

## Physico-chemical and antioxidant properties of mesocarp and exocarp from *Borassus flabellifer*

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### Abstract

The physico-chemical and antioxidant activity of the mesocarp and exocarp of *Borassus flabellifer* were determined to assess the potential of the fruit as a food ingredient. Proximate analysis indicated that both mesocarp and exocarp had a high fibre content of 23.92% and 28.20%, respectively, of which 62.5% and 79.4% were insoluble dietary fibre. The soluble dietary fibre was < 0.50% for both samples. Hemicellulose was the major component in the exocarp followed by cellulose and lignin. Meanwhile for the mesocarp, cellulose was the highest component followed by hemicellulose and lignin. Fructose, galactose, glucose, mannose and sucrose were detected in both samples. Phenol and tannins were present in both mesocarp and exocarp; however, saponin was only detected in the mesocarp. Radical scavenging activity (157.05 mM TE/g) and reducing power (213.05 mM Fe<sup>2+</sup>) of the exocarp were significantly higher as compared to those of the mesocarp.

### Keywords

Composition  
Antioxidants  
Fibre  
Sugar

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## Introduction

*Borassus flabellifer* Linn. of the Arecaceae family is known as kelapa laut Afrika in Malaysia. The palmyrah palm is widely cultivated and distributed in tropical Asian countries such as Bangladesh, Thailand, Myanmar, India, Sri Lanka and Malaysia (Jansz *et al.*, 1994; Ariyasena *et al.*, 2000; 2001). In 2002, there are about 140 million palmyrah palms distributed worldwide (Naguleswaran *et al.*, 2010). To date, statistical data are not available on global production and trade; however there are 10 million palms on 25,000 ha (two-thirds in Jaffna district) in Sri Lanka, and 60 million palms (two-thirds in Tamil Nadu) in India were reported. Central Cambodia and central Myanmar accounted to 1.8 million and 2.5 million palms, respectively on 25,000 ha. While, in Central and East Java and Madura (Indonesia), there are 0.5 million palms on 15 000 ha.

The fruit, sap and young shoots are consumed in many parts of these tropical countries. In Sri Lanka, the pulp is eaten fresh or used for making confectionary,

cordials, jams and potable alcohol (Rupasena *et al.*, 1995; Ariyasena *et al.*, 2001; Perera *et al.*, 2015). The pulp is rich in pectin, sugar, carotenoids, antioxidants, vitamin C and minerals (Ariyasena *et al.*, 2001; Tikkanen, 2007). The ripe fruit pulp can be processed into toffee, soft beverages, sweets and delicious food items (Das and Das, 2003). In Malaysia, *B. flabellifer* tree is grown in several states, and the immature soft juicy seed nuts are very popular as a natural drink. However, the husks which consist of the mesocarp and exocarp (40% - 55% w/w of fruit) are discarded. This discarded portion could be a potential source for the food ingredient.

Negligible reports are available on the chemical composition of immature mesocarp and exocarp of the *B. flabellifer* fruit. To date, limited work has been reported on the endosperm, seed coat and pulp from the mature fruit (Rupasena *et al.*, 1995; Ariyasena *et al.*, 2001; Alamelumangai *et al.*, 2014). A comprehensive study on the physico-chemical composition and antioxidant properties of the mesocarp and exocarp of the young *B. flabellifer* is

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still scarce. Hence, in the discussion, *Cocos nucifera* (coconut) is used for comparison as it is the closest palm family to *B. flabellifer*. Therefore, the objectives of the present work were to determine the physico-chemical content and antioxidant activities of the mesocarp and exocarp residues in order to assess their potentials as a food ingredient.

## Materials and methods

### Sample

The mesocarp and exocarp of the young fruit of 3 - 4 weeks old (380 - 590 g) were collected from Cameron Highland, Pahang, Malaysia. The samples were carefully selected from the heap of discards, freed of surface dirt and transported to the laboratory in insulated boxes (4°C).

### Composition and physicochemical analysis

#### Sample preparation

The collected fresh mesocarp was separated from the exocarp, cut into smaller pieces measuring 2 × 3 cm, and oven-dried at 50°C for 24 h. The oven-dried samples were ground in a grinder for 5 min (FZ-240, Zhong Xing, Malaysia), sieved through a 0.5 mm sieve and packed in air-tight containers. Packed samples were stored at room temperature (30°C) away from light until further analysis.

#### Proximate composition

The proximate composition (protein, lipid, moisture and ash) of the mesocarp and exocarp were determined in triplicate based on AOAC (2012). Carbohydrate content was determined by the difference.

#### Crude, soluble and insoluble dietary fibre

The crude fibre was determined based on AOAC (2012). An enzymatic-gravimetric procedure (AOAC, 2012) was employed for the determination of total dietary fibre (TDF), soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) contents of samples. About 1 g of sample powder was treated with  $\alpha$ -amylase (EC 3.2.1.1, Sigma-Aldrich, Germany) before digesting the sample with protease (EC 3.4.21.62, Sigma-Aldrich, Germany) and amyloglucosidase (EC 3.2.1.3, Sigma-Aldrich, Germany). The enzymatic treatments were conducted to remove protein and starch present in the sample. Consequently, IDF was filtered using the Fibertec machine (E1023, USA) and the residue was rinsed with warm distilled water. Four volumes of 95% (v/v) ethanol were added to the filtrate and the temperature

was kept constant at 60°C to precipitate SDF. The precipitate was filtered by the Fibertec machine and dried in a hot air oven at 105°C for 24 h, after which samples were weighed. Both SDF and IDF residues were corrected for ash (by incinerating the sample at 525°C), protein (by the Kjeldahl procedure) and a blank for the final calculation of SDF and IDF contents. The blank sample was prepared as the unknown sample except minus of the sample. The blank sample was also employed to evaluate any contribution of the reagents to the residue. The analyses were made in triplicates.

$$\%IDF \text{ or } \%SDF = \frac{(\text{Weight of Residue} - \text{protein} - \text{ash}) - \text{blank}}{\text{Weight of Sample}} \times 100 \quad (\text{Eq. 1})$$

$$\%TDF = \%IDF + \%SDF \quad (\text{Eq. 2})$$

#### Total soluble solids and pH

The total soluble solids and pH were determined using a refractometer (Mettler Toledo, Schwerzenbach, Switzerland) and a pH meter (HI 221, Hanna, India), respectively. Briefly, 10 g of the sample was ground with 50 mL of distilled water and filtered through filter paper (Whatman No1, USA). The filtrate was collected and the volume was made up to 100 mL. The total soluble solids and pH measurement of triplicate samples were determined and recorded.

#### Colour

Colour of the powdered mesocarp and exocarp were analysed using a chroma meter (00328QO, Konika Minolta, Japan) where  $L^*$  was for lightness from 0 (black) to 100 (white);  $a^*$  and  $b^*$  for redness (+a) to greenness (-a) and yellowness (+b) to blueness (-b), respectively (Reddy *et al.*, 2015). Samples were analysed in triplicate.

#### Sugar composition

Sugar composition of mesocarp and exocarp was determined according to Puwastien *et al.* (2011) and adopted from AOAC (1993a; 1993b). Briefly, 5 g of samples was neutralised with 3 g of CaCO<sub>3</sub> before 25 mL of 85% ethanol was mixed to the sample. The sample was then incubated at 60°C in a shaker bath for 1 h, then filtered and re-extracted three times using 25 mL of 85% ethanol for each extraction. The combined filtrate was then evaporated at 45°C until the remaining solution was approximately 3

mL. The concentrated filtrate was made up to 10 mL using distilled water before being filtered with 0.45  $\mu\text{m}$  cellulose acetate filter prior to sample injection. The identification and quantification of sugar were performed using HPLC (Agilent 1200 Series, USA) with refractive index detector and the separation was performed by a Hypersil (APS2) NH<sub>2</sub> column (250 mm  $\times$  4.6 mm  $\times$  5  $\mu\text{m}$ ) of Thermo Scientific (USA). A mixture of acetonitrile:water:ethanol (82:17.5:0.5; v/v) was used as the mobile phase with a flow rate of 1.5 mL/min. The column and detector temperature were maintained at 25 - 30°C. Standard sugars used were glucose, fructose, mannose, sucrose and galactose (Sigma-Aldrich, USA). Duplicate injections were carried out for each sample. Sugars were quantified by the generation of a three-point calibration curve of the various sugar standards. The result obtained was expressed as a weight/weight percentage (g/100 g) of each sugar on the sample.

#### *Extraction of bioactive compounds*

The bioactive compounds were first extracted following the method of Asma *et al.* (2016). A microwave-assisted extraction was performed to extract the active component of mesocarp and exocarp in an experimental microwave oven (ME71K, Samsung, Korea). About 10 g of mesocarp and exocarp samples were mixed with 200 mL of 0.1 M sodium hydroxide. The mixtures were then heated at a microwave power of 300 W for 2 min and allowed to cool down at room temperature before filtered using a filter paper (150 mm, CHM, Germany). All filtrates were kept at 4°C in the dark for the phytochemical analysis.

#### *Determination of phytochemical*

The filtrates from the previous extraction were analysed for determination of secondary metabolites such as alkaloids, saponins, flavonoids, steroid, cardiac glycosides, tannins, terpenoids and anthraquinone based on the standard procedures (Obadoni and Ochuko, 2002; Obidoa *et al.*, 2010; Aiyegroro and Okoh, 2010). The positive results from this analysis were then furthered for quantitative analysis using the standard procedures as follow. All analyses were done in triplicate.

#### *Determination of total phenolic content*

The total phenolic content in the extract was determined by the Folin-Ciocalteu reagent method (Aiyegroro and Okoh, 2010). Approximately 200  $\mu\text{L}$  samples were added to 1.5 mL of diluted Folin-Ciocalteu reagent (1:10, v/v) and allowed to equilibrate for 5 min. The sample was then mixed

with 1.5 mL of 0.566 M Na<sub>2</sub>CO<sub>3</sub> and incubated at room temperature for 90 min. The absorbance of the mixture was measured at 725 nm by a spectrophotometer (Genesys 20, USA). Triplicates of each sample were made for each analysis. Standard gallic acid ranging from 0 - 125  $\mu\text{g/mL}$  was treated similarly as 200  $\mu\text{L}$  of the sample above. The result was expressed as mg of GAE/g sample.

#### *Determination of tannins*

Tannin content in the extract was evaluated according to Eleazu *et al.* (2012). Briefly, 1 mL of sample extract was mixed with 20 mL of distilled water, 2.5 mL of Folin-Denis reagent and 10 mL of 17% Na<sub>2</sub>CO<sub>3</sub> into 50 mL volumetric flask, and mixed thoroughly. The mixture was topped up with distilled water, mixed well and allowed to stand for 20 min to allow a bluish-green colouration to develop. Standard tannic acid solutions of 0 - 500 ppm were prepared as above. The absorbance of the tannic acid standards and samples was spectrophotometrically read at 760 nm. Tannin content of the sample was determined against the tannic acid standard curve and the result was expressed in terms of mg of tannic acid equivalence (TAE) per 100 g of dried sample.

#### *Determination of saponin content*

According to Obadoni and Ochuko (2002), saponin can be determined by mixing 20 g of sample with 100 mL of 20% aqueous ethanol and heated in a water bath (55°C) for 4 h with continuous stirring. The mixture was filtered and the residue re-extracted with another 200 mL of 20% ethanol and both extract were poured together and the combined extract was reduced to about 40 mL at 90°C and transferred to a separating funnel where 20 mL of diethyl ether was added and shaken vigorously. Re-extraction by partitioning was done repeatedly until the aqueous layer become clear in colour. The saponins were extracted, with 60 mL of n-butanol. The pooled n-butanol extracts were washed twice with 10 mL of 5% aqueous sodium chloride. The remaining solution was evaporated using a rotary evaporator at 70°C before drying to a constant weight in the oven at 105°C. Samples were analysed in triplicate, and saponin content was determined by difference and calculated as a percentage of the original sample.

#### *Antioxidant activities*

##### *Determination of DPPH radical scavenging assay*

The antioxidant capacity of the samples was spectrophotometrically estimated by determining the free radical scavenging capacity evaluated with the

stable radical DPPH according to Fernandez-Orozco *et al.* (2011). A volume of 60  $\mu$ M of DPPH solution in methanol was prepared prior to mixing with 3.9 mL of the solution containing 0.1 mL extracts. The mixtures were kept in the dark for 30 min at room temperature (27°C) and the absorbance was measured at 517 nm with methanol as the blank. Standard Trolox (100 - 500  $\mu$ M/mL) was similarly treated as the sample. The results were expressed as mol of Trolox equivalent DPPH radical scavenging activity per g of sample.

#### *Ferric reducing antioxidant power (FRAP)*

The antioxidant capacity was determined using a modification of the FRAP assay described by Langley-Evans (2000). FRAP reagent was freshly prepared by mixing acetate buffer (100 mL), 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ) solution (10 mL), and ferric chloride solutions (10 mL) before incubation at 37°C. Next, 100  $\mu$ L of sample was mixed with 3 mL of working FRAP reagent. Following 10 min incubation at 30°C, absorbance was immediately measured at 593 nm. FRAP results for each sample were calculated using a dilution series of ferrous sulphate (0.1 - 1 mM), and the results of antioxidant activity were expressed as mM ferrous per g of sample. Each sample was measured in triplicate.

#### *Lignocellulosic composition*

Holocellulose was determined based on a chlorite method described by Sabiha-Hanim *et al.* (2011). Cellulose was calculated after a holocellulose content determination and hemicellulose content was estimated from the difference between the holocellulose and cellulose concentrations (Sabiha-Hanim *et al.*, 2011). The total lignin content was determined as the sum of acid insoluble lignin (or Klason lignin) based on the standard method T222 om-88 of TAPPI (Berlin *et al.*, 2006).

#### *Statistical analysis*

Statistical analysis and comparisons among means obtained from triplicate were carried out using the statistical package SPSS 12 (SPSS Inc., Chicago, IL.). The data collected for the physico-chemical and antioxidant properties were analysed by one-way analysis of variance with one factor. Tukey's post hoc test was applied for comparisons of means; while differences were considered significant at  $p < 0.05$ .

## **Results and discussion**

Proximate composition the mesocarp and the exocarp of *B. flabellifer*

Proximate composition of the mesocarp and

exocarp obtained from *B. flabellifer* (Table 1) were slightly higher than the fresh pulp of mature *B. flabellifer* (Vengaiyah *et al.*, 2015). The ash content of the mesocarp and exocarp were between 2.79% - 3.66% (w/w), respectively. The ash content is indicative of the mineral (especially the macro minerals) content of the sample and the low ash content could increase the presence of these co-products in food application (López-Vargas *et al.*, 2013). Coconut is the closest palm family to *B. flabellifer*, and has been reported by Prado *et al.* (2014) to have similar equivalent moisture content with the mesocarp and exocarp but lower protein and ash content.

#### *Crude fibre, soluble and insoluble dietary fibre*

The crude fibre, total dietary fibre (TDF), insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) of the mesocarp and exocarp, and the ratio between IDF and SDF, are shown in Table 1. Crude fibre in food or plant is an indication of the level of non-digestible carbohydrate and lignin. The fibre content of both mesocarp and exocarp is considered low in content. The high level of crude fibre content can cause intestinal irritation, lower digestibility, and decrease nutrient usage (Oladiji *et al.*, 2005). The exocarp and mesocarp had respectively 62.46% and 79.44% of IDF. The SDF for both samples was less than 0.50% (dry weight basis). The high TDF content in both samples may be related to the high content of total indigestible carbohydrates in the mesocarp and exocarp, where the amount of available carbohydrate. Overall, the IDF content in both samples was significantly higher ( $p < 0.05$ ) than the SDF. The incorporation of the *B. flabellifer* mesocarp and exocarp in food formulation could increase the insoluble fibre content, and thus may provide an avenue to improve the fibre intake in the population (García-Herrera *et al.*, 2010).

#### *pH and total soluble solids*

The mesocarp and exocarp pH value was less than 3.70 (Table 1). The low pH values of both mesocarp and exocarp can create an acidic and unfavourable condition for certain reaction which caused the low risk of deterioration (by the microorganism, enzymes, or non-enzymatic reactions) (Viuda-Martos *et al.*, 2015). The total soluble solids (TSS) values varied between 0.47% and 2.13% and were significantly different ( $p < 0.05$ ) among samples (Table 1). TSS is related to sugar content in the sample, which corresponded with the total sugar obtained for both samples. They were lower than the matured pulp of *B. flabellifer* as reported by Vengaiyah (2015).

Table 1. Phytochemical composition of mesocarp and exocarp of *Borassus flabellifer*.

Composition (%)	<i>Borassus flabellifer</i>	
	Mesocarp	Exocarp
Proximate (%)		
Protein	4.20 <sup>b</sup> ± 0.47	5.27 <sup>a</sup> ± 0.38
Fat	1.52 <sup>a</sup> ± 0.51	1.86 <sup>a</sup> ± 0.62
Moisture	10.35 <sup>a</sup> ± 0.22	9.20 <sup>b</sup> ± 0.51
Ash	3.66 <sup>a</sup> ± 0.12	2.79 <sup>b</sup> ± 0.21
Carbohydrate (by the different)	56.35	52.68
Crude Fibre	23.92 ± 1.71	28.20 ± 1.55
Dietary Fibre (%)		
Total dietary fibre (TDF)	66.89 <sup>b</sup> ± 1.69	82.69 <sup>a</sup> ± 2.13
Insoluble dietary fibre (IDF)	62.46 <sup>b</sup> ± 1.36	79.44 <sup>a</sup> ± 2.17
Soluble dietary fibre (SDF)	4.43 <sup>a</sup> ± 0.57	3.26 <sup>b</sup> ± 0.20
Ratio IDF/SDF	14.09	24.37
Total soluble solids (%)	2.13 ± 0.06	0.47 ± 0.06
pH	3.58 <sup>a</sup> ± 0.08	3.70 <sup>a</sup> ± 0.03
Colour		
<i>L</i> *	66.00 <sup>b</sup> ± 0.10	78.9 <sup>a</sup> ± 0.26
<i>a</i> *	2.70 <sup>a</sup> ± 0.10	2.17 <sup>b</sup> ± 0.15
<i>b</i> *	15.33 <sup>a</sup> ± 0.06	15.37 <sup>a</sup> ± 0.25

Data are means ± standard deviation of triplicates ( $n = 3$ ). Different superscript letters between mesocarp and exocarp of *Borassus flabellifer* indicate significant differences ( $p < 0.05$ ).

#### Colour

Colour is one of the most important quality parameters when dietary fibre products are used as food ingredients. The lightness ( $L^*$ ) value of the exocarp was significantly higher ( $p < 0.05$ ) as compared to those obtained from the mesocarp with values ranging from 66.00 - 78.90. Higher  $L^*$  value indicated a whiter sample. Both mesocarp and exocarp showed  $a^*$  (red-green) values ranging between 2.17 - 2.10, and the coordinate  $b^*$  (yellow-blue) values ranging between 15.33 - 15.37 with no statistical difference ( $p > 0.05$ ) between samples. Overall, both mesocarp and exocarp were white (high value of  $L^*$ ), with less red (low  $a^*$  value) and yellow (low  $b^*$  value). This implies that the incorporation of this mesocarp and exocarp within a food system will not affect the end product's colour.

#### Sugar composition

Fructose, sucrose, mannose, galactose and glucose were the primary sugars identified in both samples except for glucose, which was only present in the mesocarp (Table 2). Fructose and sucrose were the most abundant sugars found in both the mesocarp and exocarp. Mannose and galactose were present in minor amount. Hence, about 53% and

56% of the available carbohydrates in the exocarp and mesocarp, respectively, were simple soluble sugars (fructose, mannose, galactose, and glucose). The monosaccharides content of mesocarp was about four times higher than those reported in the mesocarp of *C. nucifera* which contained around 3.17% - 3.74% (Prado *et al.*, 2014). This higher percentage of sugar could render the mesocarp and exocarp of *B. flabellifer* to be sweeter and more prone to browning.

Table 2. Sugar composition of *Borassus flabellifer*.

Sugar	<i>Borassus flabellifer</i>	
	Mesocarp	Exocarp
Fructose	9.75 <sup>a</sup> ± 1.91	3.57 <sup>b</sup> ± 0.19
Sucrose	2.95 <sup>b</sup> ± 0.94	3.63 <sup>a</sup> ± 0.97
Mannose	1.84 <sup>a</sup> ± 0.48	1.51 <sup>a</sup> ± 0.26
Galactose	1.34 <sup>a</sup> ± 0.31	1.86 <sup>a</sup> ± 0.21
Glucose	1.58 ± 0.14	ND
† Monosaccharides	14.51	6.94
‡ Disaccharide	2.95	3.63

Data are means ± standard deviation of triplicates ( $n = 3$ ). Different superscript letters between mesocarp and exocarp of *Borassus flabellifer* indicate significant differences ( $p < 0.05$ ). †: monosaccharides (total of fructose, mannose, galactose and glucose) and disaccharide (sucrose), ND: not detected.

#### Phytochemical composition

Phenols and tannins were present in all mesocarp and exocarp extracts, but saponin was detected only in the mesocarp (Table 3). Flavonoids, cardiac glycosides, terpenoids, alkaloids, steroids and anthraquinone were not detected in both samples. In comparison to similar species, alkaloids, flavonoids, terpenes, glycosides, saponins, phenolics, tannins, carbohydrate, protein and steroids, and sterols were confirmed to be found in the aqueous and methanolic extracts of raw palmyrah palm fruit pulp (RPF) and thermally processed palmyrah palm fruit pulp (PPFP) of *B. flabellifer* at the mature stage (Saranya and Vijayakumar, 2016).

The total phenolic content of the extract from the mesocarp and exocarp was lower than the phenolic content of the *B. flabellifer* fruit and ethanol extract of the mesocarp husks of *C. nucifera* (Dey *et al.*, 2003; Wijewardana *et al.*, 2016). It has also been reported that different total phenolic contents were observed for coconut husk (mesocarp) extracts prepared using ethanol at different concentrations where the average total phenolic compound was 256 - 464 mg TAE/g sample (Buamard and Benjakul, 2015). The total tannin content in both mesocarp and exocarp of *B. flabellifer* was also lower as compared to the ethanolic extract of husk from *C. nucifera* reported by Dey *et al.* (2003). In the present work, saponin was not detected in the exocarp, while the mesocarp contained a moderate amount of 16.77%.

Table 3. Phytochemical composition of mesocarp and exocarp of *Borassus flabellifer*.

Compound	Mesocarp		Exocarp	
	Availability	Amount	Availability	Amount
Alkaloids (%)	ND	Negligible	ND	Negligible
Saponins (%)	D	16.755 ± 1.444	ND	Negligible
Flavonoids (QE/g)	ND	Negligible	ND	Negligible
Steroid (ng/mL)	ND	Negligible	ND	Negligible
Cardiac glycosides (%)	ND	Negligible	ND	Negligible
Phenol (GAE/g)	D	3.23 <sup>b</sup> ± 0.004	D	5.58 <sup>a</sup> ± 0.004
Tannins (TE/g)	D	0.007 <sup>a</sup> ± 0.005	D	0.003 <sup>a</sup> ± 0.001
Terpenoids (LE/g)	ND	Negligible	ND	Negligible
Anthraquinone (%)	ND	Negligible	ND	Negligible

Data are means ± standard deviation of triplicates ( $n = 3$ ). Different superscript letters between mesocarp and exocarp of *Borassus flabellifer* indicate significant differences ( $p < 0.05$ ). ND: not detected; D: detected.

### Antioxidant activities

Antioxidants are agents that limit the harmful effects of oxidative reactions, either by preventing radical formation or scavenging free radical (Fernandez-Orozco *et al.*, 2011). Table 4 shows the radical scavenging activity and the ferric-reducing antioxidant power of both mesocarp and exocarp. DPPH levels of the mesocarp and exocarp of *C. nucifera* (Rodiah *et al.*, 2018) had a higher value than the mesocarp and exocarp of *B. flabellifer* analysed in the present work. Natural antioxidants mainly come from plants in the form of phenolic compounds such as the flavonoids, phenolic acids and tocopherols (Ali *et al.*, 2008). Therefore, the quantity of phenolic compounds is related to the DPPH free radical scavenging effect (Liu *et al.*, 2009; Kedare and Singh, 2011). The result indicated that the mesocarp and exocarp of *B. flabellifer* have low total phenolic content and also antioxidant activity. It is proved that the antioxidant activity is related to the composition and concentration of phenolic compounds (Chavez-Santoscoy *et al.*, 2009). The mesocarp extract had significantly ( $p < 0.05$ ) higher reducing power (213.05 mM Fe<sup>2+</sup>/g) as compared to the exocarp extract (38.79 mM Fe<sup>2+</sup>/g, Table 1). These values were lower than those of the methanolic extract from *C. nucifera* mesocarp by Chakraborty and Mitra (2008) and alkaline extract of *C. nucifera* mesocarp (Rodiah *et al.*, 2018).

Table 4. Antioxidant activity of mesocarp and exocarp from *Borassus flabellifer*.

Antioxidant activity	<i>Borassus flabellifer</i>	
	Mesocarp	Exocarp
FRAP (mM Fe <sup>2+</sup> /g)	157.05 <sup>b</sup> ± 0.08	213.05 <sup>a</sup> ± 0.27
DPPH (mM TE/g)	29.90 <sup>b</sup> ± 0.056	38.79 <sup>a</sup> ± 0.04

Data are means ± standard deviation of triplicates ( $n = 3$ ). Different superscript letters between mesocarp and exocarp of *Borassus flabellifer* indicate significant differences ( $p < 0.05$ ).

### Lignocellulosic composition

Fibre includes insoluble fibre (lignin, cellulose, and hemicellulose), soluble fibre (pectin,  $\beta$ -glucans, galactomannan gums) and a large range of indigestible oligosaccharides including inulin (Mongeau, 2003). The highest among the lignocellulosic components in both samples was the holocellulosic (cellulose + hemicellulose). Hemicellulose was the major component in the exocarp followed by cellulose and lignin. The presence of hemicelluloses in the mesocarp and exocarp may be important since hemicelluloses can influence the quality of baked products and can be utilised as a thickening and gelling agent. Studies had indicated that insoluble hemicelluloses had the greatest impacts on the baking quality of cakes such as tenderness, volume, viscosity, cell size, cell wall thickness and grain (Nomanbhay *et al.*, 2013).

Cellulose was found to be the highest among other lignocellulosic materials found in the mesocarp. Cellulose can be added to or partially substituted for cryoprotectants in surimi or other textured products for their texture-modifying and freeze-thaw-stabilising properties (Ng *et al.*, 2010). The exocarp had significantly higher ( $p < 0.05$ ) lignin as compared to the mesocarp and this could prove as a characteristic of the mesocarp and exocarp as food ingredient, since the amination of lignin with epoxy amines has been shown to enhance the sorption capacity for bile acids and cholesterol (Dizhbite *et al.*, 2004). Industrial lignin is also reported as being safe, exhibit high antioxidant and stable even after exposure to UVA light. These properties are useful in food, topical medical formulations and cosmetics (Ugartondo *et al.*, 2008).

## Conclusion

The mesocarp and exocarp of *B. flabellifer* have the potential to be used in foods. The results from the physicochemical characterisation indicated that the mesocarp and exocarp presented a high content of insoluble fibres and a moderate amount of protein, ash, saponin, tannin, and phenolic content, as well as simple sugar (fructose, mannose, galactose, and glucose). Lignocellulosic materials of the exocarp were composed of cellulose as the major component, while the mesocarp contained hemicelluloses as the highest component among the other lignocellulosic materials. The mesocarp and exocarp also contained considerable free-radical scavenging activity in relation to DPPH and reducing capacity.

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