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OIL PALM LEAF FIBRE AND ITS SUITABILITY FOR PAPER-BASED PRODUCTS

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ABSTRACT

Due to the shortage of wood as origin materials for paper-based production, agro-residue materials have been explored in the quest of finding the best alternative fibre. Oil palm leaf (OPL) is one of agro-residue that has potential due to its comparable characteristics with wood fibre. Studies on chemical compositions, fibre morphology, and mechanical property of OPL have been carried out aiming to evaluate its potential as a substitute raw material for pulp and paper-based production. The chemical compositions were analysed according to the TAPPI standard, Kurscher-Hoffner and chlorite methods accordingly. The mechanical property (tensile, tearing and bursting strengths) were determined as described in TAPPI test methods. Fibre dimensions were determined using Franklin method and analysed under the optical microscope. The content of cellulose in the OPL is determined to be 43.8%. Although, this result is lower than wood fibre (53%), OPL has higher hemicellulose content (36.4%) than the wood fibre (27.5%). In addition, the lignin content (19.7%) of OPL is in the low range of those in wood resources (18 - 25%). These parameters are important components to produce good quality pulp and will provide high mechanical strength of the paper-based products. The measured fibre length of oil palm leaf (1.13 mm) is shorter than the wood fibre (1.90 mm). Meanwhile, the mechanical property of OPL showed lower indexes than wood resources, however, tear (1.80 $mN.m^2/g$) and burst (0.95 $kPa.m^2/g$) indexes of OPL are higher than other published and successful wood resources (Eucalyptus). Based on the analyses, the oil palm leaf is indeed a suitable alternative of raw material for pulp and paper-based industries.

Keywords: chemical property, fibre property, non-wood, paper-based, sustainability.

1. INTRODUCTION

Paper-based manufacturing is largely dependent on wood as its dominant fibre resources for any pulp and paper-based industries, accounting for 90% of the world fibre utilization. The global consumption of paper is around 400 million tons, cutting down about 7.2 billion trees to fulfill the demand of paper as writing, printing, wrapping and packaging purposes [1].

As significant climate change has become a global threat, the alternative resources must be searched with an aim that it offers less adverse impact on the environment, more economical and easily accessible [2]. In addition, the shortage of wood resources and continuous increasing demand of paper-based products, the non-wood plants are good candidates to be explored as alternative resources for pulp and paper-based productions. This is due to their advantages such as short growth cycles and low lignin content which in return will reduce the energy and chemicals consumptions during the pulping process [1].

Oil palm (*Elaeis guineensis)* biomass is generated from oil palm plantation. In Malaysia, plantation of oil palm is an important economy sector which provides valuable products such as edible oil, confectionaries and many other industrial uses [3]. The large plantation area has generated large biomass residues (more than 70 million tons) yearly as everyone hectare of plantation area produces between 50 to 70 tons of wastes [4]. These residues include oil palm leaf, empty fruit bunches, shell, kernel and trunks [5]. Using OPL as an alternative pulp for paper-based products could reduce not only the load of deforestation, but also preventing other environmental issues such as waste dumping, pests growth and promoting the nation's zero waste policy.

Therefore, the aim of this paper is to explore the potential of OPL as a raw material for pulp and paper-based productions through chemical, morphological and mechanical characterizations. The pulp production is via the alkaline process and the results were compared with available published non-wood and wood resources.

2. MATERIAL AND METHOD

2.1. Material preparation

Fresh OPL were obtained from the plantation area in Parit Raja, Johor. The samples were cut into 2 – 5 cm long [6, 7]. The chopped OPL were washed using tap water to eliminate contaminants and air-dried. For chemical analysis, the air-dried samples were ground (0.40 – 0.45 mm) according to the Technological Association of Pulp and Paper Industry (TAPPI) standard method, T 264

cm-07 and stored in an air tight Duran bottle prior to the analysis.

2.2. Chemical property

Chemical compositions of OPL were performed according to TAPPI standard method. The samples were first placed into soxhlet extraction for 6 hours according to method T 264 cm-07 to remove plant extractives. The determination of cellulose, hemicellulose, lignin and ash content were assessed by using the following respective standard method: Kurscher-Hoffner approach [8], chlorite [9], T 222 om-06 and T 211 om-07. As recommended by various pertinent standards, all experiments were conducted in triplicates.

2.3. Pulping process

The laboratory digester was used to cook 400 g (o.d) of chopped OPL at 170 ºC, with heating rate of 1 ºC/min. The liquid to material ratio was 7:1 and the holding time at the maximum temperature was 90 min. The cooking was done in alkaline condition as white liquor (16% sodium hydroxide) was used in the cooking process. The cooked materials were thoroughly washed with tap water, disintegrated in a hydropulper for 15 minutes and screening through vibratory flat screen with 0.25 mm slits. Then, the screened OLP pulp was spin-dried to remove excess water before being transferred into Horbert mixer to homogenize the pulp. The pulp was kept inside the refrigerator at 4 – 5 ºC for further analysis. The pulp yield was determined by using the formula below.

$$\text{Pulp yield, \%} = \frac{\text{weight of pulp, g (o.d)}}{\text{weight of samples, g (o.d)}} \times 100 \quad (1)$$

2.4. Morphological characterization

To measure the fibre length of the OPL, Franklin method [10] was applied. In this method, the OPL pulp was immersed into glacial acetic acid and hydrogen peroxide for 24 hours at 60 ± 2 ºC in a water bath. The reaction was stopped by washing the pulp, which was dispersed in distilled water. Next, the pulp was gently mixed in a magnetic stirrer container for 60 mins to separate the fibre bundles into individual fibre. Three drops of safranine-O was added into the mixture and allowed to homogenously mix. Three drops of the mixture was transferred onto the microscope slides. The fibre length was then measured using a profile projector microscope (Nikon V-12, Japan) at 100 x magnifications. Triplicates of microscope slides were used to measure fibre length in this study.

2.5. Mechanical property

The conventional papers with a basis weight of 60 g/m^2 were prepared according to T 205 sp-02. Prior to testing, the papers were put under condition at 25 ºC with 50% relative humidity for 24 hours to equilibrium with conditioning atmosphere before any appreciable drying has occurred. The produced papers of OPL were used to determine the tensile, tearing and bursting strengths according to standard method T 494 om-06, T 414 om-04 and T 403 om-08 respectively.

3. RESULTS AND DISCUSSION

The results of chemical, morphological and mechanical properties of OPL were presented in Table-1.

3.1. Chemical property

Cellulose content: Cellulose plays the most important role in fibre strength and subsequently paper strength [11]. The cellulose content of OPL was found to be 43.8% (Table-1). Although OPL contains lower cellulose (43.8%) than wood resources (53%) [12], however it is still in the acceptable range of the non-wood; sisal (43 – 56%) that has been proven to be a successful pulp for paper-based productions [13]. Cellulose is the core material for pulp. High cellulose content in the material contributes to high pulp yield after the pulping process. According to Al-Mefarrej [11], increasing cellulose content in a material will increase the fibre strength and the strength of paper-based products produced from it.

Hemicellulose content: OPL's hemicelluloses content is 36.4% (Table-1). The hemicellulose also contributes to the strength of pulp and paper-based products [14]. From Table-1, OPL has higher hemicellulose than non-wood; sisal (21 – 24%) [13]. When compared with data for hardwood resources (24 – 40%) [15], the hemicellulose content of OPL is still in the acceptable range. High hemicellulose content is advantageous for pulp and paper-based industries since it is correlated with high strength property of the paper-based products in terms of tensile, tearing and bursting strengths [16].

Lignin content: Lignin content of OPL (19.7%) is at good level (< 30%) for materials to be used in pulp and paper-based industries [17]. Based on Table-1, lignin content of OPL is significantly lower compared to the date palm leaves (31.2%) [18]. In addition, the lignin content in OPL is considered low and also in the lower range of hardwood resources (18 – 25%) [15]. Low lignin contributes to lesser chemicals usage during the pulping process [19] which subsequently generates lesser hazardous waste water. Moreover, low lignin also contributes to higher pulp yield and reducing the brownish colour of the pulp [11].

Ash content: Ash content is defined as the presence or absence of the organic and inorganic matter of the material [20]. The ash content of OPL was found to be 5.7% (Table-1). Although, the ash content of OPL is higher than hardwood resource (1.0%) [13], but this amount was markedly lower than the published non-wood, date palm leaves (9.6%) [18]. In pulp and paper-based industries, the ash content inversely correlates with the strength property of the product. Hence, due to its low ash content, it is expected that the product produced from OPL fibre will have high strength property.

3.2. Morphological property

Pulp yield: Pulp yield of OPL was 23.2% (Table-1) and this value is lower than those of wood resources (45 – 52%) [21]. Although, OPL contains lower pulp yield than wood resources, poplar (43.8%) [22], it is higher than the Alfalfa stem (20.7%) [22], which has been proven to be a successful alternative pulp for paper-based industries.

Fibre length: Fibre length is an important aspect in measuring the quality of the pulp produced. This is due to the strong relationship between the fibre length and strength property of the products. OPL fibre is characterized as short fibre length (1.13 mm), a fibre is considered short with length between 0.2 mm to 1.2 mm [23]. Interestingly, the fibre length of OPL is in the range of those fibres from non-wood resources, sisal (1 – 8 mm) [13] and wood resources (0.7 – 1.6 mm) [1]. The short fibres length in OPL contributes to a denser sheet production and high uniformed paper structure with smooth paper surface and superior printing properties [17].

3.3. Mechanical property

The mechanical property of the paper-based such as tensile, tearing and bursting indexes are found to be correlated with the morphological property which is fibre length [24]. According to Abd. Rahman and Azahari, [24] and Testova, [25], the mechanical property is also related to the inter-bonding as well as the fibre strength.

Tensile index: The tensile index of OPL (12.1 mN/g) is lower than the wood resources; Eucalyptus (49.8 mN/g) [21] and non-wood, Pamlyra plant fruit (13.8 mN/g) [26] as shown in Table-1. The lowest tensile index of OPL is probably due to the decrease in fibre bonding and fibre strength [27] and also depends on the less contact area of inter-fibre bonding [28]. However, the tensile index of OPL is comparable with commercial paper towel industries (12.5 mN/g).

Tearing index: The tear index of OPL is 1.80 $mN.m^2/g$ which is lower than date palm leaves (8.40 $mN.m^2/g$) [18] (Table-1). Reduction of tear index of OPL was probably due to less fibre bonding especially the inter-bonding of the material [29]. According to the Fišerová and Gigac, [28], less inter-fibre bonding may be related to the decreasing number of hydrogen bonds produced by hemicellulose content of the material. However, this value is still higher than the wood resource, Eucalyptus (1.19 $mN.m^2/g$) [21] and non-wood resource, rice straw (0.31 $mN.m^2/g$) [30]. Higher tear index in OPL is due its long fibre length. In addition, tear index is inversely proportional with tensile index [31].

Bursting index: The burst index of OPL is 0.95 $kPa.m^2/g$. Generally, burst index is directly proportional to the tensile index [25]. In the case of OPL, the burst index showed to be lowest than non-wood resources, date palm leaves (1.40 $kPa.m^2/g$) [21] as shown in Table-1. This is because OPL has short fibre length compared to the published date palm leaves. Interestingly, OPL burst index is higher than wood resource; Eucalyptus (0.53 $kPa.m^2/g$) [21]. Higher bursting index in OLP than Eucalyptus is related to the fibre length of OPL that is longer than Eucalyptus. According to Azizi *et al.,* [29], higher burst index is related to the longer fibre length that increases the inter-fibre bonding of the products. In addition, high burst index is also probably due to the good sheet formation of fibre and high fibre bonding [32]. From Table-1, it is clearly observed that the burst index of OPL is higher than published wood resource, Eucalyptus. Therefore, OPL is acceptable as a good candidate in producing paper-based products and collectively replaces wood resources in the paper-based industries.

Table-1. Chemical, morphological and mechanical properties of oil palm leaf, OPL.

Analysis	Parameters	Experimental work (current study)	Published researches
Chemical Property	Cellulose, %	43.8 ± 1.50	Sisal (43 - 56) [13] Wood resource (53) [8]
	Hemicellulose, %	36.4 ± 1.73	Sisal (21 - 24) [13] Hardwood (24 - 40) [15]
	Lignin, %	19.7 ± 2.41	Date palm leaves (31.20) [18] Hardwood (18 - 25) [15]
	Ash, %	5.70 ± 0.94	Date palm leaves (9.6) [18] Hardwood (1) [13]
Morphological Property	Pulp yield, %	23.2	Alfalfa stem (20.7) [22] Wood resources (45 - 52) [21]
	Fibre length, mm	1.13 ± 0.06	Sisal (1 - 8) [13] Wood resources (0.7 - 1.6) [1]
Mechanical Property	Tensile index, mN/g	12.1 ± 2.91	Pamlyra plant fruit (13.8) [26] Eucalyptus (49.8) [21]
	Tear index, $mN.m^2/g$	1.80 ± 0.19	Date palm leaves (8.4) [18] Rice straw (0.31) [30] Eucalyptus (1.19) [21]
	Burst index, $kPa.m^2/g$	0.95 ± 0.13	Date palm leaves (1.40) [18] Eucalyptus (0.53) [21]

4. CONCLUSIONS

Based on the analyses, OPL could be considered as a promising material in pulp and paper-based industries. From the chemical analysis point of view, cellulose content of OPL (43.8%) is within the acceptable range of the published non-wood resource, sisal (43 - 55%). In addition, OPL also contain slow lignin content than hardwood resources (18 - 25%) which is favourable for the pulping process. These results indicated that OPL is a potential alternative resource to be used in pulp and paper-based production. Although OPL produces lower pulp yield than wood resources, it is still within the acceptable range for pulp production. Nevertheless, the mechanical property of OPL is considered good compared to other non-woods and hence it is suitable for pulp and paper-based industries. Even though OPL has lower tensile index (12.1 $mN.m^2/g$) compared to wood resource, Eucalyptus (49.8 mN/g), it shows higher tear (1.80 $mN.m^2/g$) and burst (0.95 $kPa.m^2/g$) indexes. Nevertheless, more experiments should be conducted in the application part in order to suggest the most suitable range of products from OPL pulp such as the production of papers, box liner, books, tissue, envelope or even craft purposes.

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