OIL PALM FIBERS AS PAPERMAKING MATERIAL: POTENTIALS AND CHALLENGES

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This paper reviews the physical and chemical characteristics of fibers from the stem, fronds, and empty fruit bunches of oil palm tree in relation to their papermaking properties. Challenges regarding the use of this nonwood material for papermaking are raised, and possible solutions to them are given. A vision for the complete utilization of oil palm biomass is also outlined.

Keywords: Elaeis guineensis; Oil palm fibers; Empty fruit bunch; Fronds; Trunks; Physical and chemical characteristics; Paper properties; Pulping

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INTRODUCTION

The global production of paper and paperboard is about 300 million tonnes each year (www.tappi.org/paperu). Yearly, the United States of America alone produces about 87 million tonnes of paper and paperboard, representing approximately 1/3 of the world's total production. The global production of pulp and paper is expected to increase by 77% from 1995 to 2020 (www.printnetinc.com), due to the increasing world population, in addition to improved literacy and quality of life worldwide. The continued high growth in paper consumption will lead to increased demand for fiber, creating additional pressure on the world's diminishing forest resources. Meanwhile the paper industry is also constantly facing mounting resistance from conservationists and environmental groups. To maintain paper industry growth, governments as well as industry executives have to establish and implement policies and plans to ensure a sustainable fiber supply, including reforestation programs, plantation management, recycling, and development of nonwood fibers or alternative fibers, as they are sometimes referred to.

In many countries, particularly in North American and European regions, it is common to equate paper with forests and trees. One may even hear it said that without the forests, there would be no paper. We tend to forget that trees have been used to make paper only since about 200 years ago, and for nearly 17 centuries before that only nonwood raw materials were utilized. It is true that without trees we would not have the large amounts of high quality paper and board products that we enjoy today. However, the rising manufacturing costs and uncertainty in wood supply in some regions, due to restrictions on logging and inadequate forest resources, have caused increasing concerns over future fiber supplies. Many North American and European papermakers are searching for alternative fiber sources such as nonwood plant fibers.

Many often tend to speak of nonwoods as if they were a homogeneous group. In fact they are a mixed bag of raw materials including diverse nonwoody, cellulosic plant materials from which papermaking fibers can be extracted. The common species include, for example, rice straw, wheat straw, bamboo, bagasse, kenaf, flax, cotton, sisal, jute, and hemp, to name a few. Within that mixed portfolio, oil palm is one of the nonwoods that shows great potential as a papermaking raw material. Owing to its economic importance, particularly for Malaysia and Indonesia (Fuad et al. 1999), the present review article focuses on what oil palm fibers can do for us today. The article will examine the characteristics of this alternative fiber source and look how it is being used today in papermaking. The discussion will also consider various challenges regarding the increased use of oil palm fibers in the future.

Availability of Oil Palm Fiber

Oil palm (*Elaeis guineensis*) is cultivated at a vast scale as a source of oil in West and Central Africa, where it is originated, and in Malaysia, Indonesia, and Thailand. In Malaysia and Indonesia, oil palm is one of the most important commercial crops; their respective world productions in 2006 were 15.88 (43% of world total) and 15.90 (44%) million tons, indicating that Indonesia overtook Malaysia as the world's leader in palm oil production since mid 2006 (Anon. 2007). In 2006, other world palm oil production countries were Thailand (820,000 tons, 2%), Columbia (711,000 tons, 2%), Nigeria (815,000 tons, 2%) and others (2718,000 tons, 7%). The explosive expansion of oil palm plantations in these countries has generated enormous amounts of vegetable waste, creating problems in replanting operations, and tremendous environmental concerns. In 2006, Malaysia alone produced about 70 million tonnes of oil palm biomass, including trunks, fronds, and empty fruit bunches (Yacob 2007). An estimate based on 4.69 million ha planted area (Wahid 2010) (http://econ.mpob.gov.my/economy/overview_2009.pdf), and a production rate of dry oil palm biomass of 20.336 tonnes per ha per year (Lim 1998), shows that the Malaysian palm oil industry produced approximately 95.3 million tonnes of dry lignocellulosic biomass in 2009. This figure is expected to increase substantially when the total planted hectarage of oil palm in Malaysia could reach 4.74 million ha in 2015 (Basiron and Simeh 2005), while the projected hectarage in Indonesia is 4.5 million ha. There is a lack of information on palm biomass production in Indonesia. However, it is believed that it should be higher than that reported for Malaysia, since Indonesia produces more palm oil.

According to Yacob (2007) the breakdowns of the Malaysian palm biomass output for 2006 are as follows:

- Fronds from harvesting and maintenance pruning amounted to 43.3 million tones. Presently there is no significant commercial application for the fronds, which are usually returned to the soil as mulching material.
- Trunk/canopy derived from replanting after 25-year cycle accounted for 9.4 million tonnes. In most cases this matter is pulverized and returned to the soil. Some amounts of trunk have been converted into plywood in combination wood veneers.
- Empty fruit bunches (EFB) represented 17.4 million tonnes. This palm biomass has been commercially exploited in producing various low-value products such as

construction materials, fiberboard, and molded products, etc. According to Wahid (2010), the average fresh fruit bunches (FFB) production in 2009 for Malaysia was about 90 million tonnes (based on 4.69 million ha x 19.2 tonnes/ha). Based on a conversion rate of 22% (Anon. 2009; Singh et al. 1999) the Malaysian production of EFB in 2009 would be around 19.8 million tonnes.

Commercial Use of Oil Palm Fibres

Despite their tremendous availability and potential commercial exploitation, fronds (Wanrosli 2004, 2007) and trunks have rarely received any particular attention from investors. This may be partially due to the fact that these biomasses are not directly or closely involved in the palm oil milling process, as compared with the EFB. In particular, they do not cause any problem in the environment surrounding the palm oil mill if they are left on the ground or mulched. They do not exert any environmental pressure on the mill management. Besides, their commercial utilization would require separate and different harvesting, transportation, storage, and processing equipment, which would incur additional investment cost. In fact, the huge profits from oil milling override the interest of using fronds and oil palm trunks.

In contrast, EFB is issued directly from the palm oil milling system; its presence inside the mill's gate is unavoidable and causes great headaches for the management. Under such circumstances, solutions have to be sought to commercialize this byproduct one way or another. Hence, using EFB in papermaking, for example, is strongly promoted. In recent years we have seen some important developments in using EFB in papermaking in Malaysia; the situation in Indonesia is not clear at this point. For example, a fully integrated palm pulp mill (Metro Knight Sdn. Bhd.) in Johor, West Malaysia, has been in operation since 2007 (www.ecofuture.com.my/metro-knight.htm). It produces soda EFB pulp, which is claimed to be suitable for manufacturing printing and writing papers, corrugated cartons, and other paper based products. A second mill (Borneo Advance Pulp and Paper Sdn. Bhd.), which is also designed for making soda pulp from EFB, is now under construction in Tawau, Sabah, East Malaysia (www.etawau.com/OilPalm/PulpPaperMill.htm). This is an interesting development in the area of integrated utilization of EFB, because the proposed mill in Tawau is an integrated plant which will have four major components: a pulp mill, a biomass co-generation plant, an oil palm mill, and a palm oil mill effluent energy plant. The start-up is scheduled for 2011-2012. According to a recent report (Hasan et al. 2010) the SEA Pacific Paper Tech Sdn. Bhd. had set up, a few years ago, a semi-chemimechanical pulping facility of 30 tonnes/day capacity in Kamunting, Perak, West Malaysia. As described, the raw EFB is chopped into short fragments, mechanically pretreated, decontaminated (removal of nut, shell, spikes, sand, etc.), then soaked in hot caustic solution prior to mechanical refining. The cleaned pulp is sold for brown-paper making and molded products. Most interestingly, despite its small scale production this plant is an integrated operation adjacent to a palm oil mill and has an effluent treatment system and sludge utilization plan.

Characteristics of Oil Palm Fiber

The major components of an oil palm tree are illustrated in Fig.1. The main residue generated by the oil milling operation is the empty fruit bunches, while the fronds come from maintenance pruning and replanting, and the trunks are available only during the replanting operation. Oil palm, a monocot, is structurally similar to sugar cane in the sense that they both possess a hard peripheral layer enclosing a central region consisting of fiber bundles embedded in a parenchymatous tissue (Khoo et al. 1991). The latter do not have the character of fibers. However, a large portion of chemicals is consumed to pretreat this tissue while yielding very little usable pulp. Therefore, as much of this tissue as possible should be removed before pulping. This "*depithing*" operation would incur additional capital investment and production cost for pulp made from oil palm fibers, when compared with pulping of wood. Additionally, the yield of useable fiber mass would decrease substantially, since the parenchymatous tissue may represent about 50, 30, and 5% of the mass in the trunk, leafstalk, and empty fruit bunches (EFB), respectively (Singh 1994).

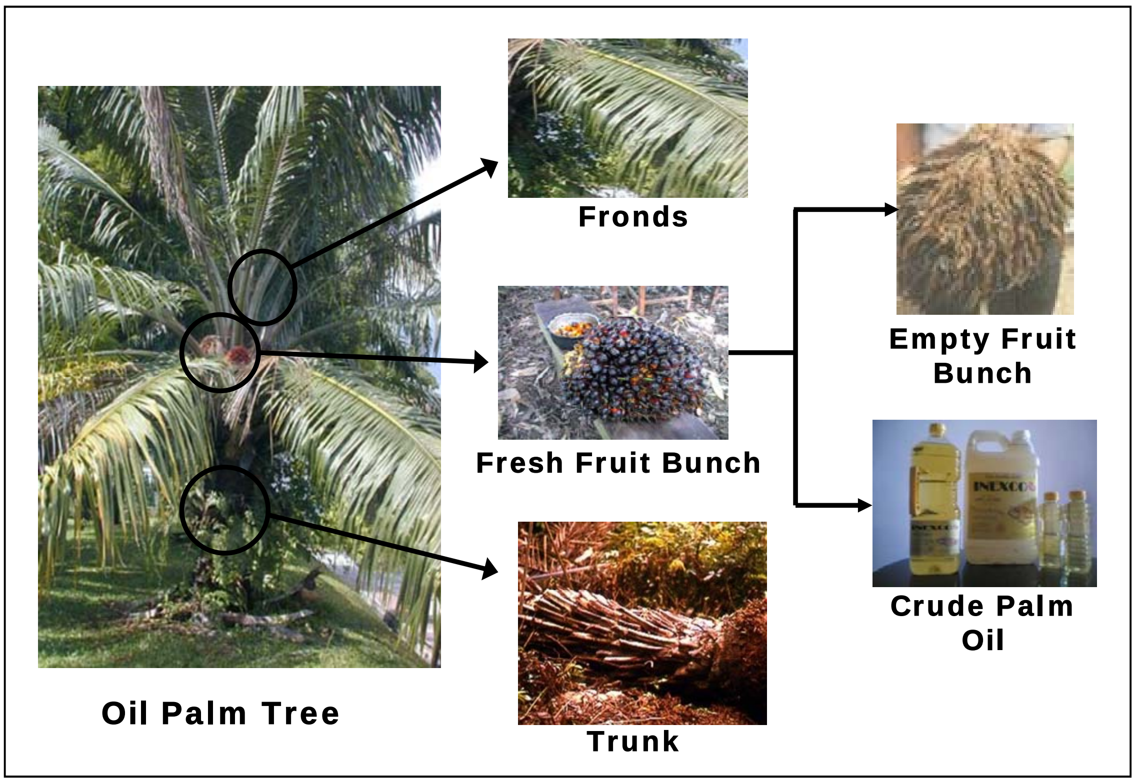


Fig. 1. Biomass/Products from Oil Palm Tree

Chemical characteristics

The data on chemical composition of oil palm components, **Table 1**, should be considered with caution since, as was stated earlier, the materials consist of other types of cells in addition to the fiber. The distribution of a particular type of cell may not be uniform in various positions of the oil palm components. More importantly, researchers might use different methods to prepare their experimental specimens, producing results that might not be comparable between studies. It is evident that there are differences in chemical composition between the tree components, as **Table 1** shows. The composition also fluctuates at various heights and positions within the stem (Khoo et al. 1991; Mansor and Ahmad 1991) and in the fronds (Jalil et al. 1991). In terms of lignin content, a factor important for chemical pulping, the stem and the EFB strands are practically similar to the common Canadian hardwoods (Berzins 1966) such as trembling aspen (*Poplus tremuloïdes* michx.) and white birch (*Betula papyrifera* Marsh.), in contrast to Acacia mangium grown in Malaysia. As for the strands of stem and those of EFB, from which the parenchyma cells had been, more or less, removed, they show slightly lower solubility in alcohol-benzene, implying that they might not pose serious pitch problems in the papermaking process. The whole stem shows particularly high solubility in 1%-NaOH and hot water when compared with its fiber strands, suggesting that the removal of the ground tissues before pulping is important for minimizing the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) loads in the mill effluent. Note that the oil palm fibers, like other nonwood plant fibers, contain comparatively high ash content. This characteristic might contribute to an abnormal mechanical wear of processing equipment. The potential build-up of silica in the black liquor recovery system might also be a concern in pulping oil palm material. In one of our recent studies we found that large amounts of minerals including silica can be removed by combined actions of hammering, washing, and DTPA treatment (Law et al. 2007).

In comparison with the stem and EFB (**Table 1)**, the frond has comparable lignin content but has relatively lower holocellulose and higher alpha-cellulose. A similar major chemical composition of frond was also reported recently by Wanrosli et al (2007). Besides, the frond seems to have particularly high solubility in alcohol/benzene, 1% NaOH, and hot water. These characteristics would somehow affect pulp yield and effluent properties. In general, it compares favorably with the common hardwoods listed in **Table 1**.

Characteristics of fibers

In terms of fiber length the oil palm fibers are similar to those of *Acacia mangium* and those of Canadian aspen and birch, as **Table 2** shows. It is noteworthy that the dimensional data for EFB and the Canadian woods (Law and Jiang 2001) were obtained by means of a Fiber Quality Analyzer (Optest Equipment, Canada), which takes into account all particles in a pulp suspension. As such, the reported fiber length is affected by the amounts of parenchyma cells in the specimen. One morphological particularity of the oil palm fibers is that they have a much thicker cell wall when compared with those of wood, yielding a substantially higher rigidity index (e.g. EFB), as Table 2 indicates. With their thick cell wall the oil palm fibers would give sheet of higher bulk and lower inter-fiber bonding potential in comparison with the wood counterparts.

Properties of Oil Palm Pulps

Pulps from oil palm trunks

Chemical pulping of oil palm trunk using various chemicals has been extensively investigated (Khoo et al. 1991; Yusoff et al. 1991). Some of these results were selected and plotted against pulp yield to show the strength potential of these pulps. Figures 2 to 5 (data source: Khoo et al. 1991; Yusoff et al. 1991) reveal that the tensile burst and tear indices show a general decrease as the pulp yield increases, despite some scattering of the data. With yields lower than 55% the pulps from oil palm trunk exhibit excellent tensile and burst indices, comparable to those from chemical wood pulp. As shown in **Figs. 5-7**, the bleached pulp from oil palm trunk behaves, in general, similarly to the semi-bleached hardwood kraft (Han et al. 2008; Paavilainen 2000). However, these pulps give a comparatively low tear index (**Fig. 6**), probably due to their relatively short fibers, as **Table 2** indicates. With its excellent tensile and burst indices the oil palm trunk pulp, when bleached to the desired brightness, can be used to replace, totally or partially, the hardwood kraft component in printing and writing grades that contain softwood kraft is a major constituent.

Table 1. Chemical Composition of Oil Palm and some Canadian Woods, %

	Lignin	Holo-cellu-lose	Alpha-cellu-lose	Pento-sans	Alcohol-benzene solubility	1%-NaO Hsol.	Hot-water sol.	Ash	Ref.
Trunk (whole)	18.8	45.7	29.2	18.8	9.8	40.2	14.2	2.3	Husin et al. 1985
Trunk (strands)	22.6	71.8	45.8	25.9	1.2	19.5	2.5	1.63	Khoo and Lee 1991
EFB (strands)	17.6	86.3	---	---	2.83	29.9	9.3	3.81	Law and Jiang 2000
EFB (strands)	17.2	70.0	42.7	27.3	0.9	17.2	2.8	0.7	Khoo and Lee 1991
Frond (strands)	15.0	84.6	50.0	23.9	1.7	22.0	---	0.48	Khoo and Lee 1991
Frond (strands)	18.5	78.6	---	---	5.5	36.1	14.1	3.7	Hosokawa et al. 1989
Frond (whole)	16.37	73.85	---	---	7.12	---	---	---	Hassan et al. 1991
Frond (strands)	16.59	76.45	---	---	7.33	---	---	---	Hassan et al. 1991
Frond (whole)	19.4	67.4	49.6	---	5.2	36.4	17.5	4.9	Jalil et al.1991
Frond* (whole)	17.1	65.7	---	---	1.5	40.1	25.5	13.7	Kamishima et al. 1994
Frond** (whole)	16.5	66.2	---	---	1.3	42.2	26.0	17.0	Kamishima et al. 1994
Acacia mangium	25.6	---	---	17.4	4.8	16.4	6.16	---	Law and Wan Rosli 2000
Trembling aspen	18.1	77.8	43.6	20.2	3.7	19.3	2.75	0.31	Berzins1966
White birch	18.4	78.2	41.0	24.1	3.6	19.1	2.8	0.33	Berzins 1966
Black spruce	27.1	74.3	---	9.1	1.9	14.1	3.7	0.23	Berzins 1966

EFB: empty fruit bunches. *: pretreated with 3% NaOH; **: sprayed with 15% KOH

Table 2. Fiber Characteristics of Oil Palm and some Canadian Woods

	Fiber length, mm	Fiber diameter (D), µm	Cell wall thickness (T), µm	Fiber coarsenes s mg/m	Rigidity index $(T/D)^3 x10^{-4}$	Ref.
Whole trunk	1.32	35.3	4.5	---	20.77	Husin et al. 1985
Trunk strand	0.96	29.6	4.8	---	42.64	Khoo and Lee 1991
EFB strand	0.99	19.1	3.38	0.107	55.42	Law and Jiang 2000
Frond strand	1.59	19.7	3.95	---	80.61	Yusoff 1997
Acacia mangium	0.9	22.3	2.9	---	22	Law and Wan Rosli 2000
Trembling aspen	0.96	20.8	1.93	0.241	7.99	Law 2000
White birch	1.32	21.6	2.44	0.296	14.42	Law 2000
Black spruce	2.48	35.0	3.62	0.382	11.06	Law 2000

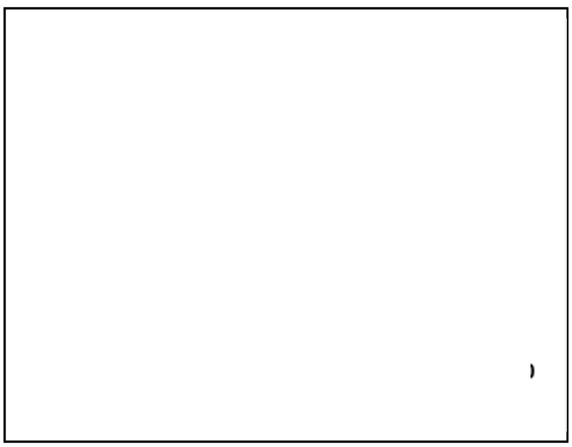


Fig. 2. Tensile index vs. pulp yield

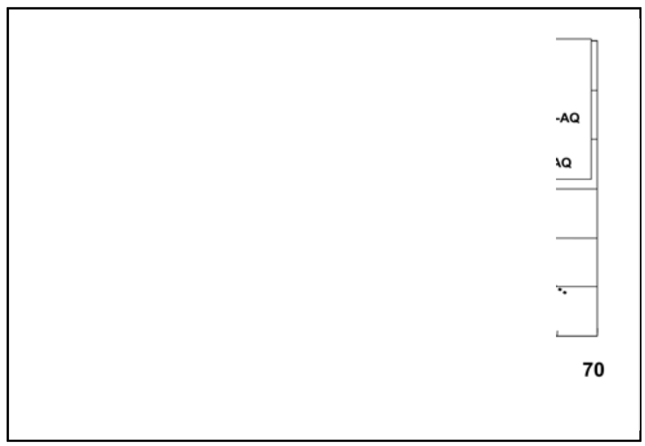


Fig. 3. Burst index vs. pulp yield

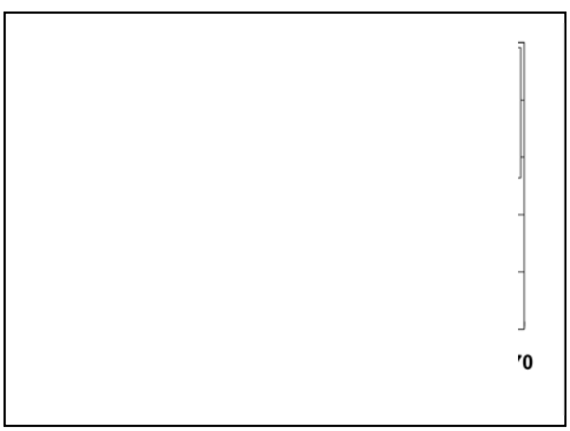


Fig. 4. Tear index vs. pulp yield

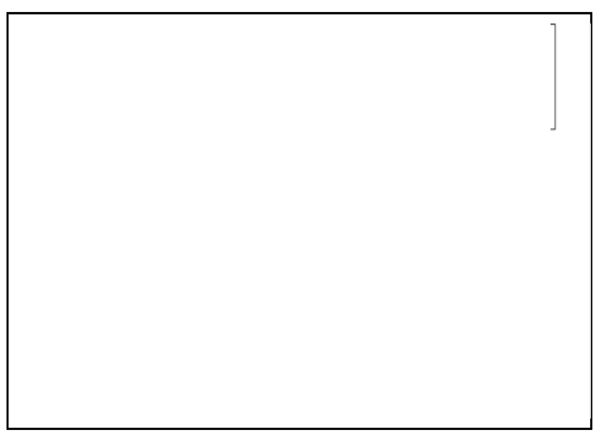


Fig. 5. Tensile index of oil palm And wood pulps. a:Yusoff 1997; b: Khoo et al. 1991; c: Han et al. 2008

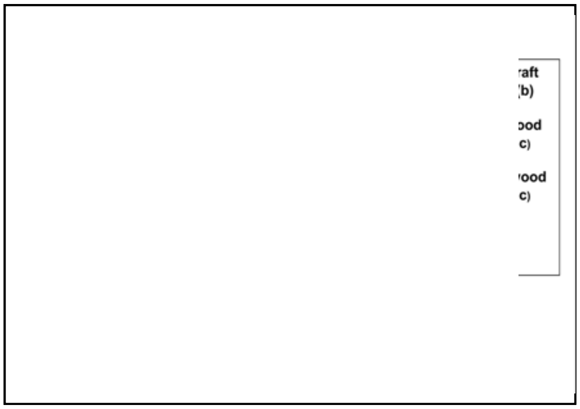


Fig. 6. Tear index of oil palm and wood pulps

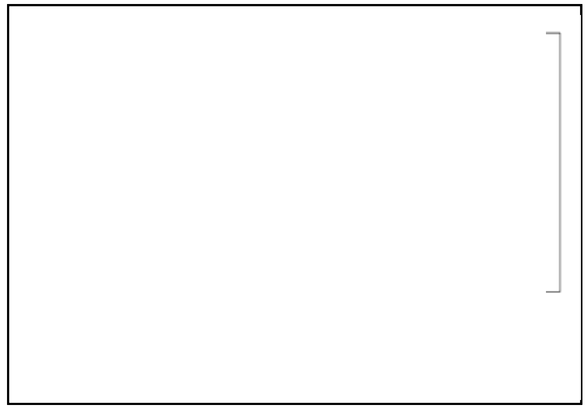


Fig. 7. Tear index vs. tensile index of oil palm and wood pulps

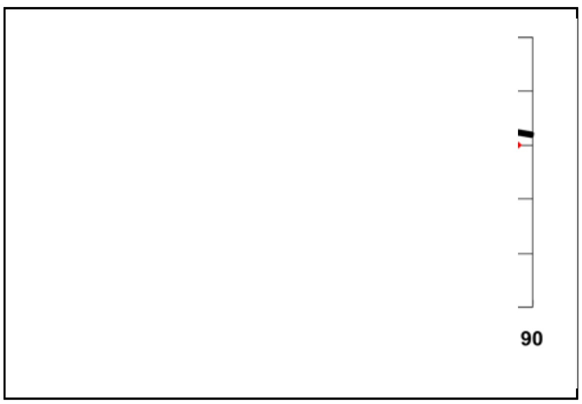


Fig. 8. Tensile index vs. pulp yield of frond NSSC pulp (Yusoff 1997)

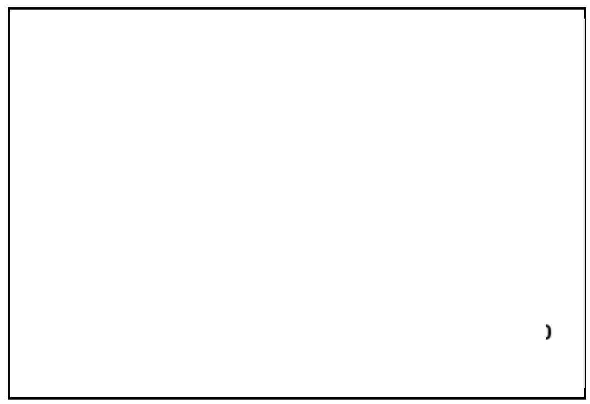


Fig. 9. Tear index vs. pulp yield of frond NSSC pulps (Yusoff 1997)

Pulps from Oil Palm Fronds

The strength properties of high-yield pulps from oil palm fronds (Yusoff 1997) are particularly interesting, as **Figs. 5** to **9** reveal. At 63% yield, a frond pulp compares well with the softwood kraft, as indicated in **Figs. 4** to **6**. This pulp shows high tensile and tear indices, probably due to its relatively long fibers (**Table 2**). Acetosolv pulping of frond chips (Wanrosli et al. 2010) to produce pulps of 45 to 50% yields gave good physical properties, for example zero-span tensile breaking length (83 km), sheet density (0.57 g cm^{-3}), tensile index (48 Nm/g), and tear index (5.4 mN* m^2 g^{-1}).

Several studies on chemithermomechanical pulping (CTMP) of oil palm fronds had been reported (Hosokawa et al. 1989; Hassan et al. 1991; Kamishima et al. 1990). The CTMP of whole frond chips without pretreatment gave a pulp yield about 80% when 5.6 to 11.2% (on o.d. basis) of KOH was used in the refiner (Hosokawa et al. 1989). The yield was substantially reduced to 43-55% when the chips were pretreated with alkali prior to refining, similar to that of chemical pulps. The pretreatment of chips improved the tensile index, passing from 18-36 to 51-57 N*m/g. The tear index increased from 4-7 to 8-11 mN*m^2/g. Evidently, better yield and strength properties could be obtained when fiber strands are used instead. The removal of parenchyma cells improved the pulp brightness, as observed by Hassan et al. (1991). However, in all cases reported the pulp brightness is poor, in the 20 to 40% range. In another work (Wanrosli et al. 1998), tensile indices of 44.1 and 53.9 N*m/g were, respectively, reported for pulp yields of 56.2 (at 248 mL freeness) and 66.9% (at 85 mL freeness) for chips pretreated with alkali. Pilot trials on CTMP of frond chips pretreated with alkali produced corrugating medium with satisfactory properties, as reported in Kamishima et al. (1994). In sum, systematic trials on CTMP of either whole frond chips or frond fiber strands are needed, since most published works were inconsistent with each other in terms of material preparation.

Pulps from oil palm bunches

Empty fruit bunch (EFB) pulps in a yield range between 45 and 65% (Wan Rosli et al. 1998) are weaker than the trunk counterpart in tensile and burst indices, as shown by **Figs. 10 and 11**. Surprisingly, they give excellent tear index (**Fig. 12**) despite the relatively short fibers (<1 mm, **Table 2**). When cooked in the same condition (Law and Jiang 2001), the EFB gave a yield lower by about 30%-points in comparison to aspen, as indicated in the legends of **Figs. 14** to **17.** The EFB pulps were inferior in tensile at both levels of pulp yields (**Fig. 13**) as compared with aspen pulps, but showed comparable burst index (**Fig. 14**) when cooked in the same condition. The tear index of EFB pulps was, however, significantly superior to that of the aspen counterparts (**Fig. 15**), confirming the finding of (Wanrosli et al. 1998). It is believed that the relatively high rigidity index (**Table 2**) of fiber and the presence of long and spiral vessel elements in the EFB pulp (Law and Jiang 2001) are accountable for the excellent tearing resistance. As shown in **Fig. 16**, the EFB pulps exhibit lower tensile strength but higher tearing resistance vis-à-vis aspen pulps, suggesting that blending of these two pulps would yield a furnish having good tensile and tear indices.

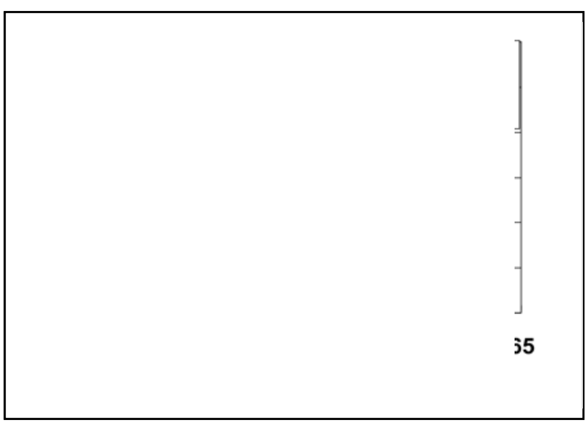


Fig. 10. Tensile index vs. pulp yield of EFB pulps (Wanrosli et al. 1998)

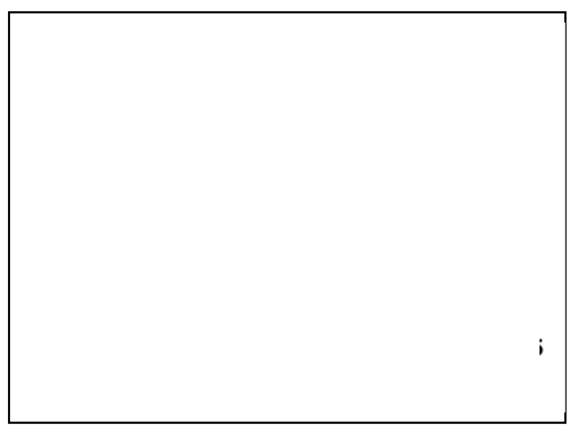


Fig. 11. Burst index vs. pulp yield of EFB pulps (Wanrosli et al. 1998)

Fig. 12. Tear index vs. pulp yield of EFB pulps (Wanrosli 1998)

Fig. 13. Tensile index vs. freeness for EFB and aspen pulps (Law and Jiang 2001)

Fig. 14. Burst index vs. freeness of EFB and aspen pulps (Law and Jiang 2001)

Fig. 15. Tear index vs. freeness of EFB and aspen pulps (Law and Jiang 2001)

Fig. 16. Tensile index vs. tear index of EFB and aspen pulps (Law and Jiang 2001)

Fig. 17. Blending of EFB with spruce TMP (Wanrosli et al. 1998)

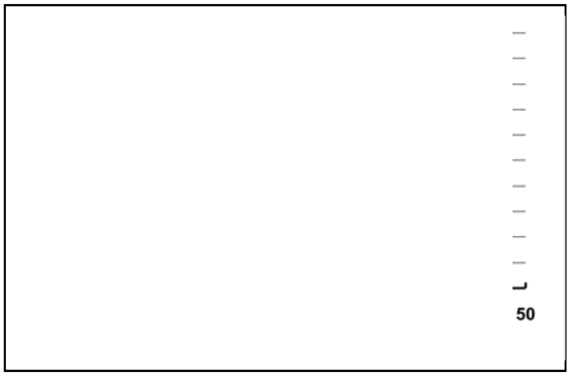


Fig. 18. Kraft cooking of mixtures of pine and EFB (Guritno et al. 1994)

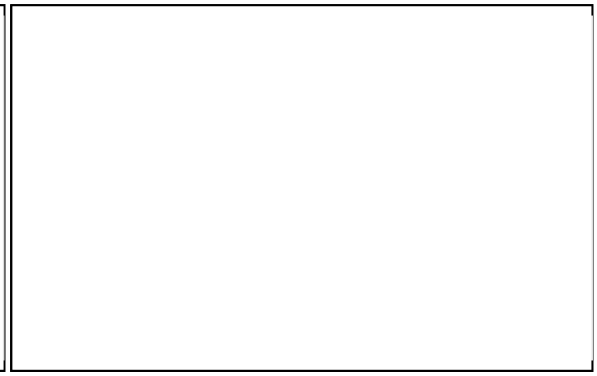


Fig. 19. Tensile and tear indices of mixtures of pine and EFB fibres (Guritno et al. 1994)

As reported by Wanrosli et al. (1998), the EFB pulp can be used as a reinforcement component in newsprint furnish. The introduction of EFB in kraft pulping of *Pinus merkusii* (Guritno et al. 1994) at levels up to 30% resulted in only a 3-point drop in pulp yield and tear and tensile indices, as shown in **Figs. 18** and **19.** At lower replacement ratios, such as 20% (**Fig. 19**), the negative effects can be minimized. The tensile index can be maintained at about 80 N*m/g and tear index at about 16 to 17 mN*m^2/g. These findings (Wanrosli et al. 1998; Guritno et al. 1994) suggest that the oil palm EFB is a useful papermaking material.

In recent years, there were some interesting research developments in high-yield pulping of EFB. Ghazali et al. (2006, 2009) found that mechanical hammering and pressing followed by treatment with DTPA (diethylenediaminepentaacetic acid) could eliminate about 80% of the silica in EFB, and that such combined treatment created fissures in the fibrous strands and weaken the attachment of silica to wall structure, facilitating the diffusion of chemicals in pulping. Other researchers (Leh et al. 2009) statistically examined the use of oxygen delignification of soda EFB pulp and observed that the process was effective in improving pulp brightness while maintaining stable yield, viscosity and alpha-cellulose content. Besides, Jiménez et al. (2009) used 1% (o.d. basis) anthraquinone in soda pulping of EFB (15% NaOH, 170 C, 70 min) and obtained good sheet properties, for example, tensile index 60 N*m/g, burst index 4 kPa*m^2/g and tear index 7 mN*m^2/g.

CHALLENGES

Since the past half decade or so there have been encouraging signs on the commercialization of EFB, exemplified by commercial operations in Malaysia. However, on the fronts of frond and trunk fibers the scenario has been rather disappointing, which may be associated to the inherent supply nature of these biomasses. Their availability relies principally on replanting cycles (about 25 years). Further, the scattering of same-aged plantations over vast areas could also have large negative impact on the cost of transportation, unless the planting operations are well planned in view of future utilization of the resulting biomasses.

Table 3 lists some of the major barriers and their possible solutions. The development of an economical and efficient means to transform the crude material into high quality fiber strands is of great importance. A complete segregation of parenchyma cells from the fiber strands is highly desirable because the former can have significant adverse influence on pulping and pulp quality. Among the barriers listed, the most challenging one would be, perhaps, the development of an efficient technique to pulp mixtures of fiber strands from the stems, fronds, empty fruit bunches, and mesocarp, for example. The success of such a process could have a remarkable impact on the palm oil industry as well as the pulp and paper industry, economically and environmentally.

VISION FOR COMPLETE UTILIZATION

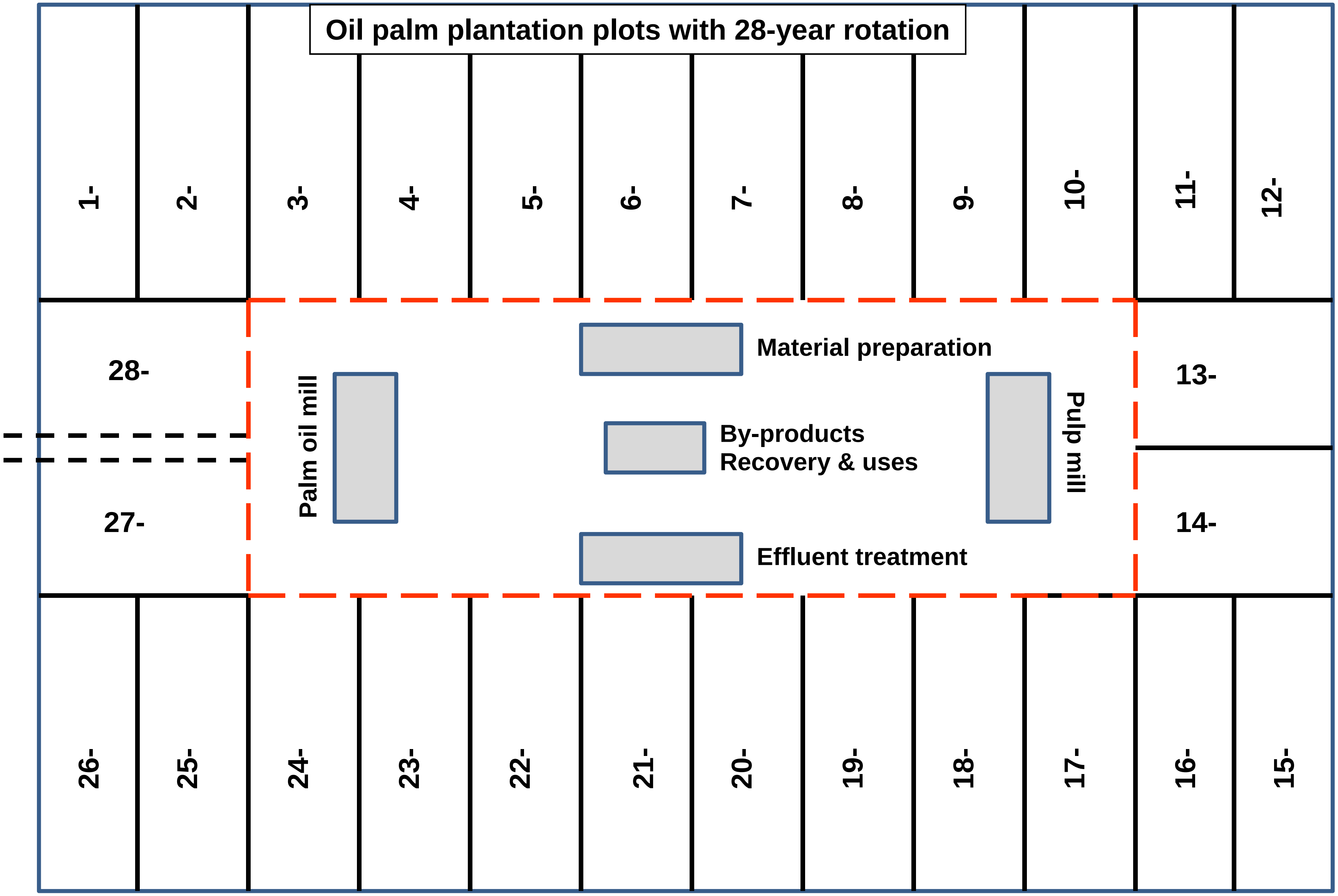
The exploitation of oil palm gives important economic growth to countries such as Malaysia and Indonesia. Meanwhile, it also creates enormous environmental stresses. The slash-and-burn practices are particularly harmful. The tremendous amounts of solid wastes including the trunks, fronds, fruit bunches and many other mill residues (for example, mesocarp fiber, shell, and mill effluent, etc.) generated by the palm oil industry can pose grave risks to human beings as well the ecological system. All these risks can be minimized through consistent governmental regulations and sound industrial practices with maximal utilization of oil palm biomass. To achieve this goal, a rational planning and management of the palm oil industry and the pulp and paper industry is of great importance. A vision of such a planning is illustrated in **Fig. 20**. The proposed scheme would provide a sustainable and balanced flow of raw material of uniform quality. The distance of transportation of raw material would be greatly reduced, and hence the transportation cost. A centralized raw material preparation would ensure good quality, which is important for obtaining the best possible quality of final products. The combined effluent treatment system would increase its efficiency and reduce the operation costs. Further, the multiple uses of raw materials would yield economic and environmental benefits. The management would also be significantly simplified through integrated operations of the palm oil production and pulp manufacture. In essence, to increase the competitiveness of any operation one should aim at reducing the production cost, increasing the product quality, and protecting the environmental. Integration of a pulp mill operation and other by-products processing facilities along with the palm oil mill would ensure a complete utilization of the valuable renewable raw materials and protect the environment. The ultimate goal would be a zero-waste industry.

CONCLUDING REMARKS

As discussed earlier, the fiber strands from the oil palm stem, fronds, and fruit bunches are a good source of raw material for the production of various grades of paper product. However, an economical and effective technique of extraction is needed to produce high quality fiber strands for pulp and paper making. Recovery and utilization of mill residues generated by the palm oil industry and the treatment of mill effluent deserve much attention to achieve a sound and sustainable exploitation of the oil palm resource. In reality, the cost and quality of products and the environmental factor are interconnected and should be taken into consideration in future planning and development of the industry.

Table 3. Potential Barriers to the Use of Oil Palm Fibers and Possible Solutions

Barrier	Solution
High ash and silica content	- Avoid soil contamination, - Thorough separation and washing, - Modified pulping process
High moisture content and bulkiness	- On site processing, - Seasoning, - Location of pulp mill
Heterogeneity of material	- Improvement in fiber extraction technique of (e.g., depithing technique)
Short fiber length	- Optimization of pulp yield, - Blending with softwood fibers
Parenchyma cells	Search for potential uses and means of disposal
Pulping efficiency	Process development for the mixed raw material (stems + fronds + bunches + mesocarp)
Pulp bleaching	Optimization of chlorine free bleach sequences
New pulping processes	- Bivis process for high-yield pulping, - Soda-Oxygen pulping, - Mild acid pulping, - Biopulping, - Alkaline peroxide pulping
Competitiveness	- Integration of palm oil and paper industry operations, - Mechanization of field operations, - Automation of processes
Paper grades	Optimized blending of furnishes
Palm oil mill residues	Search for new uses
Palm oil mill effluent	Zero-Effluent technology – reuse of process water
Residual oil in pulp	Alkaline pretreatment/alkaline pulping


Oil palm plantation plots with 28-year rotation
1-
2-
3-
4-
5-
6-
7-
8-
9-
10-
11-
12-
28-
13-
Material preparation
Palm oil mill
By-products Recovery & uses
Pulp mill
27-
14-
Effluent treatment
26-
25-
24-
23-
22-
21-
20-
19-
18-
17-
16-
15-

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