SUGAR PALM: FIBERS, BIOPOLYMERS AND BIOCOMPOSITES

S.M. Sapuan[1,2*] and R.A. Ilyas[1]
[1]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia
[2]Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia,

Introduction

Synthetic fibers are dominantly used in the composites industry for the past several decades. However, the negative environmental and health effects associated with these fibers fueled the increasing usage of natural fibers as promising alternative. The escalating usage of natural fibers can be ascribed to their availability, affordability, processability, renewability, recyclability, biodegradability, specific tensile properties, less health hazards, acceptable insulating properties, low density and less energy consumption during processing over synthetic fibers (Sanyang et al., 2016). Natural fibers are classified depending on their origin either from plants, animals or minerals. However, natural fibers from plants are the most widely used reinforcement material in biocomposites. Plant fibers are subdivided based on the type of plants or parts of the plant the fibers were extracted included leaf, seed, stalk, fruit, grass fibers, and bast (Jawaid & Abdul Khalil, 2011). Malaysia has rich and vast untapped natural fiber resources available as potential alternative to synthetic fibers. These indigenous existing natural fibers range from kenaf, coconut trunk fibers, sugar palm fibers, sugarcane, sago, pineapple leaf, cocoa pod husk to oil palm fruit bunches oil palm fronds, oil palm trunks and many others. This article attempts to explore potential uses of one of the natural fibers namely sugar palm and its fiber composites to further develop sugar palm trees as a new crop in the near future.

Sugar Palm

Sugar palm (Figure 1.) belongs to the sub-family of Arecoideae and the tribe of Caryoteae (Dransfield & Uhl, 1986; Mogea et al., 1991). In 1917 during the International Congress of Botany in Vienna, it was officially named as Arenga pinnata. In Malaysia it is known as either enau or kabung. Sugar palm is a natural forest species that originates from the Palmae family. It is known as a fast growing palm that is able to reach maturity within 10 years (Mogea et al., 1991). It is a tall and large palm with a single unbranched stem which can grow up to 20 m high and 65 cm in diameter. Geographical distribution of sugar palm trees covers as wide as Asia to West Africa from Taiwan to the Philippines, Indonesia, Papua New Guinea, India, Thailand, Myanmar, Vietnam, North Australia, Malaysia, The Gambia, Senegal, Guinea Bissau and other West African countries (Ishak et al., 2013). Sugar palm is one of the most versatile palm species because almost all parts of the tree can be used, with at least 60 different products can be generated from a single sugar palm tree. This including palm neera, fresh juices, traditional sugar blocks, toddy, crystal and brown sugar, vinegar, bio-ethanol from sugar palm sap, edible hear from fruits, leaves for roofing, sea water resistant fiber, septic tank base filter, door mats, brooms, matting, baskets, cigarette papers, rope, chair/sofa cushion, cattle feeds from fiber and its starch inside the stem can be processed to make biopolymer (Ishak et al., 2013; Ilyas et al., 2016; Sanyang et al., 2016).

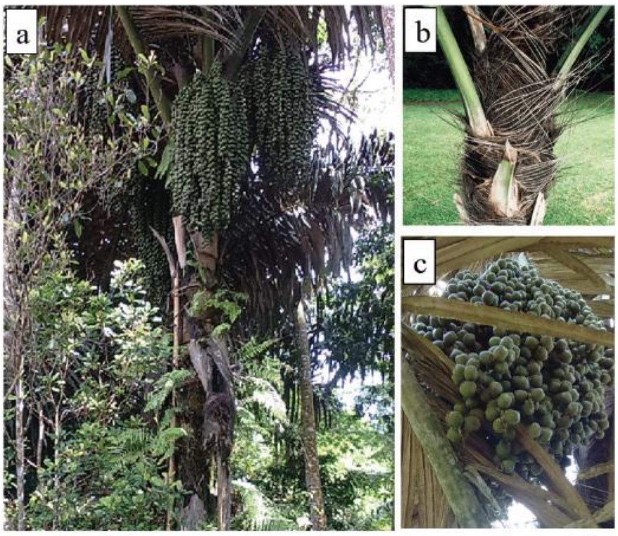

Figure 1. (a) Sugar palm tree (Arenga pinnata (Wurmb) Merr.), (b) sugar palm fiber, and (c) sugar palm fruit

Sugar Palm Fibers

Sugar palm starch (SPS) accumulates in the core of the stem of the sugar palm. Not all sugar palm trees yield sugar rich sap from the flower bunches. The non-productive palms can sometimes sum up to half the trees in a plantation. Starch is normally harvested from these unproductive trees following similar procedures as in the production of sago starch. The starch is extracted from the trunk of the sugar palm tree. It was reported that one sugar palm tree can yield 50–100 kg of starch. In the SPS extraction process, the sugar palm tree is brought down just before the first bloom and the trunk is split lengthwise to remove the woody fiber mixed with the starch powder from the inner soft core of the sugar palm trunk. This is followed by the washing process, where water was gradually introduced into the fiber and starch mixture and thoroughly kneaded by hand. The mixture is filtered to allow the water to flow through the sieve with starch granules in suspension. The starch is granted enough time to settle at the bottom of the container and the water is later decanted. Thereafter, the white powdered starch is kept in an open air for a moment and later dried in an air circulating oven at 120 °C for 24 h. Sahari et al. (2013) investigated the properties of SPS to explore their potential as a novel alternative polymer. SPS registered superior Amylose (37.60%) when compared to other starches such as tapioca (17%), sago (24–27%), potato (20–25%), wheat (26–27%) and maize (26–28%).

Sugar Palm Starch/Fibers as Reinforcement for Polymer Composites

Utilization of natural fibers with polymer matrices is essential for the mitigation of ecosystem devastation and provides low cost polymeric reinforced composites. The introduction of sugar palm fibers into polymer matrices further helps to address environmental problems associated with land filling of non-biodegradable conventional composites. In the past decade, a number of articles were published on sugar palm fiber reinforced polymers composites. Table 1 shows summary investigations on sugar palm fiber reinforced polymers composites.

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Researcher	Form of Fiber	Matrix	Process
Januar (2005)	Long Fiber	Epoxy	Hand lay-up
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Ridzwan (2009)	Long Fiber	Unsaturated polyester	Hand lay-up
Sahari (2011)	Frond, Bunch Fiber	Unsaturated polyester	Cold press
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Bachtiar (2012)	Short Fiber	Polystyrene	Compression molding
Hatim (2013)	Long Fiber	Thermoset	Cold press
Sahari (2013)	Ash	Sugar palm starch	Compression molding
Sanyang (2015)	Cellulose Fiber	Sugar palm starch	Solution casting
Ilyas (2017)	Nanocellulose Fiber	Sugar palm starch	Solution casting

Fiber Applications

Sugar palm fibers are extremely durable, even in contact with seawater. They possess good resistance to seawater and thus, use for making shipping ropes. A 12 ft (length) hybrid composite boat that was fabricated from the combination of sugar palm and glass fiber with unsaturated polyester as the matrix. In addition, a safety helmet was also developed from epoxy reinforced with sugar palm fiber. It is water resistant and could absorb and withstand high impact. The helmet was referred to as Helmet-Ijuk Reinforced Composite (HIReC). Besides, this strong fiber can be manufactured into broom, brush and portable composite table. The figures below show some of the fiber application such as broom (Figure 2), rope (Figure 3), boat (Figure 4), fibers used in automotive anti-roll bar (Figure 5), brushes (Figure 6a and b), portable composite table (Figure 7) and Helmet-Ijuk Reinforced Composite (HIReC) helmet (Figure 8).

Figure 2: Broom (NBOS project)


Figure 3: Rope from sugar palm fiber resistance to seawater


Figure 4: Hybrid composite boat combination of sugar palm and glass fiber with unsaturated polyester


Figure 5: Hybrid glass/sugar palm fiber reinforced polyurethane composite used in automotive anti-roll bar

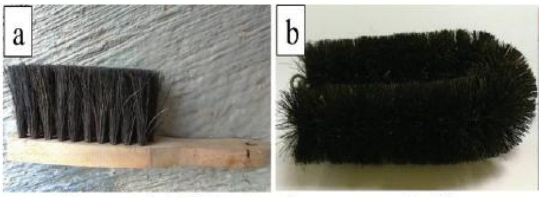

Figure 6: (a) (b) Brushes from sugar palm fibers

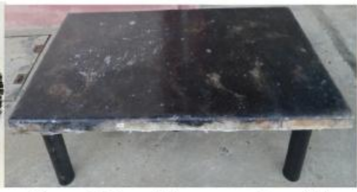
Figure 7: Portable composite table


Figure 8: Helmet-Ijuk Reinforced Composite (HIReC) (Credited to Dato' Ahmad Mujahid Mohd Zaidi, Universiti Pertahanan Nasional Malaysia)

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The most readily recognisable characteristics of Eucalyptus species are the distractive flowers and fruit (capsules or "gumnuts"). Flowers have numerous fluffy stamens which may be white, cream, yellow, pink, or red; in bud, the stamens are enclosed in a cap known as an operculum which is composed of the fused sepals or petals or both. Thus, flowers have no petals, but instead decorate themselves with the many showy stamens (Refer to Figure 2 for the Eucalyptus structure). As the stamens expand, the operculum is forced off, splitting away from the cup-like base of the flower; this is one of the features that unite the genus. The name Eucalyptus, from the Greek words eu-well and *kaluptos*-cover, meaning "well-covered", describes the operculum. The woody fruits or capsules are roughly cone-shaped and have valves at the end which open to release the seeds, which are waxy, rod-shaped, about 1 mm in length, and yellow-brown in colour. Most species do not flower until adult foliage starts to appear; *E. cinerea* and *E. perriniana* are notable exceptions. Figure 3 shows the structure of the Eucalyptus fruits (Australian National Botanic Gardens, 2016).

Figure 2. Flowers of Eucalyptus
(Source: Australian National Botanic Gardens, 2006)

Figure 3: Fruits of Eucalyptus
(Source: Australian National Botanic Gardens, 2006)

The appearance of Eucalyptus bark varies with the age of the plant, the length of the bark fibres, the degree of furrowing, the thickness, the hardness and the colour. All mature Eucalyptus put on an annual layer of bark, which contributes to the increasing diameter of the stems. In some species, the outermost layer dies and is annually deciduous either in long strips (as in E. sheathiana) or in variably sized flakes *(E. diversicolor, E. cosmophylla or E. cladocalyx)*. These are the gums or smooth-barked species. The gum bark may be dull, shiny or satiny (as in E. ornata) or matte *(E. cosmophylla)*. In many species, the dead bark is retained. The outermost layer gradually fragments with weathering and sheds without altering the essentially rough-barked nature of the trunks or stems-for example *E. marginata, E. jacksonni, E. oblique and E. porosa.* Furthermore, many species are 'half-barks' or 'blackbutts' in which the dead bark is retained in the lower half of the trunks or stems – such as E. brachycalyx, *E. orhrophloia and E. occidentalis* – or only in a thick, black accumulation at the base as in *E. clelandii.*

In some species in this category for example *E. youngiana* and *E. viminalis* the rough basal bark is very ribbony at the top, where it gives way to smooth upper stems. The smooth upper bark of the half-barks and that of the completely smooth-barked trees and malless can produce remarkable colour and interest for instance *E. deglupta*. Figure 4 shows the structure of the Eucalyptus bark.

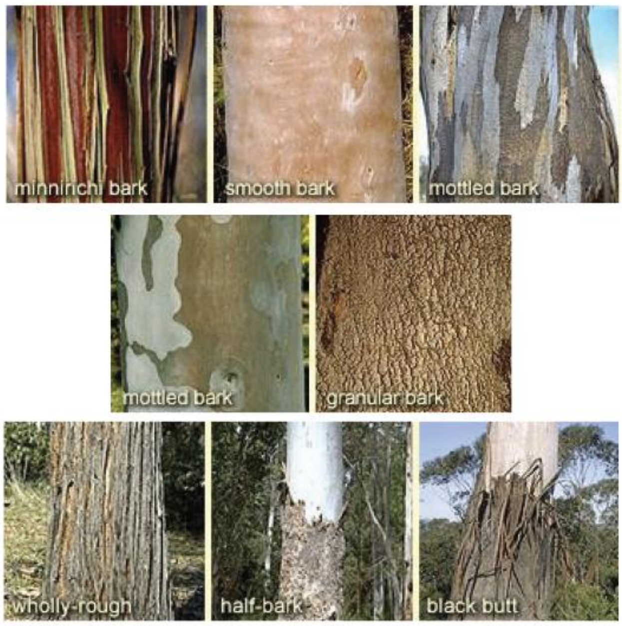

Figure 4: Bark of Eucalyptus
(Source: Australian National Botanic Gardens, 2006)

Eucalyptus plantations started in Australia in the 1980's to service the Eucalyptus oil industry. Due to its success, other countries such as Indonesia, China and the United States have initiated Eucalyptus growing programs. Nowadays, Eucalyptus tree plantations are valuable for timber, oil and biomass. Eucalyptus is currently present in over 90 countries and is spread over more than 22 million hectares worldwide, although only 13 million hectares have a productivity of interest from the industrial standpoint (Zalesny *et al.* 2011).

Eucalyptus began to be used in plantations outside its natural distribution area (Australia), over 200 years ago in Europe. In the United States, it was introduced in the mid-nineteenth century as a result of the migratory flow with New Zealand and Australia. Eucalyptus reached South Africa and Brazil in the late nineteenth century and in the early twentieth century. In South Africa, it was prompted by the demand for wood, needed for mining activities; in Brazil to produce the coal used in the steel industry.

Forest plantation is not a new concept and practice in Malaysia. Rubberwood and Acacia spp. are the two major species of the nine-selected species, other additional fast growing timber species promoted including *Tectona grandis, Azadirachta excelsa, Khaya spp., Neolamarckia cadamba, Falcataria moluccana, Octomeles sumatrana and Bamboo spp*. Recently Eucalyptus species has attracted the attention of the industry players particularly the plywood manufacturers, and investors in Malaysia.

Earlier attempts to plant Eucalyptus in Malaysia were in lowland area with 40 ha of Eucalyptus plantation as trial plots in 1931-1941 mainly with *Eucalyptus robusta*. In Sabah, a total of 7,000 ha were planted with *Eucalyptus deglupta* by Sabah Softwood Sdn. Bhd. and another 620 ha planted with *Eucalyptus grandis, E. urophylla, E. globulus and E. camaldulensis* by Sabah Forest Industries Sdn. Bhd. in 1991. Seeds from Australia, New Guinea, Indonesia and Sri Lanka have been used for plantations in Malaysia. Seeds from some of the older plantations have also been collected for further small scale plantation programmes (Appanah & Weinland, 1993). Most of the land used for plantation was logged-over forest, wasteland - consisting of mainly lalang grassland *(Imperata cylindrica)* and non-commercial secondary forests. These lands have been classified as 'not suitable' to 'marginally suitable' for agricultural use.

Forest plantations have been expanding yearly. In 2014, a total of 127,849 ha of forest plantation area in Peninsular Malaysia. However, in 2016, the number dropped to 113,503.99 ha. Table 3 shows forest plantation area in Sarawak while Table 4 shows in Sabah.

Table 1: Forest Plantation Area (ha) in Peninsular Malaysia by Species, 2008-2014

Year	2008	2009	2010	2011	2012	2013	2014
Acacia	55,503	59,486	74,438	28,978	41,989	46,126	34,258
Teak	2,698	2,709	2,709	2,901	2,847	2,847	2,847
Pine	2,667	2,667	716	374	374	374	374
Rubberwood	17,544	21,936	22,401	21,930	34,877	40,372	71,094
Azadiratha excelsa	281	281	281	881	868	868	875
Others	22,376	21,673	8,112	6,521	6,489	7,209	18,401
Total	101,069	108,752	108,657	61,585	87,444	97,796	127,849

Source: Forestry Department of Peninsular Malaysia (2015)

Table 2: Forest Plantation Development Area (ha) in Peninsular Malaysia, 2016

State	Forest Plantation area (ha)
Johor	36,212.88
Kedah	3,900.00
Kelantan	33,820.42
Melaka	-
Negeri Sembilan	1,197.38
Pahang	20,542.76
Perak	2,870.55
Perlis	671.00
Pulau Pinang	-
Selangor	11,381.00
Terengganu	2,908.00
Wilayah Persekutuan	-
Total	113,503.99

Source: Forestry Department of Peninsular Malaysia (2017)

Table 3: Forest Plantation Area (ha) in Sarawak by Species, 2008-2015

Major species planted	2008	2009	2010	2011	2012	2013	2014	2015
Acacia	168,517.48	192,339.02	193,047.02	214,180.82	221,089.08	227,635.49	236,936.24	239,748.50
Neolamarkia	30.90	17,442.51	17,442.51	18,849.47	19,913.04	20,420.96	21,762.02	21,951.24
Paraserianthes	16,254.00	22,603.17	22,603.17	29,993.04	38,104.34	42,546.60	48,485.62	51,625.56
Eucalyptus	**12,998.76**	**17,137.31**	**17,137.31**	**20,213.77**	**21,790.92**	**24,446.80**	**28,087.54**	**30,582.71**
Others	25,783.18	5,381.39	5,381.39	6,578.95	6,038.61	10,263.80	11,122.36	12,147.39
Total	**223,584.32**	**254,903.40**	**255,611.40**	**289,816.05**	**306,935.99**	**325,313.65**	**346,393.78**	**356,055.40**

Source: Forest Department Sarawak (2016)

Table 4: Forest Plantation Area (ha) in Sabah by Species, 2008-2016

Species/Year	2012	2013	2014	2015	2016 (as of October)
Acacia mangium	73,719.30	68,833.20	70,397.70	62,158.40	64,936.80
Acacia hybrid	-	1,003.00	1,672.00	1,266.00	1,266.00
Albizia falcataria	12,486.20	12,106.00	12,315.78	13,390.30	13,865.50
Gmelina arborea	782.70	754.30	754.30	130.90	152.70
Eucalyptus grandis	18,553.20	21,041.80	26,214.81	18,863.30	18,863.30
Eucalyptus pellita	-	-	-	7,884.60	7,884.60
Rubber	118,043.60	108,931.50	111,304.75	158,723.70	158,723.70
Teak	6,094.20	6,149.10	6,149.10	6,148.60	6,148.60
Binuang	1,472.40	1,450.10	1,077.00	1,190.00	1,077.00
Laran	3,269.60	2,912.30	2,824.80	2,936.40	3,218.60
Dipterocarpaceae spp.	5,011.40	7,087.00	8,410.00	8,410.00	8,410.00
Gaharu	142.70	121.00	121.00	70.00	70.00
Other species	9,463.30	8,779.70	3,431.70	6,080.50	5,789.50
Total	**239,112.40**	**239,169.00**	**244,673.00**	**287,252.70**	**290,406.30**

Source: Sabah Forestry Department (2017)

Planting of E. deglupta in Malaysia was stopped in 1982 due to poor performance when compared to other species (Sulaiman, 1996). Problems with insect and fungal pathogens are noted based on the historical background of this species in Malaysia. Thus, up to this date, most investors have a negative perspective towards this tree (Japarudin, 2016). Nevertheless, for the past several years Eucalyptus trees has been planted in some parts of Peninsular Malaysia, Sabah and Sarawak and the planted areas are growing. The sudden change of interest towards Eucalyptus may have arisen as a result of new interests by other countries, in particular China and Vietnam.

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