31	25.21-32.22	7.32-21.45	Reddy and Yang (2005)
Pineapple	70.55-82.31	18.73-21.90	5.35-12.33	Pardo *et al.* (2014)
Rice straw	28.42-48.33	23.22-28.45	12.65-16.72	Reddy and Yang (2005)
Jute	69.21-72.35	12.55-13.65	12.67-13.21	Leao *et al.* (2006) and Mwaikambo (2009)
Kenaf	37.50-63.00	15.10-21.40	18.00-24.30	Leao *et al.* (2006), Abdul Khalil *et al.* (2006) and Thiruchitrambalam *et al.* (2012)
Flax	69.22-71.65	18.31-18.69	3.05-2.56	Bismarck *et al.* (2002), Leao *et al.* (2006) and Thiruchitrambalam *et al.* (2012)
Sisal	43.85-56.63	21.12-24.53	7.21-9.20	Favaro *et al.* (2010)
Abaca	69.23-70.64	21.22-21.97	5.15-5.87	Leao *et al.* (2006) and Del Riao and Gutiearrez (2006)
Kapok	65.63-69.87	6.66-10.49	5.46-5.63	Chaiarrekij *et al.* (2011) and Anigo *et al.* (2013)

Table 4: Physical and mechanical properties of selected agricultural waste fibers

Types of fiber	Density ($g\ m^{-3}$)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	References
Oil Palm	0.7-1.55	227.5-278.4	2.7-3.2	2.13-5.00	Abdul Khalil *et al.* (2008) and Hemmasi *et al.* (2011)
Sugarcane	0.31-1.25	257.3-290.5	15-18	6.20-8.2	Driemeier *et al.* (2012)
Banana	0.65-1.36	51.6-55.2	3.00-3.78	1.21-3.55	Alwani *et al.* (2015), Sumaila *et al.* (2013) and Sakthive and Ramesh (2013)
Coconut (coir)	0.67-1.15	173.5-175.0	4.0-6.0	27.21-32.32	Alwani *et al.* (2015) and Sakthive and Ramesh (2013)
Corn stalks	0.21-0.38	33.40-34.80	4.10-4.50	1.90-2.30	Rodriguez *et al.* (2010)
Pineapple	1.25-1.60	166-175	5.51-6.76	2.78-3.34	Alwani *et al.* (2015)
Rice straw	0.86-0.87	435-450	24.67-26.33	2.11-2.25	Bouasker *et al.* (2014) and Reddy and Yang (2006)
Jute	1.3-1.45	300-700	20-50	1.69-1.83	Alves *et al.* (2009), Bongarde and Shinde (2014) and Vijayalakshmi *et al.* (2014)
Kenaf	0.15-0.55	295-955	23.1-27.1	1.56-1.78	Wambua *et al.* (2003), Munawar *et al.* (2007) and Paridah and Khalina (2009)
Flax	1.27-1.55	500-900	50-70	2.70-3.6	Soiela *et al.* (2005) and Bongarde and Shinde (2014)
Sisal	1.45-1.5	300-500	10-30	4.10-4.3	Alves *et al.* (2009), Bongarde and Shinde (2014) and Vijayalakshmi *et al.* (2014)
Abaca	1.42-1.65	879-980	38-45	9-11	Vijayalakshmi *et al.* (2014)
Kapok	0.68-1.47	80.3-111.5	4.56-5.12	1.20-1.75	Mwaikambo and Ansell (2001), Mojica *et al.* (2002) and Chaiarrekij *et al.* (2011)

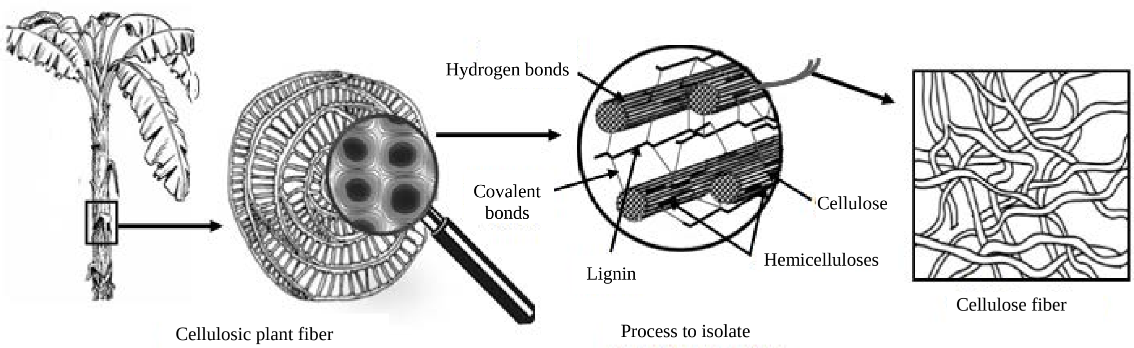

Fig. 2: Schematic principle of isolation process isolate from cellulosic plant fiber to cellulose fiber

and stiff fiber was provided by the smaller angles whereas larger angles responsible for higher ductility (John and Thomas, 2008; Methacanon *et al.*, 2010). Ductility of fiber is shown if microfibrils possess a spiral orientation to the fibre axis, whereas if microfibrils are oriented parallel to the fibre axis, the fibres is rigid and inflexible (Satyanarayana *et al.*, 2009; Monteiro *et al.*, 2011).

EXPLORATION TECHNIQUE FOR CELLULOSE PLANT FIBERS EXTRACTION

Many factors play important roles in the success of extraction cellulose, such as chemical composition, which vary from plant to plant (Siqueira *et al.*, 2009) and methods to extract cellulose (Chen *et al.*, 2012; Abdul Khalil *et al.*, 2014; Fatah *et al.*, 2014). The principle of all methods to extract cellulose is to remove the non-cellulosic components present in the fibers such as lignin, hemicellulose and pectin as well as for the manufacture of fibers to produce nanofibers.

Cellulose fibres can be extracted from a wide variety of cellulosic sources, such as kenaf, banana, oil palm, jute, kapok, sisal, pineapple, abaca, etc. Selecting the cellulosic source depends on the availability of the fibre in a country, the chemical components for its application and economic considerations (Kalia *et al.*, 2011c). There are several methods have been used to isolate natural fibers from cellulosic materials. Chakraborty *et al.* (2005), Abe *et al.* (2009) and Nakagaito and Yano (2004) have isolated fibers using mechanical treatments, whereas chemical treatments have been used to isolate fibers by Araki *et al.* (2001) and Liu *et al.* (2010). Jonoobi *et al.* (2011) and Fatah *et al.* (2014) have isolated of nanofibrillated cellulosic fiber from oil palm empty fruit bunch by chemo-mechanical technique. The schematic principle of isolation process from cellulosic plant fiber to cellulose fiber shown in Fig. 2.

The retting process is simplest extraction methods. It is a chemical process for removing non-cellulosic material attached to fibres to release individual fibres, which are normally applied to jute, flax and kenaf. The fiber obtained by this method is delicate,thin and has color adequate to the quality of use draw material (Akin *et al.*, 2007). According to the literature, isolating cellulose fibers with retting methods can be conducted in five process, namely, dew (Lu *et al*., 1999), water (Banik *et al*., 2003), enzymatic (Akin *et al*., 2007), mechanical (Goodman *et al*., 2002) and chemical retting (Paridah and Khalina, 2009). Because of this characteristic, fibers that are separated from bast plants are often reffered to as crude fiber, which are usually much coarser and much longer, futher process and fibers can be isolated from cellulosic fibres using various mechanical or chemo mechanical processes, including high-pressure homogenization, microfluidization, microgrinding, high-intensity ultrasonication, electrospinning and steam explosion.

Chemical treatment: Chemical treatment has been extensively used for removal non-celulosic compound in natural fiber and destroying its crystalline structure. Many researchers studied the extraction of cellulose from agricultural waste fiber by chemical treatment using chlorite bleaching, alkali treatment and acid hydrolysis, etc. Johar *et al*. (2012) have been using sulfuric acid hydrolysis (H_2SO_4) on cellulose fibers from rice husk and from jute cellulose (Jahan *et al*., 2011). In addition to these isolation studies, the characterization of cellulose fibers derived from cellulosic plant fiber has been reported.

The chemical treatment for preparing cellulosic fibers from cellulosic plant fibers including using sulphuric acid (H_2SO_4) and hydrochloric acid (HCl) have been successfully carried out. Qua *et al*. (2011) and Brinchi *et al*. (2013) have been studied to isolate nanofibers from cellulosic plant. They reported that chemical treatment with acid hydrolysis have a influence on the surface charge and dimensions of the cellulose nanofibers. Meanwhile, Fahma *et al*. (2010) have been extracted cellulose nanofibers from oil palm empty-fruit-bunch using sulphuric acid hydrolysis. Other studies by Leitner *et al*. (2007) showed isolation of cellulose from a by-product of sugar beet chips production by wet chemistry.

Another treatment has been used by several researcher is multistage chemical treatment. Kopania *et al*. (2012) reported that the use of oxygen and peroxide compounds, allowed the safe removal of lignin and other non-cellulosic components without degradation of the cellulose fibres obtained.

Mechanical treatment: There are several mechanical processes have been used to isolate fibers cellulosic materials, such as homogenization, ultrasonication and electrospinning. Apart from the isolation process of fiber cellulose by homogenization, refining (Stelte and Sanadi, 2009; Karande *et al*., 2011), cryocrushing (Wang and Sain, 2007; Alemdar and Sain, 2008), grinding (Wang *et al*., 2012; Hassan *et al*., 2012) and microfluidization (Ferrer *et al*., 2012) can also be considered as other mechanical approaches.

The ultrasonication with high intensity can be considered as a mechanical method for isolation cellulose fibers with hydrodynamic forces (Cheng *et al*., 2009). Several attempts have been done to isolate cellulose fiber by ultrasonication from various cellulose sources such as flax, wood, wheat straw and bamboo (Chen *et al*., 2011). The ultrasonic has been used as combination with other methods to more successfully in extraction of cellulose fiber. For example, ultrasonication and acid hydrolysis with H_2SO_4 (Li *et al*., 2011) or ultrasonic and homogenization (Cheng *et al*., 2010). These combination methods increased fibrillation of cellulose and gave more efficient cellulose fiber production than ultrasonic solely (Mishra *et al*., 2012).

Electrospinning is a versatile and simple process for formation of fibers from various sources such as cellulosic fibers by electrical force. In this process, nanofibers are formed from polymer solution between two electrodes with opposite polarity, one electrode connected to syringe and the other one to collector (Huang *et al*., 2003). Furthermore Vallejos *et al*. (2012) reported that processing of cellulose via electrospinning is a big challenge because of its limited solubility in common solvents as well as its tendency to agglomerate.

One of the other mechanical processes is steam explosion. The principle of this process described by Giri and Adhikari (2013), steam penetrates to cellulose fiber due to the high pressure of the equipment and when the pressure suddenly releases, creates shear force, hydrolyze the glycosidic and hydrogen bonds and leads to formation of fibers.

Chemo-mechanical treatment: In recent years, the chemo-mechanical technique with combination method of chemical and mechanical treatment have been used to isolate cellulose fibers from various lignocellulosic plant. This technique can produce fibers without degrading the cellulose (Kalia *et al*., 2011b). Several researchers (Fahma *et al*., 2010; Jonoobi *et al*., 2011; Qua *et al*., 2011; Brinchi *et al*., 2013) reported that the chemical treatment was conducted as a pre-treatment of lignocellulosic pulp fibers using chemical compound and bleaching processes. In the process of mechanical treatment, chemically-treated lignocellulosic pulp fibers was refined, cryo-crushed and homogenized using a high pressure homogenization (HPH).

Utilization of sulphuric acid hydrolysis and HPH process is bearing considerable interest regarding of the production of fibrillated cellulose of natural fibers (Pan *et al*., 2013; Siqueira *et al*., 2009; Qing *et al*., 2012). Studies by Fatah *et al*. (2014) and Jonoobi *et al*. (2011) revealed that combination of sulphuric acid hydrolysis and HPH could be an effective to isolate cellulose nanofibers from oil palm empty fruits bunch.

Previous studies by Jonoobi *et al.* (2009) also showed that chemo-mechanical processes could be utilized as an effective process for nanocellulose production from kenaf bast. In the study by Alemdar and Sain (2008) cellulose nanofibers from agricultural waste were prepared by chemo-mechanical technique.

UTILIZATION OF AGRICULTURAL WASTE FIBERS

For years, agro-based biocomposite material has been used for many applications. Some common applications include using natural fiber composites for automotive and building components. Another special application is the use of nanocellulose fibers biocomposites to create loose-fill packing and biomedical application (Fig. 3).

Building component: Natural fiber composites for building applications was reviewed by Singh and Gupta (2005). Some building products such as panels, door shutters, door frames, roofing sheets and dough molding compounds made from jute, sisal, coir were elaborated. Many countries have been used agricultural waste fibers alone or in combination with other materials for building components to complement or replace wood. For example, study of agriculture waste fiber in India have been produced a good insulation boards with bagasse fibers (Acharya *et al.*, 2011). In China bagasse has been used to make particleboard (Verma *et al.*, 2012). Hardboards made from Thai hardwoods and coconut fiber have been investigated in Thailand. Their properties met or exceeded the Japanese standards (Gonzalez-Garcia *et al.*, 2011).

In the Philippines, the utilization of agricultural waste fibers in the production of composite panels has focused on coconut coir (or husks) and banana stalks for particleboards (Yevich and Logan, 2003). Indonesia, Malaysia and Papua New Guinea have many types of natural fibers from agricultural waste that have been applied for composite but many research are more directed to develop a green composite from oil palm fibers (Bakar *et al.*, 1999; Abdul Khalil *et al.*, 2008, 2010a, 2012; Yuliansyah *et al.*, 2009; Steve and Sumanasiri, 2011).

Furniture application: With increasing developments of newer bio-composites into the furniture industry, the use of agricultural waste fibers in furniture making could support the concept of reducing waste. The natural fibers can be used for the manufacture of biocomposite advanced (Abdul Khalil *et al.*, 2012). The EFB fibers can be used for the manufacture of medium density fibreboard (MDF) (Izani *et al.*, 2012). Additionally, the flax fibers can be used in a wide range of applications is reported by Van de velde and Kiekens (2001) for furniture application. The considerable investigations have been made in plant bast fibers, such as kenaf, banana, jute and flax as a reinforcement has grown

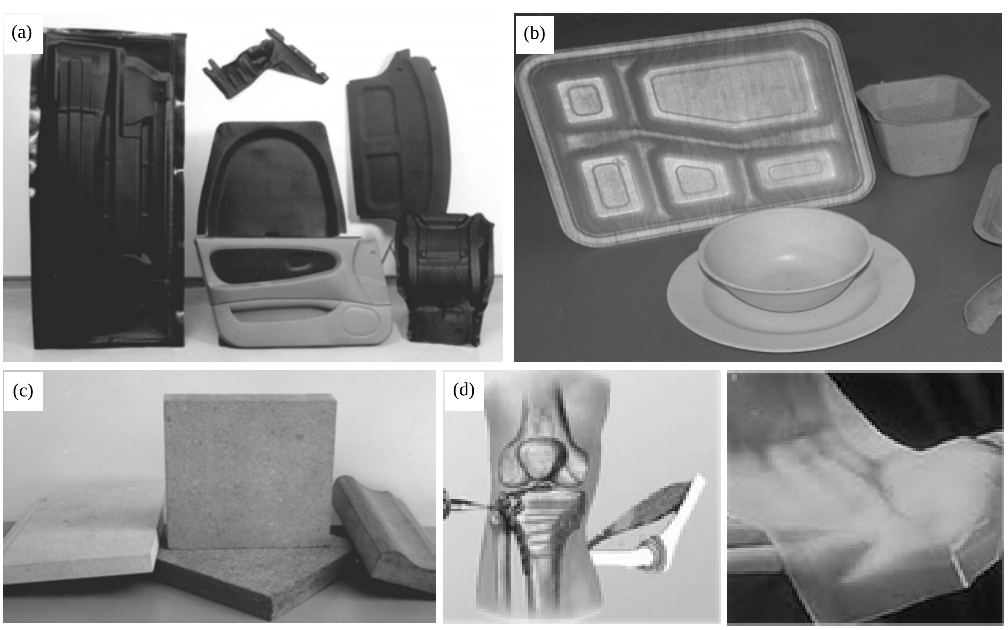

Fig. 3(a-d): Various applications of agro-based biocomposite, (a) Automotive component, (b) Food packaging, (c) Building component and (d) Medical applications, sources: Dungani *et al.* (2014) and Lina *et al.* (2011) with permission substantially in the past decade and they are other products, such as extruded plastic fencing, decking and furniture padding (Thiruchitrambalam *et al*., 2009).

Automotive applications: Agricultural waste fibers biocomposite is the prime candidate for automotive industries. Usage of natural fibers may reduce the car weight up to 30% so it will reduce fuel consumption. Biocomposites of polymer reinforced with naturals fibers can be used for interior and exterior parts of automotive components. Among the automotive parts that made from biocomposites are seat back, side and door panel, boot lining, hat rack, spare tire lining, dashboard, business table, piller cover panel, under body protection trim, instrumental panel and headliner panel (Suddell and Evans, 2005; Bledzki *et al*., 2006; Holbery and Houston, 2006). Ikpambese *et al*. (2016) studied utilization of palm kernel fibers for asbestos-free automotive brake pads.

Some automotive industries that have been used natural fibers for their parts are Audi, BMW, DaimlerChrysler, Fiat, Ford, Mitsubishi, Opel, Peugeot, Renault, Saab, Volkswagen, Volvo (Suddell and Evans, 2005; Bledzki *et al*., 2006). Mitsubishi especially developed prototype of door trim from bamboo composite (Abdul Khalil, 2012).

Medical applications: Natural fibers used for biomedical application should possess long-term usage in the body without rejection (Namvar *et al*., 2014). Recent work has studied the use of nanofibers as reinforcing material for the development of polymer composites specifically for medical applications. The researchers have explored the use of palm tree fibers for industrial and biomedical applications (Namvar *et al*., 2014). The potential use of biocomposites in the biomedical industry includes skins replacements for burnings and wounds; drugs releasing system; blood vessel growth; nerves, gum and dura-mater reconstruction; scaffolds for tissue engineering; stent covering and bone reconstruction (Hsu and Kao, 2005; Millon *et al*., 2006; Macocinschi *et al*., 2012; Musteata *et al*., 2010).

Development of biocomposites from natural fibers in biomedical applications are prepared using various types of polymer materials such as polyurethane and polvinyl alcohol (Hsu and Kao, 2005; Macocinschi *et al*., 2012; Musteata *et al*., 2010; Millon *et al*., 2006). On their studies, the stress-strain properties for porcine aorta are matched by at least one type of polyvinyl alcohol (PVA)-nanocellulose composite in both the circumferential and the axial tissue directions. A PVA-nanocellulose composite with similar properties as heart valve tissue is also developed.

Sporting goods: Bio-composite materials have used some sporting goods. A flax based bicycle and tennis racket that are currently available on the market (Francois, 2013). Advanced composites are now found in products used for 7 of the top 10 most popular outdoor sports and recreational activities (Lee, 2010). Carbon reinforced composites (hybrids with other fibres) continue to successfully replace wood and metal in high-volume components such as fishing rods, tennis racquets, golf clubs, spars/shafts for kayak paddles, windsurfing masts, kites and bicycle handebars, ski equipment.

Packaging applications: Packaging materials from renewable resources using natural fibers as reinforcement in their composite materials have been studied in recent years. The challenges in this application is that natural fibers filled polymer composites cannot replace the synthetic polymers due to their dominant hydrophilic character (permeability to gases and vapors), degradability and low mechanical properties (Johansson *et al*., 2012). However, synthetic polymers causes many environmental problems, so that natural fibers based composite can be employed in packaging application.

Several studies reported application of natural fibers as potential packaging materials because these materials have many advantages such as recyclability (Hirvikorpi *et al*., 2011). Microfibrillated cellulose (MFC) from various plant sources is possible to produce such films with high transparency and improved oxygen barrier properties (Siro and Plackett, 2010; Majeed *et al*., 2013). Singh *et al*. (2008) reported that empty fruit bunch fibers embedded in polyester matrix was used in food packaging. Their products become an excellent barrier against gas and vapor transmission due to cellulose fiber reinforced to polymer in the composite.

CONCLUSION

The applied technology for converting agricultural biomass into products has been established for decades, however the production has not been realized due to the uncompetitiveness of the prices of the biomass to synthetic products. Nevertheless, current projections of future green, sustainable and renewable products suggest increased use of agriculture biomass in the coming decades. Cellulose fibers from agricultural waste are being used as potential reinforcing materials for various applications. Applications of cellulose fibers are mainly considered to be in the paper and packaging products, although those of construction, automotive, furniture, sporting good, electronics, pharmacy and cosmetics are also being considered. The interesting points of these materials are they are waste biomass and exhibit good mechanical properties. Increased use of agricultural waste for agro-based biocomposite product is expected to have some ripple effects in the agriculture sectors.

ACKNOWLEDGMENTS

The authors would like to thank the School of Life Sciences and Technology, Institut Teknologi Bandung and Indonesian Institute of Sciences (LIPI) for providing the necessary facilities that has made this work possible.

REFERENCES

Abba, H.A., I.Z. Nur and S.M. Salit, 2013. Review of agro waste plastic composites production. J. Miner. Mater. Charact. Eng., 1: 271-279.

Abdul Khalil, H.P.S., M.S. Alwani and A.K.M. Omar, 2006. Chemical composition, anatomy, lignin distribution and cell wall structure of Malaysian plant waste fibers. BioResource, 1: 220-232.

Abdul-Khalil, H.P.S., S. Hanida, C.W. Kang and N.A.N. Fuaad, 2007. Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/Glass hybrid reinforced polyester composites. J. Reinforced Plastics Compos., 26: 203-218.

Abdul Khalil, H.P.S., M.S. Alwani, R. Ridzuan, H. Kamarudin and A. Khairul, 2008. Chemical composition, morphological characteristics and cell wall structure of Malaysian oil palm fibers. Polymer-Plastics Technol. Eng., 47: 273-280.

Abdul Khalil, H.P.S., A.H. Bhat, M. Jawaid, P. Amouzgar, R. Ridzuan and M.R. Said, 2010a. Agro-wastes: Mechanical and physical properties of resin impregnated oil palm trunk core lumber. Polym. Compos., 31: 638-644.

Abdul Khalil, H.P.S., P. Firoozian, I.O. Bakare, H.M. Akil and A.M. Noor, 2010b. Exploring biomass based carbon black as filler in epoxy composites: Flexural and thermal properties. Mater. Design, 31: 3419-3425.

Abdul Khalil, H.P.S., 2012. Biomass and biocomposite: Potential and future of green technology in Malaysia. Public Lecture Series of Professorship, Universiti Sains Malaysia, pp: 22.

Abdul Khalil, H.P.S., P. Amouzgar, M. Jawaid, A. Hassan, F. Ahmad, A. Hadiyana and R. Dungani, 2012. New approach to oil palm trunk core lumber material properties enhancement via resin impregnation. J. Biobased Mater. Bioenergy, 6: 299-308.

Abdul Khalil, H.P.S., N.A.S. Aprilia, A.H. Bhat, M. Jawaid, M.T. Paridah and D. Rudi, 2013. A *Jatropha* biomass as renewable materials for biocomposites and its applications. Renew. Sustain. Energy Rev., 22: 667-685.

Abdul Khalil, H.P.S., Y. Davoudpour, M.N. Islam, A. Mustapha, K. Sudesh, R. Dungani and M. Jawaid, 2014. Production and modification of nanofibrillated cellulose using various mechanical processes: A review. Carbohydr. Polym., 99: 649-665.

Abe, K., F. Nakatsubo and H. Yano, 2009. High-strength nanocomposite based on fibrillated chemi-thermomechanical pulp. Compos. Sci. Technol., 69: 2434-2437.

Acharya, S.K., P. Mishra and S.K. Mehar, 2011. Effect of surface treatment on the mechanical properties of bagasse fiber reinforced polymer composite. BioResources, 6: 3155-3165.

Akil, H.M., M.F. Omar, A.A.M. Mazuki, S. Safiee, Z.A.M. Ishak and A.A. Bakar, 2011. Kenaf fiber reinforced composites: A review. Mater. Design, 32: 4107-4121.

Akin, D.E., B. Condon, M. Sohn, J.A. Foulk, R.B. Dodd and L.L. Rigsby, 2007. Optimization for enzyme-retting of flax with pectate lyase. Ind. Crops Prod., 25: 136-146.

Alberts, B., A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter, 2002. Molecular Biology of the Cell. 2nd Edn., Garland Science, New York.

Albinante, S.R., E.B.A.V. Pacheco, L.L.Y. Visconte, G. Platenik and L.N. Batista, 2014. Modification of Brazilian natural fibers from banana's tree to apply as fillers into polymers composites. Chem. Eng. Trans., 37: 715-720.

Alemdar, A. and M. Sain, 2008. solation and characterization of nanofibers from agricultural residues-Wheat straw and soy hulls. Bioresour. Technol., 99: 1664-1671.

Alves, C., P.M.C. Ferrao, M. Freitas, A.J. Silva, S.M. Luz and D.E. Alves, 2009. Sustainable design procedure: The role of composite materials to combine mechanical and environmental features for agricultural machines. Mater. Design, 30: 4060-4068.

Alwani, M.S., H.P.S. Abdul Khalil, M.N. Islam, O. Sulaiman, A. Zaidon and R. Dungani, 2015. Microstructural study, tensile properties, and scanning electron microscopy fractography failure analysis of various agricultural residue fibers. J. Nat. Fibers, 12: 154-168.

Anigo, K.M., B.M.D. Dauda, A.B. Sallau and I.E. Chindo, 2013. Chemical composition of kapok (*Ceibapentandra*) seed and physicochemical properties of its oil. Niger. J. Basic Applied Sci., 21: 105-108.

Araki, J., M. Wada and S. Kuga, 2001. Steric stabilization of a cellulose microcrystal suspension by poly (ethylene glycol) grafting. Langmuir, 17: 21-27.

Arami-Niya, A., W.M.A.W. Daud and F.S. Mjalli, 2010. Using granular activated carbon prepared from oil palm shell by $ZnCl_2$ and physical activation for methane adsorption. J. Anal. Applied Pyrolys., 89: 197-203.

Azwa, Z.N., B.F. Yousif, A.C. Manalo and W. Karunasena, 2013. A review on the degradability of polymeric composites based on natural fibres. Mater. Des., 47: 424-442.

Bakar, E.S., O. Rachman, W. Darmawan and I. Hidayat, 1999. Utilization of oil-palm trees as building and furniture material (II): Mechanical properties of oil-palm wood. J. For. Prod. Technol., 12: 10-20.

Banik, S., M.K. Basak, D. Paul, P. Nayak and D. Sardar *et al*., 2003. Ribbon retting of jute-a prospective and eco-friendly method for improvement of fibre quality. Ind. Crops Prod., 17: 183-190.

Batra, S.K., 1985. Other Long Vegetable Fibers. In: Handbook of Fiber Science and Technology, Dekker, M. (Ed.). Academic Press, San Diego, CA., pp: 727-808.

Bismarck, A., I. Aranberri-Aranberri, J. Spronger, T. Lampke and B. Wielage *et al*., 2002. Surface characterization of flax, hemp and cellulose fibers; Surface properties and the water uptake behavior. Polym. Compos., 23: 872-894.

Bledzki, A.K. and J. Gassan, 1999. Composites reinforced with cellulose based fibres. Prog. Polym. Sci., 24: 221-274.

Bledzki, A.K., O. Faruk and V.E. Sperber, 2006. Cars from bio-Fibres. Macromol. Mater. Eng., 291: 449-457.

Bongarde, U.S. and V.D. Shinde, 2014. Review on natural fiber reinforcement polymer composites. Int. J. Eng. Sci. Innovat. Technol., 3: 431-436.

Bouasker, M., N. Belayachi, D. Hoxha and M. Al-Mukhtar, 2014. Physical characterization of natural straw fibers as aggregates for construction materials applications. Materials, 7: 3034-3048.

Brinchi, L., F. Cotana, E. Fortunati and J.M. Kenny, 2013. Production of nanocrystalline cellulose from lignocellulosic biomass: Technology and applications. Carbohydr. Polym., 94: 154-169.

Chaiarrekij, S., A. Apirakchaiskul, K. Suvarnakich and S. Kiatkamjornwong, 2011. Kapok I: Characteristcs of kapok fiber as a potential pulp source for papermaking. BioResources, 7: 475-488.

Chakraborty, A., M. Sain and M. Kortschot, 2005. Cellulose microfibrils: A novel method of preparation using high shear refining and cryocrushing. Holzforschung, 59: 102-107.

Chen, W., H. Yu, Y. Liu, P. Chen, M. Zhang and Y. Hai, 2011. Individualization of cellulose nanofibers from wood using high-intensity ultrasonication combined with chemical pretreatments. Carbohydr. Polym., 83: 1804-1811.

Chen, D., D. Lawton, M.R. Thompson and Q. Liu, 2012. Biocomposites reinforced with cellulose nanocrystals derived from potato peel waste. Carbohydr. Polym., 90: 709-716.

Cheng, Q., S. Wang and T.G. Rials, 2009. Poly(vinyl alcohol) nanocomposites reinforced with cellulose fibrils isolated by high intensity ultrasonication. Compos. Part A: Applied Sci. Manuf., 40: 218-224.

Cheng, Q., S. Wang and Q. Han, 2010. Novel process for isolating fibrils from cellulose fibers by high-intensity ultrasonication. II. Fibril characterization. J. Applied Polymer Sci., 115: 2756-2762.

Cristaldi, G., A. Latteri, G. Recca and G. Cicala, 2010. Composites based on Natural Fibre Fabrics. In: Woven Fabric Engineering, Dubrovski, P.D. (Ed.). Chapter 17, InTech Publ., Rijeka, Croatia, ISBN 978-953-307-194-7, pp: 317-342.

Del Rio, J.C. and A. Gutierrez, 2006. Chemical composition of abaca (*Musa textilis*) leaf fibers used for manufacturing of high quality paper pulps. J. Agric. Food Chem., 54: 4600-4610.

Dittenber, D.B. and H.V.S. GangaRao, 2012. Critical review of recent publications on use of natural composites in infrastructure. Compos. Part A: Applied Sci. Manuf., 43: 1419-1429.

Domke, P.V., 2012. Improvement in the strength of concrete by using industrial and agricultural waste. IOSR J. Eng., 2: 755-759.

Doree, C., 1947. The Methods of Cellulose Chemistry: Including Methods for the Investigation of Substances Associated with Cellulose in Plant Tissues. 2nd Edn., Van Nostrand Co., New York, Pages: 543.

Driemeier, C., W.D. Santos and M.S. Buckeridge, 2012. Cellulose crystals in fibrovascular bundles of sugarcane culms: Orientation, size, distortion and variability. Cellulose, 19: 1507-1515.

Dungani, R., H.P.S. Abdul Khalil, I. Sumardi, Y. Suhaya and E. Sulistyawati *et al*., 2014. Non-Wood Renewable Materials: Properties Improvement and its Application. In: Biomass and Bioenergy: Applications, Hakeem, K.R., M. Jawaid and U. Rashid (Eds.). Chapter 1, Springer, USA., ISBN: 978-3-319-07577-8, pp: 1-29.

FAO., 2014. Statistic of crop production in the world. Food and Agriculture Organization, Rome.

Fahma, F., S. Iwamoto, N. Hori, T. Iwata and A. Takemura, 2010. Isolation, preparation and characterization of nanofibers from Oil Palm Empty-Fruit-Bunch (OPEFB). Cellulose, 17: 977-985.

Fatah, I.Y.A., H.P.S. Abdul Khalil, M.S. Hossain, A.A. Aziz, Y. Davoudpour, R. Dungani and A. Bhat, 2014. Exploration of a chemo-mechanical technique for the isolation of nanofibrillated cellulosic fiber from oil palm empty fruit bunch as a reinforcing agent in composites materials. Polymers, 6: 2611-2624.

Favaro, S.L., T.A. Ganzerli, A.G.V. de Carvalho Neto, O.R.R.F. da Silva and E. Radovanovic, 2010. Chemical, morphological and mechanical analysis of sisal fiber-reinforced recycled high-density polyethylene composites. eXPRESS Polymer Lett., 4: 465-473.

Ferrer, A., I. Filpponen, A. Rodriguez, J. Laine and O.J. Rojas, 2012. Valorization of residual Empty Palm Fruit Bunch Fibers (EPFBF) by microfluidization: Production of nanofibrillated cellulose and EPFBF nanopaper. Bioresour. Technol., 125: 249-255.

Francois, V., 2013. Lineo-flax fibres impregnation. http://www.lineo.eu/.

Gassan, J., A. Chate and A.K. Bledzki, 2001. Calculation of elastic properties of natural fibers. J. Mater. Sci., 36: 3715-3720.

Giri, J. and R. Adhikari, 2013. A brief review on extraction of nanocellulose and its application. BIBECHANA, 9: 81-87.

Gonzalez-Garcia, S., G. Feijoo, C. Heathcote, A. Kandelbauer and M.T. Moreira, 2011. Environmental assessment of green hardboard production coupled with a laccase activated system. J. Cleaner Prod., 19: 445-453.

Goodman, A.M., A.R. Ennos and I. Booth, 2002. A mechanical study of retting in glyphosate treated flax stems (*Linum usitatissimum*). Ind. Crops Prod., 15: 169-177.

Hassan, M.L., A.P. Mathew, E.A. Hassan, N.A. El-Wakil and K. Oksman, 2012. Nanofibers from bagasse and rice straw: Process optimization and properties. Wood Sci. Technol., 46: 193-205.

Hemmasi, A.H., A. Samariha, A. Tabei, M. Nemati and A. Khakifirooz, 2011. Study of morphological and chemical composition of fibers from Iranian sugarcane bagasse. Am.-Eurasian J. Agric. Environ. Sci., 11: 478-481.

Hermawan, D., B. Subiyanto and S. Kawai, 2001. Manufacture and properties of oil palm frond cement-bonded board. J. Wood Sci., 47: 208-213.

Hermawan, D., T. Hata, S. Kawai, W. Nagadomi and Y. Kuroki, 2002. Manufacturing oil palm fronds cement-bonded board cured by gaseous or supercritical carbon dioxide. J. Wood Sci., 48: 20-24.

Hirvikorpi, T., M. Vaha-Nissi, J. Nikkola, A. Harlin and M. Karppinen, 2011. Thin Al_2O_3 barrier coatings onto temperature-sensitive packaging materials by atomic layer deposition. Surf. Coatings Technol., 205: 5088-5092.

Holbery, J. and D. Houston, 2006. Natural-fiber-reinforced polymer composites in automotive applications. J. Miner. Met. Mater. Soc., 58: 80-86.

Hsu, S.H. and Y.C. Kao, 2005. Biocompatibility of poly(carbonate urethane)s with various degrees of nanophase separation. Macromol. Biosci., 5: 246-253.

Huang, Z.M., Y.Z. Zhang, M. Kotaki and S. Ramakrishna, 2003. A review on polymer nanofibers by electrospinning and their applications in nanocomposites. Compos. Sci. Technol., 63: 2223-2253.

Huang, X. and T.T. Lim, 2006. Performance and mechanism of a hydrophobic-oleophilic kapok filter for oil/water separation. Desalination, 190: 295-307.

Huang, Y.H., B.H. Fei, Y. Yu and R.J. Zhao, 2012. Plant age effect on mechanical properties of MOSO bamboo (*Phyllostachys heterocycla* var. *Pubescens*) single fibers. Wood Fiber Sci., 44: 196-201.

Ikpambese, K.K., D.T. Gundu and L.T. Tuleun, 2016. Evaluation of Palm Kernel Fibers (PKFs) for production of asbestos-free automotive brake pads. J. King Saud Univ.-Eng. Sci., 28: 110-118.

Izani, M.A.N., M.T. Paridah, A.A. Astimar, M.Y.M. Nor and U.M.K. Anwar, 2012. Mechanical and dimensional stability properties of medium-density fibreboard produced from treated oil palm empty fruit bunch. J. Applied Sci., 12: 561-567.

Jahan, M.S., A. Saeed, Z.B. He and Y.H. Ni, 2011. Jute as raw material for the preparation of microcrystalline cellulose. Cellulose, 18: 451-459.

Jawaid, M. and H.P.S. Abdul Khalil, 2011. Effect of layering pattern on the dynamic mechanical properties and thermal degradation of oil palm-jute fibers reinforced epoxy hybrid composite. BioResources, 6: 2309-2322.

Johansson, C., J. Bras, I. Mondragon, P. Nechita and D. Plackett *et al*., 2012. Renewable fibers and bio-based materials for packaging applications-a review of recent developments. BioResources, 7: 2506-2552.

Johar, N., I. Ahmad and A. Dufresne, 2012. Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. Ind. Crops Prod., 37: 93-99.

John, M.J. and S. Thomas, 2008. Biofibres and biocomposites. Carbohydr. Polym., 71: 343-364.

Jonoobi, M., K.O. Niska, J. Harun and M. Misra, 2009. Chemical composition, crystallinity and thermal degradation of bleached and unbleached kenaf bast (*Hibiscus cannabinus*) pulp and nanofibers. BioResources, 4: 626-639.

Jonoobi, M., A. Khazaeian, P.M. Tahir, S.S. Azry and K. Oksman, 2011. Characteristics of cellulose nanofibers isolated from rubberwood and empty fruit bunches of oil palm using chemo-mechanical process. Cellulose, 18: 1085-1095.

Joshi, S.V., L.T. Drzal, A.K. Mohanty and S. Arora, 2004. Are natural fiber composites environmentally superior to glass fiber reinforced composites? Compos. Part A: Applied Sci. Manuf., 35: 371-376.

Kalia, S., B.S. Kaith and I. Kaur, 2009. Pretreatments of natural fibers and their application as reinforcing material in polymer composites-a review. Polym. Eng. Sci., 49: 1253-1272.

Kalia, S., A. Dufresne, B.M. Cherian, B.S. Kaith, L. Averous, J. Njuguna and E. Nassiopoulos, 2011a. Cellulose-based bio- and nanocomposites: A review. Int. J. Polym. Sci. 10.1155/2011/837875

Kalia, S., B.S. Kaith and I. Kaur, 2011b. Cellulose Fibers: Bio- and Nano-Polymer Composites: Green Chemistry and Technology. Springer-Verlag, Berlin, Germany, ISBN-13: 9783642173707, Pages: 738.

Kalia, S., S. Vashistha and B.S. Kaith, 2011c. Cellulose Nanofibers Reinforced Bioplastics and their Applications. In: Handbook of Bioplastics and Biocomposites Engineering Applications, Pilla, S. (Ed.). John Wiley and Sons, New York, USA., pp: 342-361.

Karande, V.S., A.K. Bharimalla, G.B. Hadge, S.T. Mhaske and N. Vigneshwaran, 2011. Nanofibrillation of cotton fibers by disc refiner and its characterization. Fibers Polym., 12: 399-404.

Karim, M.S., H.P. Seal, M.A. Rouf, M.I. Rahman, M.H.R. Talukder and P.G. Karmaker, 2010. Acetic acid pulp from jute stick, rice-straw and bagasse. J. Agrofor. Environ., 3: 171-174.

Kopania, E., J. Wietecha and D. Ciechanska, 2012. Studies on isolation of cellulose fibres from waste plant biomass. Fibres Textiles Eastern Eur., 20: 167-172.

Leao, A.L., S.M. Sartor and J.C. Caraschi, 2006. Natural fibers based composites-technical and social issues. Mol. Cryst. Liquid Cryst., 448: 161-177.

Lee, S., 2010. An overview of advanced composite materials and their industrial applications. Federation of Hong Kong Industries, Hong Kong, March 12, 2010.

Leitner, J., B. Hinterstoisser, M. Wastyn, J. Keckes and W. Gindl, 2007. Sugar beet cellulose nanofibril-reinforced composites. Cellulose, 14: 419-425.

Li, W., R. Wang and S.X. Liu, 2011. Nanocrystalline cellulose prepared from softwood kraft pulp via ultrasonic-assisted acid hydrolysis. BioResources, 6: 4271-4281.

Li, X., L.G. Tabil and S. Panigrahi, 2007. Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A Review. J. Polym. Environ., 15: 25-33.

Lina, F., Z. Yue, Z. Jin and Y. Guang, 2011. Bacterial Cellulose for Skin Repair Materials. In: Biomedical Engineering-Frontiers and Challenges, Fazel-Rezai, R. (Ed.). Chapter 13, InTech Publ., Rijeka, Croatia, ISBN-13: 978-953-307-309-5, pp: 213-294.

Liu, H., D. Liu, F. yao and Q. Wu, 2010. Fabrication and properties of transparent polymethylmethacrylate/cellulose nanocrystals composites. Bioresour. Technol., 101: 5685-5692.

Lu, J.Z., Q.L. Wu, I.I. Negulescu and Y. Chen, 2006. The influences of fiber feature and polymer melt index on mechanical properties of sugarcane fiber/polymer composites. Applied Polym. Sci., 102: 5607-5619.

Lu, S.S., X.B. Huang and J.H. Chen, 1999. Study on anaerobic microbe retting of kenaf in China. J. China Textiles Univ., 25: 107-110.

Macocinschi, D., D. Filip, S. Vlad, M. Cristea, V. Musteata and S. Ibanescu, 2012. Thermal, dynamic mechanical, and dielectric analyses of some polyurethane biocomposites. J. Biomater. Applic., 27: 119-129.

Majeed, K., M. Jawaid, A. Hassan, A.A. Bakar, H.P.S. Abdul Khalil, A.A. Salema and I. Inuwa, 2013. Potential materials for food packaging from nanoclay/natural fibres filled hybrid composites. Mater. Des., 46: 391-410.

Methacanon, P., U. Weerawatsophon, N. Sumransin, C. Prahsarn and D.T. Bergado, 2010. Properties and potential application of the selected natural fibers as limited life geotextiles. Carbohydr. Polym., 82: 1090-1096.

Millon, L.E., H. Mohammadi and W.K. Wan, 2006. Anisotropic polyvinyl alcohol hydrogel for cardiovascular applications. J. Biomed. Mater. Res. Part B Applied Biomater., 79B: 305-311.

Mishra, S.P., A.S. Manent, B. Chabot and C. Daneault, 2012. The use of sodium chlorite in post-oxidation of TEMPO-oxidized pulp: Effect on pulp characteristics and nanocellulose yield. J. Wood Chem. Technol., 32: 137-148.

Mojica, E.R.E., F.E. Merca and J.R.L. Micor, 2002. Fiber of kapok (*Ceiba pentandra*) as component of a metal sensor for lead in water samples. Philippine J. Crop Sci., 27: 37-42.

Monteiro, S.N., F.P.D. Lopes, A.P. Barbosa, A.B. Bevitori, I.L.A. da Silva and L. da Costa, 2011. Natural lignocellulosic fibers as engineering materials-An overview. Metall. Mater. Trans. A, 42: 2963-2974.

Munawar, S.S., K. Umemura and S. Kawai, 2007. Characterization of the morphological, physical and mechanical properties of seven nonwood plant fiber bundles. J. Wood Sci., 53: 108-113.

Musteata, V.E., D. Filip, S. Vlad and D. Macocinschi, 2010. Dielectric relaxation of polyurethane biocomposites. Optoelectron. Adv. Mater.-Rapid Commun., 4: 1187-1192.

Mwaikambo, L.Y. and M.P. Ansell, 2001. The determination of porosity and cellulose content of plant fibers by density methods. J. Mater. Sci. Lett., 20: 2095-2096.

Mwaikambo, L.Y., 2009. Tensile properties of alkalised jute fibres. BioResources, 4: 566-588.

Nakagaito, A.N. and H. Yano, 2004. The effect of morphological changes from pulp fiber towards nano-scale fibrillated cellulose on the mechanical properties of high-strength plant fiber based composites. Applied Phys. A, 78: 547-552.

Namvar, F., M. Jawaid, P.M. Tanir, R. Mohamad and S. Azizi *et al*., 2014. Potential use of plant fibres and their composites for biomedical applications. BioResources, 9: 5688-5706.

Nazir, M.S., B.A. Wahjoedi, A.W. Yussof and M.A. Abdullah, 2013. Eco-friendly extraction and characterization of cellulose from oil palm empty fruit bunches. BioResources, 8: 2161-2172.

Nguong, C.W., S.N.B. Lee and D. Sujan, 2013. A review on natural fibre reinforced polymer composites. Int. J. Chem. Mol. Nuclear Mater. Metall. Eng., 7: 52-59.

Norashikin, M.Z. and M.Z. Ibrahim, 2009. The potential of natural waste (corn husk) for production of environmental friendly biodegradable film for seedling. World Acad. Sci. Eng. Technol., 3: 1808-1812.

Ogah, A.O., J.N. Afiukwa and A.A. Nduji, 2014. Characterization and comparison of rheological properties of agro fiber filled high-density polyethylene bio-composites. Open J. Polym. Chem., 4: 12-19.

Osorio, L., E. Trujillo, A.W. van Vuure, F. Lens, J. Ivens and I. Verpoest, 2010. The relationship between the bamboo fibre microstructure and mechanical properties. Proceedings of the 14th European Conference on Composite Materials, June 7-10, 2010, Budapest, Hungary, pp: 467-473.

Pan, M., X. Zhou and M. Chen, 2013. Cellulose nanowhiskers isolation and properties from acid hydrolysis combined with high pressure homogenization. BioResources, 8: 933-943.

Pardo, M.E.S., M.E.R. Cassellis, R.M. Escobedo and E.J. Garcia, 2014. Chemical characterisation of the industrial residues of the pineapple (*Ananas comosus*). J. Agric. Chem. Environ., 3: 53-56.

Paridah, M. and A. Khalina, 2009. Effects of soda retting on the tensile strength of kenaf (*Hibiscus cannobnius* L.) bast fibres. Project Report Kenaf EPU, pp: 21.

Pickering, K.L., 2008. Properties and Performance of Natural-Fibre Composites. Woodhead Publishing Ltd., Cambridge, UK.

Preethi, P. and G.B. Murthy, 2013. Physical and chemical properties of banana fibre extracted from commercial banana cultivars grown in tamilnadu state. Agrotechnol, 10.4172/2168-9881.S11-008

Qing, Y., R. Sabo, Y. Wu and Z. Cai, 2012. High-performance cellulose nanofibril composite films. BioResources, 7: 3064-3075.

Qua, E.H., P.R. Hornsby, H.S.S. Sharma and G. Lyons, 2011. Preparation and characterisation of cellulose nanofibres. J. Mater. Sci., 46: 6029-6045.

Reddy, N. and Y. Yang, 2005. Biofibers from agricultural byproducts for industrial applications. Trends Biotechnol., 23: 22-27.

Reddy, N. and Y. Yang, 2006. Properties of high-quality long natural cellulose fibers from rice straw. J. Agric. Food Chem., 54: 8077-8081.

Rodriguez, M., A. Rodriguez, R.J. Bayer, F. Vilaseca, J. Girones and P. Mutje, 2010. Determination of corn stalk fibers' strength through modeling of the mechanical properties of its composites. BioResources, 5: 2535-2546.

Rowell, R.M., J.S. Han and J.S. Rowell, 2000. Characterization and Factors Effecting Fiber Properties. In: Natural Polymers and Agrofibers Composites, Frollini, E., A.L. Leao and L.H.C. Mattoso (Eds.). San Carlos, Brazil, ISBN-13:9788586463068, pp: 115-134.

Saheb, D.N. and J.P. Jog, 1999. Natural fiber polymer composites: A review. Adv. Polym. Technol., 18: 351-363.

Sakthivel, M. and S. Ramesh, 2013. Mechanical properties of natural fiber (banana, coir, sisal) polymer composites. Sci. Park, 1: 1-6.

Sapuan, S.M., M. Harimi and M.A. Maleque, 2003. Mechanical properties of epoxy/coconut shell filler particle composites. Arab. J. Sci. Eng., 28: 171-181.

Satyanarayana, K.G., G.G.C. Arizaga and F. Wypych, 2009. Biodegradable composites based on lignocellulosic fibers-An overview. Progr. Polym. Sci., 34: 982-1021.

Setyanto, R.H., K. Diharjo, P. Setyono and I.M. Miasa, 2013. A preliminary study: The influence of alkali treatment on physical and mechanical properties of coir fiber. J. Mater. Sci. Res., 2: 80-88.

Shibata, M., K.I. Takachiyo, K. Ozawa, R. Yosomiya and H. Takeishi, 2002. Biodegradable polyester composites reinforced with short abaca fiber. J. Applied Polym. Sci., 85: 129-138.

Shibata, M., K. Ozawa, N. Teramoto, R. Yosomiya and H. Takeishi, 2003. Biocomposites made from short abaca fiber and biodegradable polyesters. Macromol. Mater. Eng., 288: 35-43.

Siddiqui, N., R.H. Mills, D.J. Gardner and D. Bousfield, 2011. Production and characterization of cellulose nanofibers from wood pulp. J. Adhesion Sci. Technol., 25: 709-721.

Singh, B. and M. Gupta, 2005. Natural Fiber Composites for Building Applications. In: Natural Fibers, Biopolymers and Biocomposites, Mohanty, A.K., M. Misra and L.T. Drzal (Eds.). CRC Press, USA., ISBN: 9780849317415, pp: 261-287.

Singh S., A.K. Mohanty, T. Sugie, Y. Takai and H. Hamada, 2008. Renewable resource based biocomposites from natural fiber and polyhydroxybutyrate-co-valerate (PHBV) bioplastic. Compos. Part A: Applied Sci. Manuf., 39: 875-886.

Siqueira, G., J. Bras and A. Dufresne, 2009. New process of chemical grafting of cellulose nanoparticles with a long chain isocyanate. Langmuir, 26: 402-411.

Siro, I. and D. Plackett, 2010. Microfibrillated cellulose and new nanocomposite materials: A review. Cellulose, 17: 459-494.

Soiela, M., A. Ilves, A. Viikna and E. Erberg, 2005. Properties of flax fiber-reinforced polyethylene films. Chemine Technologija, 36: 38-45.

Stelte, W. and A.R. Sanadi, 2009. Preparation and characterization of cellulose nanofibers from two commercial hardwood and softwood pulps. Ind. Eng. Chem. Res., 48: 11211-11219.

Steve, A.K. and K.E.D. Sumanasiri, 2011. Development of natural fiber composite in Papua New Guinea (PNG). Innov. Technol. Transfer, 2: 123-129.

Suddell, B.C. and W.J. Evans, 2005. Natural Fiber Composites in Automotive Applications. In: Natural Fibers, Biopolymers and Biocomposites, Mohanty, A.K., M. Misra and L.T. Drzal (Eds.). CRC Press, USA., ISBN: 9780849317415, pp: 231-259.

Sumaila, M., I. Amber and M. Bawa, 2013. Effect of fiber length on the physical and mechanical properties of random oreinted, nonwoven short banana (*Musa balbisiana*) fibre/epoxy composite. Asian J. Nat. Applied Sci., 2: 39-49.

Thiruchitrambalam, M., A. Alavudeen, A. Athijayamani, N. Venkateshwaran and A.E. Perumal, 2009. Improving mechanical properties of banana/kenaf polyester hybrid composites using sodium laulryl sulfate treatment. Mater. Phys. Mech., 8: 165-173.

Thiruchitrambalam, M., A. Alavudeen and N. Venkateshwaran, 2012. Review on kenaf fiber composites. Rev. Adv. Mater. Sci., 32: 106-112.

Thomas, S., S.A. Paul, L.A. Pothan and B. Deepa, 2011. Natural Fibres: Structure, Properties and Applications. In: Cellulose Fibers: Bio-and Nano-Polymer Composites, Kalia, S., B.S. Kaith and I. Kaur (Eds.). Springer, Berlin, Heidelberg, ISBN: 978-3-642-17369-1, pp: 3-42.

Thygesen, A., A.B. Thomsen, G. Daniel and H. Lilholt, 2007. Comparison of composites made from fungal defibrated hemp with composites of traditional hemp yarn. Ind. Crops Prod., 25: 147-159.

Vallejos, M.E., M.S. Peresin and O.J. Rojas, 2012. All-cellulose composite fibers obtained by electrospinning dispersions of cellulose acetate and cellulose nanocrystals. J. Polym. Environ., 20: 1075-1083.

Van de Velde, K. and P. Kiekens, 2001. Thermoplastic pultrusion of natural fibre reinforced composites. Compos. Struct., 54: 355-360.

Venkateshwaran, N., A. Elayaperumal and G.K. Sathiya, 2012. Prediction of tensile properties of hybrid-natural fiber composites. Compos. Part B: Eng., 43: 793-796.

Verma, D., P.C. Gope, M.K. Maheshwari and R.K. Sharma, 2012. Bagasse fiber composites-A review. J. Mater. Environ. Sci., 3: 1079-1092.

Ververis, C., K. Georghiou, N. Christodoulakis, P. Santas and R. Santas, 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. Ind. Crops Prod., 19: 245-254.

Vijayalakshmi, K., C.Y.K. Neeraja, A. Kavitha and J. Hayavadana, 2014. Abaca fibre. Trans. Eng. Sci., 2: 16-19.

Wahlang, B., K. Nath, U. Ravindra, R. Chandu and K. Vijayalaxmi, 2012. Processing and utilization of sugarcane bagasse for functional food formulations. Proceedings of the International Conference and Exhibition on Food Processing and Technology, September 22-24, 2012, Hyderabad, India, pp: 106-112.

Wambua, P., J. Ivens and I. Verpoest, 2003. Natural fibres: Can they replace glass in fibre reinforced plastics? Compos. Sci. Technol., 63: 1259-1264.

Wang, B. and M. Sain, 2007. Isolation of nanofibers from soybean source and their reinforcing capability on synthetic polymers. Compos. Sci. Technol., 67: 2521-2527.

Wang, Q.Q., J.Y. Zhu, R. Gleisner, T.A. Kuster, U. Baxa and S.E. McNeil, 2012. Morphological development of cellulose fibrils of a bleached eucalyptus pulp by mechanical fibrillation. Cellulose, 19: 1631-1643.

Yang, H.S., M.P. Wolcott, H.S. Kim, S. Kimand H.J. Kim, 2006. Properties of lignocellulosic material filled polypropylene bio-composites made with different manufacturing processes. Polym. Testing, 25: 668-676.

Yevich, R. and J.A. Logan, 2003. An assessment of biofuel use and burning of agricultural waste in the developing world. Global Biogeochem. Cycles, Vol. 17, No. 4. 10.1029/2002GB001952

Yuhazri, Y.M., H. Sihombing, A.R. Jeefferie, A.Z.A. Mujahid, A.G. Balamurugan, M.N. Norazman and A. Shohaimi, 2011. Optimization of coconut fibers toward heat insulator applications. Global Eng. Technol. Rev. 1: 35-40.

Yuliansyah, A.T., T. Hirajima and Rochmadi, 2009. Development of the Indonesian palm oil industry and utilization of solid waste. J. Mining Mater. Proc. Inst. Jpn., 125: 583-589.