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DURIAN RIND SODA-ANTHRAQUINONE PULP AND PAPER: EFFECTS OF ELEMENTAL CHLORINE-FREE BLEACHING AND BEATING

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A study was conducted to investigate the preliminary characteristics of soda-anthraquinone (soda-AQ) durian rind waste pulp and paper with the effects of elemental chlorine-free (ECF) bleaching and beating revolutions. Pulping was carried out using rotary digester with 0.1% antraquinone, 20% active alkali (NaOH), cooking time of 120 min and temperature of 170 °C. ECF bleaching with chlorine dioxide – alkali extraction – chlorine dioxide – alkali extraction – peroxide sequence and beating in the range of 0 to 1000 revolutions were applied to the unbeaten and unbleached pulp. ECF bleached pulp produced soda-AQ durian rind paper with greater tensile index, burst index, tear index, number of folds, brightness and scattering coefficients, but with slightly lower opacity compared with paper made from unbleached pulp. The results also showed that beating revolutions improved the overall physical and mechanical characteristics of durian rind soda-AQ pulp. Bleaching and beating enhanced the durian rind soda-AQ pulp fiber-to-fiber bonding and strength. Durian rind has potential characteristics as promising new material for papermaking.

Keywords: Soda-AQ, refining, chlorine dioxide, alkali extraction, unbeaten and unbleached pulp, EFC bleaching

INTRODUCTION

The increasing production of global pulp and paper products leads to shortage of wood-based raw materials forcing the Malaysian pulp and paper industry to depend on imported raw materials for sustenance. Typically, the Malaysian packaging industry uses secondary fibres such as old corrugated containers and waste paper as main raw materials (Main et al. 2014). Thus, the insufficient supply of raw materials for pulp and paper has increased the initiatives to search for alternative fibre sources, such as non-wood plant fibres. Currently, the rapid expansion of plantations in Malaysia has generated enormous amounts of agricultural waste that have not been fully utilised, creating problems in replanting operations and tremendous environmental concerns (Abdul Khalil et al. 2006, Daud et al. 2013). These wastes have huge potential in the paper industry, but they have not been commercially exploited (Requejo et al. 2012). Hence, economical utilisation of these large amounts of agricultural wastes as raw material for pulp and paper industry would be beneficial.

In addition to Thailand and Indonesia, Malaysia is one of the major durian flesh exporters. The aril comprises between 15 and 30% of the mass of the fruit (Brown 1997). One durian fruit has approximately 60 to 75% durian skin fibre (Nur Aimi et al. 2014). In 2014, 75,370 ha areas were planted with durian and these produced 373,565 t of fruits (Anonymous 2015). Disposal of massive amounts of peels has caused problems in the community (Hameed & Hakimi 2008). Durian rind has high content of hemicellulose (Khedari et al. 2003, Zddin & Risby 2010), which makes it suitable as a pulp and paper material.

The potential use of durian rind has been investigated in insulation particle boards (Khedari et al. 2003), fibreboards (Wiyaratn & Watanapa 2012, Watanapa & Wiyaratn 2013), light weight construction materials (Charoenvai et al. 2005), and absorbent materials (Mohammed et al. 2012). Perdinan et al. (2014) produced durian rind paper which consisted of durian rind soda pulp, starch and alkyl ketene dimer sizing agent. However, the physical characteristics of the paper did not fulfil the basic specifications for plastic laminated wrapping paper, as outlined by the SNI 14-6519 (SNI 2001). Durian skin fibre has great future potential and suitability for packaging due to its renewable and biodegradable properties and cost-effectiveness (Nur Aimi et al. 2014). Durian rind unbleached pulp produced via chemi-mechanical pulping has great potential for papermaking (Masrol et al. 2015a). Hence, other types of pulping such as chemical soda-anthraquinone (soda-AQ) pulping and various bleaching and beating processes are proposed to improve the characteristics of durian rind pulp produced via chemi-mechanical pulping.

Soda-AQ, a common chemical pulping method, is mainly suitable for non-wood fibres. Soda-AQ pulp produces the highest content of alpha-cellulose and has the highest viscosity compared with soda, kraft and kraft-AQ processes (Ibrahim 2002). The quality of soda-AQ kenaf pulp was comparable or even slightly better than kraft and kraft-AQ kenaf pulps (Ang et al. 2010). Several non-wood based natural pulps have been successfully produced using soda-AQ pulping such as kenaf (Adnan et al. 2004), oil palm empty fruit bunch (EFB) (Ibrahim 2003b), *Gigantochloa scortechinii* (Mohd Hassan et al. 2013), coir fibre (Main et al. 2014), and oíl palm male flower spikes (Masrol et al. 2014). However, anthraquinone cannot be applied to food contact paper and paper products (OEHHA 2011), BfR 2013).

A multistage bleaching sequence is usually applied to improve pulp ISO brightness. Elemental chlorine-free (ECF) and totally chlorine free (TCF) treatments were developed to avoid chlorine or chlorinated compound-based bleaching (Jiménez et al. 2008). Paper manufacturers usually prefer ECF pulp, even if the gap (i.e. environmental impact, pulp properties such as strength, yield, brightness and cost effectiveness) between ECF and TCF pulp is narrowing due to the lower production cost (Bajpai 2012). It is necessary to utilise the ECF or TCF bleaching sequences for pulp to increase awareness of the danger associated with chlorine and its derivatives (Tanaka et al. 2004, Carvalho et al. 2008). Beating or refining is a common mechanical treatment to improve pulp characteristics.

Beating improves the characteristics of paper sheet made from virgin pulp, which has low strength, high bulkiness and a rough surface (Bhardwaj et al. 2004). Masrol et al. (2015b) concluded that the overall physical and mechanical characteristics of soda-AQ oil palm male flower spikes were enhanced after beating between 0 and 3000 revolutions.

This preliminary study investigated the effects of ECF bleaching and beating processes on the characteristics of durian rind virgin unbeaten and unbleached soda-AQ pulp. The findings of this research offer huge research opportunities for the utilisation of durian rind as a newly explored raw material for the pulp and paper industry.

MATERIALS AND METHODS

Material preparation

Durian rinds from D24 variety were collected from Batu Pahat, Johor, Malaysia. Firstly, durian rinds (Figure 1a) were cleaned from the residual aril and dirt. Next, the middle part of durian rind connected to the aril was removed (Figure 1b). Using a knife, the durian rinds were sliced into 10 to 15 mm wide strips, followed by removing the sharp and hard spines (Figure 1c). Durian rind slices were then cut into cubes (Figure 1d) and dried naturally (and economically) under direct sunlight (Figure 1e) for 3 to 5 days to reduce the moisture content as described by Masrol et al. (2015a). Durian rind requires 7 days to reduce moisture content from 85 to 13% when dried under the sun (Zddin & Risby 2010). Finally, the dried durian rind cubes (Figure 1f) were stored in air-tight containers until use. Results of chemical analysis of durian rind conducted according to the standards are shown in Table 1. With alpha-cellulose content of 34.9%, durian rind is suitable and promising for pulp and paper alternative material. Plant fibers with an alpha-cellulose content of 34% and higher are considered as promising material for pulp and paper production (Nieschlag et al. 1960).

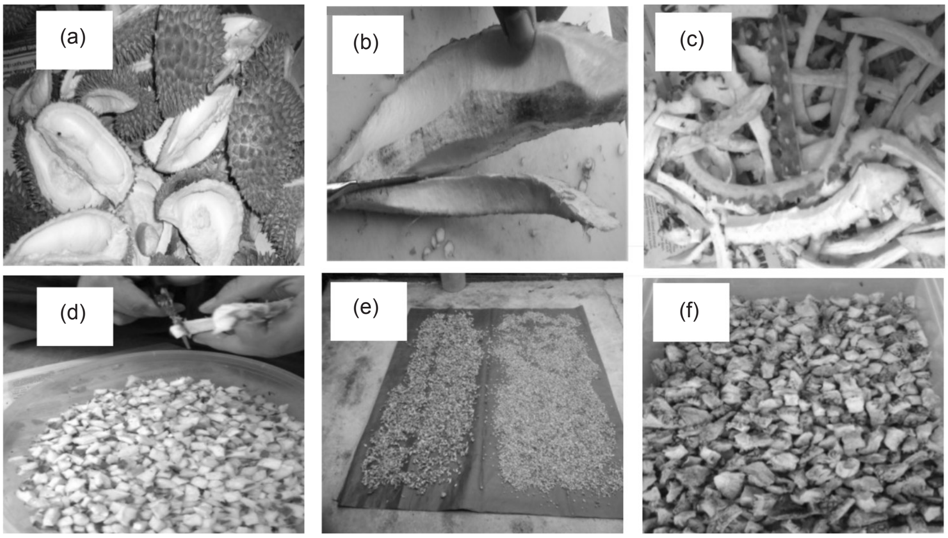

Figure 1 Raw material preparation: (a) fresh durian rinds, (b) middle part of durian rind connected to the aril removed, (c) durian rind slices, (d) durian rind cubes, (e) natural drying process, and (f) dried durian rinds

Table 1 Chemical composition of durian rind

Composition	Value (%)
Holocellulose	55.3 ± 0.7
Alpha-cellulose	34.9 ± 0.9
Ash	6.1 ± 0.04
Lignin	19.3 ± 0.5
Pentosan	10.6 ± 0.1

Soda-anthraquinone pulping

Soda-AQ chemical pulping method was conducted to produce durian rind pulp. An amount of 1000 g oven-dry weight of dried durian rinds were mixed together with anthraquinone ($C1_4H_8O_2$) and sodium hydroxide (NaOH) solution in a rotary digester. The initial digester temperature was set at 25 °C. The amount of anthraquinone (0.1%) based on the oven-dry weight of the rinds added to the pulping liquor was the maximum allowable limit as specified by FDA (2015). Soda-AQ pulp produced with 0.1% anthraquinone has the highest tensile and burst indices (Akgül & Tozluoglu 2009). Maximum cooking temperature was 170 °C and time to maximum temperature was 90 min, while time hold was 120 min (Ibrahim 2003b, Adnan et al. 2004, Ibrahim et al. 2011). Active NaOH charge used was 20% of the oven-dry weight of the rinds and liquor-to-material ratio was 7:1 (Ibrahim 2003b, Masrol et al. 2014, 2015b).

After digestion was complete, the softened durian rind pulp was disintegrated in a hydropulper and washed thoroughly on a wire mesh screen to remove the black liquor. The pulp was screened on a fractionator with a slot size of 0.15 mm to remove oversize debris (TAPPI 2012). This process is crucial to ensure smooth and uniform paper texture (Mohd Hassan et al. 2013). A spin-dry extractor was used to remove excess water. The screened pulp was dispersed into smaller sizes using commercial mixer. Finally, durian rind soda-AQ pulps were stored in a chiller at 6 °C until used for preparation of hand sheets.

ECF bleaching process

ECF bleaching process uses chlorine dioxide instead of chlorine gas, which is toxic. The five stages of the ECF bleaching sequence (chlorine dioxide (D_1) – alkali extraction (E) – chlorine dioxide (D_2) – alkali extraction (E) – peroxide (P)—D_1ED_2EP) were conducted according to Ashori et al. (2006). Instead of the conventional chlorine dioxide final stage, this study employed a final hydrogen peroxide stage due to its benefit to paper characteristics, especially brightness reversion (Ashori et al. 2006, Carvalho et al. 2008). Table 2 shows the overall bleaching process conditions and the chemical charges. A total of 65 g of oven dried unbleached durian rind soda-AQ pulp was used for bleaching.

Table 2 Bleaching sequence details

Stage	D_1	E	D_2	E	P
Bleaching step	Chlorine dioxide bleaching	Alkaline extraction with sodium hydroxide	Chlorine dioxide bleaching	Alkaline extraction with sodium hydroxide	Peroxide bleaching
Chemical charge	3% ClO_2 2% acetic acid	2% NaOH	3% ClO_2 2% acetic acid	2% NaOH	2.5% NaOH 2.5% Na_2SiO_3 0.2% DTPA 3.5% H_2O_2
Pulp consistency (%)	10	10	10	10	10
Time (min)	120	60	90	60	90
Temperature (°C)	70	70	70	70	70

ClO_2 = chlorine dioxide, NaOH = sodium hydroxide, Na_2SiO_3 = sodium silicate, H_2O_2 = hydrogen peroxide and DTPA = diethylene triamine pentaacetic acid

For each stage, the consistency of slurry was adjusted to 10% with distilled water and then sealed inside a polyethylene bag and immersed in water bath at 70 °C for the times shown in Table 2. The pulp was manually kneaded every 10 min to mix the slurry and enhance chemical absorption. After bleaching ended, the pulp was washed and cleaned thoroughly under running water until there was no slime left. Inter-stage washing, which removes dissolved impurities, improves the extent and efficiency of bleaching (Mohamad Jani & Rushdan 2014). After washing, the bleached pulp was spin-dried using an extractor to reduce excess water and then dispersed using commercial mixer before continuing to the next pulping stage. The air-dry weight and moisture content of the final stage ECF bleaching were measured to determine the final yield percentage of bleached durian rind soda-AQ pulp. Finally, bleached durian rind soda-AQ pulps were stored in chillers at 6 °C overnight to reach equilibrium moisture content before laboratory hand sheets were prepared.

Beating process

A laboratory PFI mill machine located at the Pulp and Paper Laboratory, Forest Research Institute Malaysia, Kepong was used to beat 24 g oven-dry weight of unbeaten screened pulp (TAPPI 2008) at 500 and 1000 revolutions.

Preparation of laboratory hand sheets

Durian rind soda-AQ laboratory paper sheets were produced using a semi-automatic sheet machine (TAPPI 2002, MS 2007c). The sheets were produced according to a standard grammage of 60 ± 3 gsm. Pulp drainage time and freeness (Canadian Standard Method) test were evaluated according to TAPPI (1999a, b respectively). The sheets were dried and conditioned at 23 ± 1 °C and 50 ± 2% relative humidity according to TAPPI (2003) and MS (2001a) for at least 24 hours before further evaluation.

Characteristics of hand sheets

Structural, mechanical and optical properties of hand sheets were determined in a controlled temperature (23 ± 1 °C) and relative humidity (50 ± 2%) as stipulated in TAPPI (2003) and MS (2001a). Sampling was conducted according to MS (2003) and laboratory hand sheets were evaluated according to Malaysian Standard ISO for various characteristics, namely, grammage (MS 2001b), moisture content (MS 2010a), paper bulk density (MS 2007a), brightness (MS 2010c), opacity (MS 2010d), tensile index (MS 2010b), tear index (MS 1999a), burst index (MS 2007b) and number of folds (MS 1999b).

Image analysis

Image of fibre surface was observed using a scanning electron microscope (SEM). Paper samples (8 mm long × 5 mm wide) were coated with gold and attached to the specimen mounts with double sided conductive adhesive tape before examination.

RESULTS AND DISCUSSION

Pulp and paper characteristics: effect of ECF bleaching

The oven-dry weight of unbleached soda-AQ durian rind pulp decreased by about 32.0% from 65.0 to 44.2 g after D_1ED_2EP sequence of ECF-bleaching (Table 3). Intense bleaching conditions increase the loss of pulp (Zeinaly et al. 2013). Thus, yield was decreased to 68.03% after the bleaching process. Drainage time decreased from 20.2 to 12.20 s as the ECF bleaching was applied to the unbleached pulp, resulting in faster paper sheet formation. The value of Canadian Standard Freeness (CSF) for unbleached pulp was 210.25 mL, which increased to 297.25 mL due to ECF bleaching.

Paper bulk density increased by about 7.1% after ECF bleaching (Table 4). The D_1ED_2EP bleaching sequence increased tensile index, tear index, burst index and number of folds by approximately 2.4, 44.9, 16.3 and 37.1% respectively. Bleaching of coir fibre pulp produced paper with better tensile index, burst index, tear index and folding endurance (Mohamad Jani & Rushdan 2014). Higher values of tensile index and tear index of wheat straw pulp were also achieved in ECF sequences (Ghosh 2006).

Table 3 Effect of ECF bleaching on soda-AQ durian rind pulp properties

Characteristic	Unbleached soda-AQ	D_1ED_2EP
Bleaching yield (%)	100	68.03
Losses (%)	0	31.97
Moisture content (%)	84.96	82.29
Oven-dry content (%)	15.04	17.71
Oven-dry weight (g)	65	44.22
Drainage time (s)	20.2	12.2
CSF (mL)	210.25	297.25

EFC = elemental chlorine-free, soda-AQ = soda-anthraquinone, CSF = Canadian Standard Freeness, D_1ED_2EP sequence is explained in Table 2

Table 5 shows that soda-AQ durian rind ECF bleached pulp achieved 61.89% of ISO brightness after completing D_1ED_2EP bleaching sequence. However, opacity was reduced to 81.16% compared with unbleached pulp. Similar results were shown by Mohamad Jani and Rushdan (2014) in their study in which bleaching of coir fibre pulp produced paper with better brightness properties and lower opacity. Simultaneously, the scattering coefficient was increased from 18.96 in unbleached pulp up to 26.48 in bleached pulp. The final brightness is increased through the reduction of light absorbing chromophoric groups in lignin, resulting in lower light absorption coefficient and higher scattering coefficient (Zhao et al. 2010, Resalati et al. 2012). Unbleached pulp is able to absorb more light, which may be influenced by the higher lignin content in the pulp (Mohamad Jani & Rushdan 2014). The fibre flexibility and relative bonding area which influence the strength of paper can be determined by the apparent density and light-scattering coefficient of the paper (Ibrahim 2003b). Paper sheet sample of bleached durian rind soda-AQ pulp was brighter in colour (near to white) compared with unbleached pulp (Figure 2).

Pulp and paper characteristics: effect of beating

Drainage time for unbeaten soda-AQ durian rind pulp was 20.7 s which increased to 53.2 s after beating of 500 revolutions (Table 6). Drainage time continued to increase to 76.2 s after 1000 revolutions. Drainage time increased as refining degree increased due to shortening of fibres and production of fines (Ibrahim 2003a). CSF

Table 4 Effect of ECF bleaching on physical and mechanical characteristics

Characteristic	Unbleached pulp	D_1ED_2EP	% difference
Paper bulk density (g cm^{-3})	0.715 ± 0.002	0.766 ± 0.004	7.13
Tensile index (N m g^{-1})	55.72 ± 0.30	57.07 ± 1.06	2.42
Tear index (m N m^2 g^{-1})	6.44 ± 0.12	9.33 ± 0.19	44.90
Burst index (kPa m^2 g^{-1})	3.01 ± 0.04	3.50 ± 0.04	16.30
Number of double folds	264 ± 6	362 ± 10	37.12

Values are means ± standard deviations; EFC = elemental chlorine-free, D_1ED_2EP sequence is explained in Table 2

Table 5 Effect of ECF bleaching (D_1ED_2EP) on optical characteristics of paper

Durian rinds soda-AQ pulp	Brightness (%)	Opacity (%)	Scattering coefficient ($m^2 kg^{-1}$)	Absorption coefficient ($m^2 kg^{-1}$)
Unbleached	19.21	98.32	18.96	19.50
ECF bleached (D_1ED_2EP)	61.89	81.16	26.48	1.73

EFC = elemental chlorine-free, soda-AQ = soda-anthraquinone, D_1ED_2EP sequence is explained in Table 2

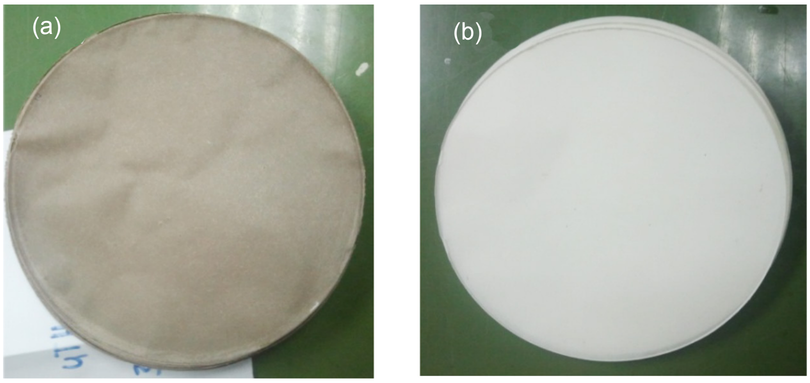

Figure 2 Durian rind soda- anthraquinone 60 gsm paper sheets: (a) unbleached and (b) D_1ED_2EP bleached; D_1ED_2EP sequence is explained in Table 2

Table 6 Effects of refining process on pulp characteristics

Characteristic	Unbeaten	500 revolutions	1000 revolutions
CSF (mL)	210.25	190.50	183.50
Drainage time(s)	20.7	53.2	76.2

CSF = Canadian Standard Freeness

value of unbeaten durian rind soda-AQ pulp was 210.25 mL but the value decreased until it reached 183.50 mL at 1000 revolutions (Table 6). CSF values decreased as beating revolutions increased due to increment of fibre surface and density of paper (Main et al. 2015). Pulp with the low CSF value has high probability of water-to-fibre bonding which causes poor draining of water from the pulp (Mohd Zukeri et al. 2013), hence the poor drainage when soda-AQ durian rind pulp was refined at 1000 revolutions. Higher CSF value corresponds to higher and faster draining (Gharehkhani et al. 2015).

Paper bulk density increased to 0.920 g cm^{-3} after 1000 revolutions due to increased compaction as fibre walls collapse upon beating (Table 7). Mechanical properties (i.e. tensile index, burst index, folding endurance and tear index) increase with increasing apparent or bulk density (Ibrahim 2003b, Rushdan et al. 2007). Tensile index was highest for paper sheet subjected to beating at 1000 revolutions (71.17 N m g^{-1}) compared with 500 revolutions (68.21 N m g^{-1}), while paper from unbeaten pulp had the lowest reading (55.72 N m g^{-1}). Burst index also increased with the increased beating revolutions. Pulp refining increased the collapse of fibre and promoted greater contact area between fibres, leading to higher value of burst index (Main et al. 2015). These trends were also observed with other raw materials such as semantan bamboo (Mohd Hassan et al. 2013), wood and non-wood (Banavath et al. 2011), and EFB (Jiménez et al. 2009).

Increment of tensile and burst index could be promoted by increment of fines fraction due to beating (Mohd Zukeri et al. 2013, Main et al. 2015). Fines contribute to sheet consolidation, wet web strength and interfibre bonding (Banavath et al. 2011). Fines also reduce

Table 7 Effects of refining process on physical and mechanical characteristics of hand sheet

Characteristic	Unbeaten	500 revolutions	1000 revolutions
Paper bulk density (g cm^{-3})	0.715 ± 0.002	0.889 ± 0.003	0.920 ± 0.002
Tensile index (N m g^{-1})	55.72 ± 0.30	68.21 ± 0.28	71.17 ± 0.87
Burst index (kPa m^2 g^{-1})	3.01 ± 0.04	4.54 ± 0.03	4.95 ± 0.04
Tear index (m N m^2 g^{-1})	6.44 ± 0.12	7.11 ± 0.35	8.87 ± 0.12
Number of double folds	264 ± 6	1327 ± 82	1893 ± 73

Values are means ± standard deviations

the possibility of fibres being pulled out of the paper plane, and thus, enhancing pulp network resistance to burst impact (Mohd Zukeri et al. 2013). This is the reason for decreased CSF and increased drainage time by beating or refining (Table 6). Decrease in CFS and increase in drainage time are indicators of fines fraction due to beating. Fines retain two or three times more water than fibres and behave like gel to cause pulp freeness to decrease (Ibrahim 2003a).

The highest tear index (8.87 m N m^2 g^{-1}) and number of folds (1893) were also observed in pulp beaten at 1000 revolutions (Table 7). Beating enhances tearing properties and number of folds (Mohd Hassan et al. 2013, Masrol et al. 2014). Thus, the overall mechanical characteristics of soda-AQ durian rind pulp were enhanced by beating in the range of 0 to 1000 revolutions.

Image analysis

Fibre surface morphologies of control pulp, ECF bleached pulp and beaten pulp were observed by SEM as shown in Figures 3–5. Control unbleached durian rind soda-AQ paper (Figure 3a) had smoother surface and less fibrillation compared with the ECF-bleached soda-AQ paper (Figure 3b). With unbleached fibres mostly intact, there are more long fibres, and the fibre surface of control pulp is smoother (Chen et al. 2015). Bleached paper surface were rougher and less intact, and more fibrils and longitudinal tearing were observed on the fibre surface. This effect demonstrated that bleached pulp was delignified on the fibre surface, releasing more fibrils than control unbleached pulp (Chen et al. 2015). Fibre morphology changed as bleaching process was applied to control pulp and resulted in better fibre-to-fibre bonding and higher paper strength. The improvement in paper strength is caused by the collapse of fibre lumens due to delignification, dissolving of other fibre components and increment of cellulose fibre swelling that lead to increase of fibre-to-fibre contact area and surface area (Chen et al. 2015). Increment of collapsed fibre lumens and fibre swelling corresponds with increased CSF and decreased drainage time (faster) in ECF-bleached soda-AQ durian rind pulp (Table 3). The ECF-bleached durian rind soda-AQ pulp fibre arrangement (Figure 3b) also resulted in higher density (Table 4) and scattering coefficient (Table 5) compared with unbleached pulp (Figure 3a).

Increased fibrillation was observed on the surface of pulps produced at 500 and 1000 revolutions (Figure 4a and Figure 4b) compared with unbeaten pulps (Figure 3a). Fibres from unbeaten slurry had smooth and well-preserved surface without any appreciable damage or external fibrillation. Internal fibrillation increases fibre swelling and flexibility by loosening the cell wall structure, and external fibrillation increases the outer surface of fibres (Banavath et al. 2011). Beating increases fibre internal and external fibrillation and the surface contact area between fibres, producing denser paper with higher strength properties (Main et al. 2015). External fibrillation was clearly seen on the surface of soda-AQ durian rind beaten pulps (Figure 4). These fibrils increased the surface area of fibre (allowing better interaction between fibres), as well as increased hydrogen bonding and filled empty spaces (González et al. 2012). Beating increases the surface charge and specific surface area, thus enhancing paper fibre-to-fibre bonding (Bhardwaj et al. 2007, Banavath et al. 2011, González et al. 2012).

Masrol et al. (2015a) reported that fibre arrangement and bonding of durian rind pulp

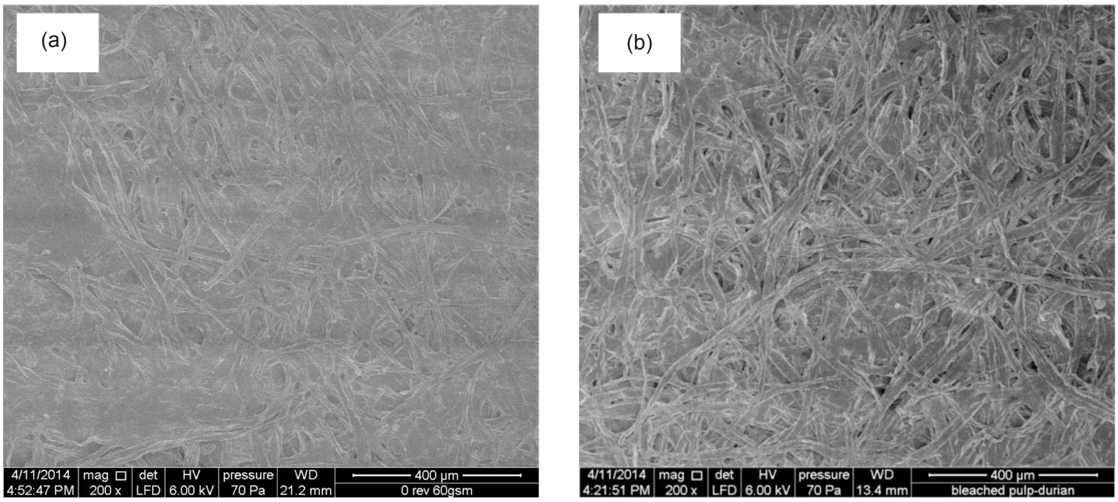

Figure 3 Scanning electron micrograph of the surface morphology of soda-anthraquinone durian rind pulp: (a) unbleached and unbeaten and (b) ECF-bleached; 200× magnification; EFC = elemental chlorine free

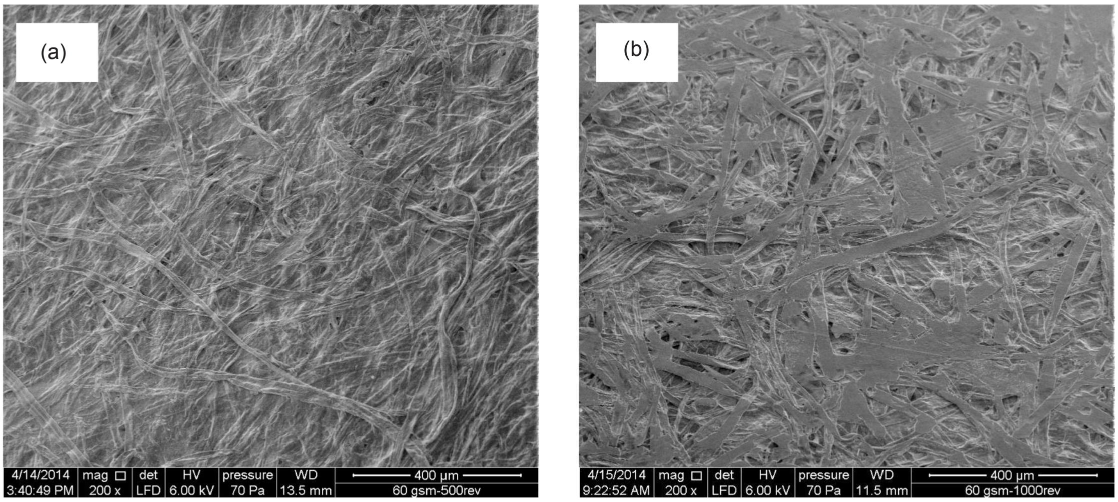

Figure 4 Scanning electron micrograph images of the surface morphology of soda- anthraquinone durian rinds pulp beaten at (a) 500 revolutions and (b) 1000 revolutions; 200× magnification

produced by chemi-mechanical pulping process were not uniform, not straight and had some kinks and crimps compared with soda-AQ pulp. The soda-AQ pulp (Figure 5) was more compact than pulp produced through chemi-mechanical pulping; hence the higher bulk density value of 0.715 g cm^{-3} compared with 0.458 g cm^{-3} for pulp produced through chemi-mechanical pulping (Masrol et al. 2015a). The reason for lower strength in the latter is that during mechanical defibrillation, lignin is plasticised and remains in the pulp (Holik 2006).

CONCLUSIONS

Durian rind pulp was produced via chemical soda-AQ pulping, but the screened yield of this pulp was low (23.8%). It could be improved by optimising pulping variables such as active alkali percentage, maximum temperature and time at maximum temperature. EFC bleaching using the five-stage D_1ED_2EP sequence improved the characteristics of unbleached soda-AQ durian rind pulp. The ISO brightness value reached 61.89% with D_1ED_2EP bleaching, which was

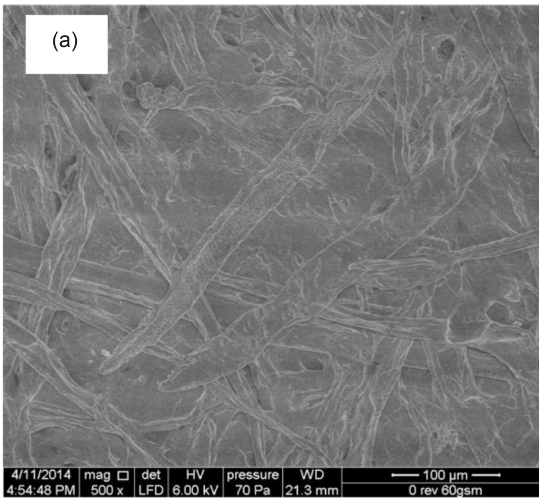

Figure 5 Scanning electron micrograph images of the surface morphology of unbleached and unbeaten soda-anthraquinone durian rinds pulp; 500× magnification

a lot higher compared with unbleached pulp (19.21%). Beating process significantly improved mechanical characteristics of unbeaten durian rind soda-AQ pulp and paper. However, higher beating revolutions should be considered to obtain the optimum values. SEM analysis showed that fibre-to-fibre bonding was improved by the beating and bleaching processes, resulting in improved mechanical characteristics. Pulping variable optimisation is needed in order to obtain the optimum pulping conditions especially for pulp yield. This study has demonstrated that durian rind have great potential as an alternative raw material for the pulp and paper industry. The findings also unlocked a huge area for research and improvement on utilising durian rind as a packaging raw material.

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