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Valuable components of bambangan fruit (*Mangifera pajang*) and its co-products: A review

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ABSTRACT

Fruits are important food commodities that can be consumed either raw or processed and are valued for their taste, nutrients, and healthy compounds. *Mangifera pajang* Kosterm (bambangan) is an underutilized fruit found in Malaysia (Sabah and Sarawak), Brunei, and Indonesia (Kalimantan). It is highly fibrous and juicy with an aromatic flavour and strong smell. In recent years, bambangan fruit has been gaining more attention due to its high fibre, carotenoid content, antioxidant properties, phytochemicals, and medicinal usages. Therefore, the production, trade, and consumption of bambangan fruit could be increased significantly, both domestically and internationally, because of its nutritional value. The identification and quantification of bioactive compounds in bambangan fruit has led to considerable interest among scientists. Bambangan fruit and its waste, especially its seeds and peels, are considered cheap sources of valuable food and are considered nutraceutical ingredients that could be used to prevent various diseases. The use of bambangan fruit waste co-products for the production of bioactive components is an important step towards sustainable development. This is an updated report on the nutritional composition and health-promoting phytochemicals of bambangan fruit and its co-products that explores their potential utilization. This review reveals that bambangan fruit and its co-products could be used as ingredients of dietary fibre powder or could be incorporated into food products (biscuits and macaroni) to enhance their nutraceutical properties.

1. Introduction

The *Mangifera* genus belongs to the Anacardiaceae family and consists of 70 species. There are 25 species in Malaysia and *Mangifera indica* is the most well-known species because of its health and economic value. There are 17 *Mangifera* species in Sabah, Malaysia, and bambangan (*Mangifera pajang* Kosterm) is a forest fruit. Bambangan fruit is ovoid in shape and is three times larger than the commercial mango (*Mangifera indica*). It is characterized by a bright yellow colour with a sweet-sour taste. It is juicy, has an aromatic flavour, and has a strong smell similar to commercial mango. Bambangan is rich in water, minerals, vitamins, fibre, sugars, protein, and antioxidants (Ibrahim, Prasad, Ismail, Azlan, & Hamid, 2010; Tangah et al., 2017). The cultivation of bambangan is constantly increasing due to its valuable chemical composition. For example, the production increased from 115.3 to 121.6 metric tons in Sabah from 2013 to 2015 (Department of Agriculture, Malaysia, 2015).

In Malaysia, consumers prefer ripe bambangan fruit with a brown colour. Various types of food preparations, such as pickles, dehydrated fruits, minimally processed fruits, or juices, can be prepared using bambangan fruit. Currently, *M. pajang* pulp and *M. pajang* juice powders are commercially used. These products are also used for the production of various functional foods and are additionally suitable as an added ingredient in various food products (Al-Sheraji et al., 2011, 2012). The flesh constitutes 60–65% of the total weight of the fruit, whereas the seeds constitute 15–20%, and the peel constitutes10–15% (Bakar, Mohamed, Rahmat, & Fry, 2009). Meanwhile, various studies have been carried out to determine the chemical composition of these

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Fig. 1. Bambangan tree (a), fruit (b), cross-section of fruit (c), and kernel (d).

wastes. Bambangan fruit and its co-products (peel and kernel) are rich sources of antioxidants. These *co*-products also contain phytochemicals such as polyphenols, flavonoids, carotenoids, and anthocyanins (Bakar et al., 2009; Bakar, Mohamed, Rahmat, Burr, & Fry, 2010a, 2010b; Khoo, Prasad, Ismail, & Mohd-Esa, 2010). The presence of a wide range of phytochemicals in bambangan fruit and its co-products offers opportunities for nutraceutical and functional food applications. Moreover, the powder prepared from bambangan peel contains high amounts of total dietary fibre, a high glucose retardation index, a water-holding capacity, an oil-holding capacity, and a swelling capacity (Hassan, Ismail, Hamid, Azlan, & Al-sheraji, 2011). Recently, fats from bambangan kernel have been extracted using solvents and evaluated for their quality by Azrina, Aznira, and Khoo (2015) and Jahurul et al. (2018a); Jahurul et al., 2018b). They reported that bambangan kernel fat (BKF) is similar to that of mango, illipe, shea, and cocoa butter (CB) and can be used in the food industry (e.g., as confectionary products).

Fruit wastes such as seeds and peels are naturally rich in antioxidants due to their phenolic constituents (Zulkifli, Abdullah, Abdullah, Aziman, & Wan Kamarudin, 2012). These compounds possess anticancer, antimicrobial, and antioxidant properties, and control periodontal disease and dental caries (Lin, Liu, Shyu, Hsu, & Yang, 2016). Phytochemicals (responsible for antioxidant activities) are important for removing or neutralizing free radicals, which may prevent or reduce the risk of cancer (Abbasi et al., 2015; Bakar et al., 2009). Researchers have put intense effort into exploring new chemotherapeutic drugs made from natural resources such as fruits and vegetables (Mukherjee, Basu, Sarkar, & Ghosh, 2001). This is because plants are rich sources of phytochemicals such as tocopherol, carotenoids, and polyphenols that have chemoprotective properties for different stages of carcinogenesis. A recent study showed that bambangan kernel contains higher levels of phytochemicals that have antioxidant properties compared to other parts of the fruit (Bakar et al., 2009). It has also been demonstrated that polyphenols can prevent and treat cancers, cardiovascular diseases, neurodegenerative diseases, osteoporosis and diabetes (Scalbert, Manach, Morand, Remesy, & Jimenez, 2005). The nutritional and antioxidant properties of bambangan peel and flesh, including the presence of phytochemicals such as phenolics, flavonoids and carotenoids, are reported by Bakar and Fry (2013). Tangah et al. (2017) reported the phytochemicals and pharmacological properties of antioxidants, as well as the antibacterial, anticancer and cytoprotective activities of the bambangan fruit. However, the literature on bambangan kernel fat (BKF) and its properties, including the nutritional composition, the total phenolic content, and the carotenoid content of all parts of bambangan fruit (peel, flesh, and seed), is still scarce. Thus, the aim of this article is to review the physical and chemical properties of BKF and to review the carotenoid content, antioxidants, nutrients, total phenolic content, and phenolic acids of all parts of bambangan fruit (peel, flesh, and seed) to compare bambangan with closely related fruits that are commonly used by food industries. This review will also serve as an update on the scientific findings of all parts of bambangan fruit such as the flesh, peel, and kernels to explore their possible application in food and pharmaceutical industries.

2. Botanical aspects

Generally, bambangan is not grown commercially but can be found in forests in Sabah and Sarawak, Malaysia (Rukayah, 1999). The tree can grow on a wide range of soils, especially in alluvial clay and sandy loam in a pH range of 5–7. However, the tree will not tolerate acid peat swamps or leached coastal sandy beaches. The bambangan tree can grow up to 15–50 m tall and bears many brown-skinned fruits that can weigh up to 3 kg (Bakar & Fry, 2013; Lim, 2012). The flowers of this plant are elliptic-oblong or lanceolate with ridges and have 5 petals that are purplish-red on the inner surface and pinkish-white on the outside.

Table 1
Chemical composition of bambangan juice powder and other fruit juice powder.

Composition (%)	Bambangan fruit juice powder	Mango juice powder	Pineapple juice powder	Grape juice powder	Guava powder	Dragon fruit powder
Moisture	10.01	0.8–3.3	1.6–3.9	0.6	3.1	4.07
Protein	3.78	1.3–4.1	0.7–3.8	1.4	5.0	0.18
Fat	1.75	0.1–2.3	0.1–0.5	0.02	4.1	1.20
Carbohydrate	76.09	87.0–95.8	88.1–96.3	96.5	79.5	
Ash	3.30	0.7–2.1	0.7–2.6	0.9	3.1	0.79
Total fibre	0.8	1–1.4	0.7–0.9	0.3	5.03	38.05
Insoluble fibre	0.12	–				
Soluble fibre	0.68	–				
Gross energy (kcal/100 g)	335.23	389	389	392		
Ascorbic acid (mg/100 g)	132.14	63.25				
β-carotene (mg/100 g)	35.59	0.003375				
Total phenolics (mg GAE/100 g)	19.30	–	–	–	–	
References	Ibrahim et al. (2010)	Hymavathi and Khader (2005); Prasad et al. (2000); Saifullah, Yusof, Chin, and Aziz (2016)	Prasad et al. (2000); Saifullah et al. (2016)	Prasad et al. (2000)	Saifullah et al. (2016)	Tze et al. (2012)

The fruit formed from the fertilization of the flower is a drupe with a brownish, globose shape 15–20 cm across and has a rough skin. The unripe fruit of bambangan has a green outer skin which changes to a brown colour when ripe. The peel is very tough and has a corrosive latex layer (Lim, 2012). The bambangan tree, fruit, and seeds are shown in Fig. 1. The outer skin of the bambangan fruit is brown and is 5–7 mm thick (Prasad et al., 2011). The fruit has a thick, yellow, fibrous flesh which is aromatic and tastes sweet and sour. The aroma is one of the criteria used by the locals to determine the ripeness of the bambangan fruit (Department of Agriculture, 2015).

3. Uses of bambangan fruits, kernels, peels, shoots, and leaves

In Malaysia, bambangan fruit pulp and powders made from its juice are commercially used (Al-Sheraji et al., 2012). The bambangan fruit pulp is homogenized with distilled water (1:1, *v*/v) and freeze-dried. The freeze-dried samples are used as bambangan fruit juice powder (Ibrahim et al., 2010). The nutritional characteristics of the bambangan fruit, its juice powder and juice powders made from other fruits are presented in Table 1. The nutrient contents of the bambangan juice powder are higher than pineapple, grape, and mango juice powders. Possible explanations for the high and low nutrient contents in various fruit juice powders may be the different methods, ingredients, and equipment used for the preparation of the juice powder. Moreover, other factors such as the cultivar and tissues used, the climatic conditions, the maturation stage, and the post-harvest treatments may also influence the nutrient contents (Ibrahim et al., 2010). Furthermore, bambangan products are used for the production of various functional foods (Ibrahim et al., 2010). In addition, the shoots or young leaves of bambangan can be consumed as side dishes or as vegetables, where they are usually blanched in boiling water or boiled with meat. The young bambangan fruits are usually consumed by native Sabah people (Salma, Mohd Nor, Masrom, & Raziah, 2006). Young fruits are also eaten as side dishes or boiled with meat in soup, and the sweet variety can be eaten raw in the same way as a mango. In addition, the flesh and grated seed kernels of the bambangan fruit are pickled together and kept for extended periods of time for consumption with other side dishes. The ripe fruit is also eaten fresh or made into fruit juice (Fig. 2).

Prasad et al. (2011) stated that the peel of bambangan fruit can be eaten and that it has a high polyphenol content compared to the flesh and seed. Past studies have also shown that the bambangan peel is rich in antioxidants compared to the other parts. The peel is usually used by locals for cooking curry (Haron & Said, 2004). In addition to that, the peel of a young fruit can be used to make pickles. The kernel makes up 14–20% of the fruit, and the weight percentage of the kernel decreases as the total weight of the fruit increases, similar to a mango (Haron & Said, 2004). To make pickles, bambangan kernels are used with the flesh. This pickle is usually eaten with plain rice or with other side dishes (Bakar & Fry, 2013). M. *pajang* is fibrous and its polysaccharides might be a potential prebiotic that could be incorporated into food products. The fermentation properties of M. *pajang* fibres and the polysaccharides in theses fibres were determined by Al-Sheraji et al. (2012). Their results showed strong fermentation and non-digestibility properties for M. *pajang* fibres and M. *pajang* fibrous polysaccharides. The authors recommended that the polysaccharides could be used to enhance various food products, such as dairy products, products designed for overweight individuals, diabetic prevention products and prebiotic products. However, additional studies are needed to evaluate the quality of the products and their bioavailability.

3.1. Proximate composition of bambangan fruit and its co-products

The proximate nutrient composition of bambangan fruit and its co-products is shown in Table 2. Carbohydrates are the major component of the pre-dried flesh of the fruit, followed by water. In the peel, carbohydrates are the main component, whereas water makes up almost half of the seed kernel of bambangan fruit. The protein contents of bambangan co-products are consistent with the protein contents present in the co-products of other fruits such as guava, pineapple, and apple (Martínez et al., 2012; Santo et al., 2012). However, the values are lower than those reported by Abdalla, Darwish, Ayad, and El-Hamahmy (2007) and Martínez et al. (2012) for mango co-products. Although the bambangan co-products had low protein content, the composition of essential amino acids such as leucine (6.7), valine (5.0), lysine (4.8), threonine (4.7), phenylalanine (4.2), isoleucine (4.1), tyrosine (2.1), and methionine (0.7) (g/100 g protein) indicates that the protein is of good quality (Jahurul, Soon, et al., 2018b). Bambangan kernel showed a high fat content, similar to the values reported by Abdalla et al. (2007) (12.3%), Muchiri, Mahungu, and Gituanja (2012) (8.5–10.5%), and Jahurul, Zaidul, Norulaini, Sahena, and Mohd Omar (2014a) for various mango varieties cultivated in Egypt, Kenya, and Malaysia. The ash content of bambangan co-products is comparable with that reported by Abdalla et al. (2007), Santo et al. (2012), and Martínez et al. (2012) for mango, apple, and guava co-products, respectively. Based on chemical composition, bambangan co-products are a promising alternative source of food that could be used as nutritional supplements, especially for fat and protein.

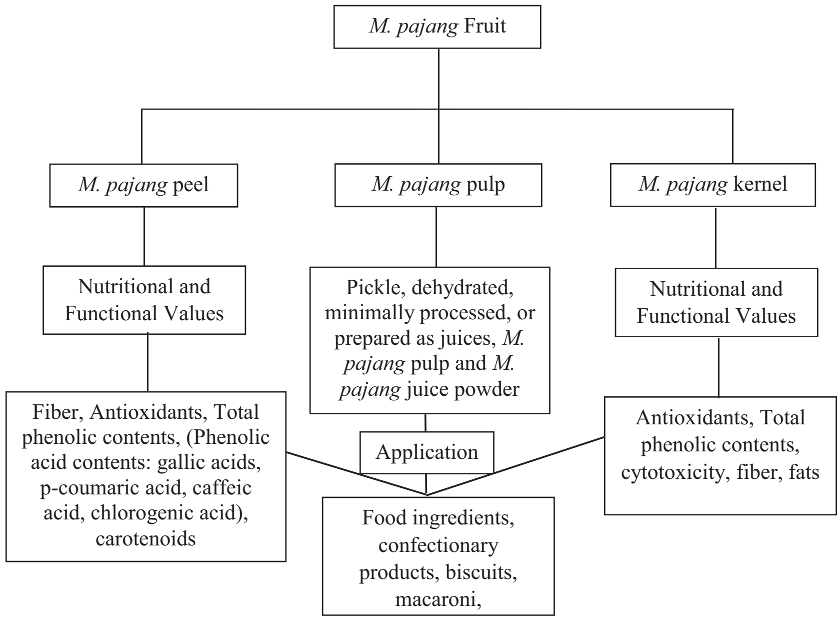

Fig. 2. Probable food products, nutritional and functional compounds from *M. pajang* fruit and its co-products.

3.2. Antioxidant properties of bambangan fruit and its co-products

Antioxidants have the ability to stabilize or deactivate free radicals before these substances attack body cells. These substances significantly delay or inhibit the oxidation of the substrate. Antioxidants are known as scavengers of free radicals as they bind to these free species and reduce their deleterious effects. Moreover, antioxidants help repair damage to proteins, carbohydrates, lipids and DNA caused by oxidation (Halliwell & Gutteridge, 1995). Antioxidants in food are able to delay, prevent or retard rancidity or the off-flavour that occurs due to oxidation. They prevent or delay the oxidation of fat content in food and thus prolong freshness and shelf life (Gordon, 2001).

Many studies have proven that every part of bambangan fruit including the flesh, peel, and kernel and its products have high antioxidant properties (Bakar et al., 2009; Ibrahim et al., 2010; Zabidah, King, & Amin, 2011). The authors reported that bambangan kernel (dry matter) showed the highest DPPH scavenging effect compared to peel and flesh. Bambangan kernel also showed a higher result than its peel or flesh in the FRAP assay. Bambangan kernel (dry matter) had approximately 9 and 20 times the reducing ability than its peel and flesh, respectively. Different studies have reported the antioxidant properties of various parts of mangos, oranges, pineapples, and grapes (Guo et al., 2003; Maisuthisakul & Gordon, 2009; Silva & Sirasa, 2016; Zang et al., 2017; Zulkifli et al., 2012). Table 3 shows that the antioxidant properties of bambangan are higher than mangoes, oranges, pineapples, strawberries, and grapes. The DPPH radical scavenging activity of mango flesh, peel, and kernel are lower than bambangan flesh, peel, and kernel. Moreover, in the FRAP analysis, mango flesh, peel, and kernel showed a lower reducing ability than bambangan (Table 3). Proteggente et al. (2002) ranked the antioxidant activities of fruits and vegetables in the following order: strawberry > red plum > > > grapefruit = orange > green grape > apple > pear > peach (fresh weight). In another study, apples exhibited the highest antioxidant activity, followed by red grapes, strawberries, peaches, lemons,

Table 2
Nutrient contents of various parts of bambangan fruit and other fruits.

Samples	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Total fibre	Carbohydrate (%)	References
Bambangan Flesh (Pre-dried)	13.63–15.97	2.32–2.42	0.2–0.4	3.10–3.33		77.9–80.7	Kalsum and Mirfat (2014)
Bambangan Flesh fibre	4.65	0.84	0.79	3.73		87.57	Al-Sheraji et al. (2011)
Bambangan Peel (Pre-dried)	3.9	2.7	2.9	4.6		72.3	Hassan, Ismail, Hamid, et al. (2011)
Bambangan seed kernel	41.38	2.23–2.8	9.8–11	3.08–4.1		38.68–72.9	Haron and Said (2004); Jahurul, Soon, et al. (2018b)
Mango flesh	79.06	0.5	0.32	0.98	3.7	15.56	Mamiro et al. (2007)
Mango seed kernel[a]	8.5	2.5	7.6–13.7	6.7		–	Abdalla et al. (2007); Muchiri et al. (2012); Jahurul, Zaidul, Norulaini, Sahena, Abedin, Mohamed & Mohd Omar et al. (2014b)
Mango co-products (peel and pulp, d.m.)	9.4	4.2	5.9	8.0		11.9	Martínez et al. (2012)
Passion co-products (peel, pulp and seeds, d.m.)	9.3	5.0	0.8	6.2		6.5	Martínez et al. (2012)
Guava co-products (peel, pulp and seeds, d. m.)	9.3	2.4	1.4	4.8		22.2	Martínez et al. (2012)
Pineapple co-products (peel and heart, d.m.)	9.3	4.5	1.3	4.0		14.4	Martínez et al. (2012)
Passion fruit co-products (PFSP) (pulp and seeds, d.m)	–	5.77	29.54	1.49		–	López-Vargas et al. (2013)
Passion fruit albedo (PFA) co-products (pulp and seeds, d.m)	–	8.08	1.0	0.35		–	López-Vargas et al. (2013)

[a] Dry matter.

Table 3
Antioxidant activity of various parts of bambangan and other fruits.

Samples	DPPH radical scavenging activity (mg AEAC/g)[a]	FRAP assay (mM/100 g)	References
Bambangan			
Flesh	9.94	15.0	Bakar et al. (2009)
Peel	20.32	1248[c]	Hassan et al. (2011a)
Kernel	23.23	34.32	Bakar et al. (2009)
		313.0	Bakar et al. (2009)
Mango[b]			
Flesh	1.77	0.38	Silva and Sirasa (2016); Guo et al. (2003)
Peel	0.138	10.13	Zulkifli et al. (2012); Guo et al. (2003)
Kernel	14.0	14.59	Maisuthisakul and Gordon (2009); Guo et al. (2003)
Mango Flesh[d]	0.70–0.92	–	Zang et al. (2017)[d]
Black grape[d]	1.36–1.52		Zang et al. (2017)
Orange[d]	0.34–0.36		Zang et al. (2017)
Strawberry[d]	1.40–1.44		Zang et al. (2017)
Lychee[d]	0.86–0.94	1.58	Saikia, Mahnot, and Mahanta (2016); Zang et al. (2017)
Pineapple[d]	0.38–0.40	0.44	Saikia et al. (2016); Zang et al. (2017)
Olive[d]		0.65	Saikia et al. (2016)
Watermelon[d]		0.86	Saikia et al. (2016)
Mulberry[d]	4.21–5.0	–	Zang et al. (2017)
Genipap peel	15.43	71.0	Omena et al. (2012)
Siriguela peel	31.89	162.0	Omena et al. (2012)
Umbu peel	52.5	197.1	Omena et al. (2012)

[a] mg ascorbic acid equivalent antioxidant capacity (AEAC) in 1 g of dry sample.
[b] Mango variety (Villard, chokonan).
[c] µg/mL.
[d] Fresh weight.

oranges, pears and grapefruits (fresh weight) (Sun, Chu, Wu, & Liu, 2002). The antioxidant capacities of fruit depend on their phytochemical content, such as vitamins A, C and E, mineral elements, flavonoids, coumarins, limonoids, carotenoids, pectin, and other polyphenols (Müller, Gnoyke, Popken, & Böhm, 2010; Zou, Xi, Hu, Nie, & Zhou, 2016). Variations of antioxidant activity in the same fruits could be due to the studied fruits being from different geographical regions and being grown in different climatic conditions (Park et al., 2015). Moreover, this could also be due to the stage of fruit maturity when analysed, the type of solvent used for extraction, the concentration of solvent used, and the drying methods (Roiaini, Seyed, Jinap, & Norhayati, 2016). The antioxidants present in fruits have attracted interest from the scientific community and from consumers due to the beneficial effects against diseases such as cancer (Opie & Lecour, 2007). Currently, synthetic antioxidants, such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), are used in some processed foods (Carocho & Ferreira, 2013; Lorenzo, González, Sánchez, Amado, & Franco, 2013; Sarafian, Kouyoumjian, Tashkin, & Roth, 2002). However, the harmful effects of synthetic antioxidants can be avoided by substituting them with natural antioxidants, such as those present in bambangan fruit and its co-products.

3.2.1. *Total phenolic content (TPC) of bambangan fruit and its co-products*

Several types of phenolic acids have been detected in fruits and these may vary depending on fruit type and fruit part. Gallic acid is one of the phenolic acids that exhibits anticancer activities towards several cell lines, especially prostate cancer cells. Moreover, chlorogenic acid has been demonstrated to be the most abundant polyphenol in human diets, and it acts as an antioxidant, anticancer, and antiedematogenic agent (Bakar et al., 2010b). Similarly, caffeic acid is also reported to inhibit hypertension and cardiotoxicity in rats.

Bakar et al. (2009) reported that the bambangan flesh, peel, and kernel are rich sources of polyphenolic compounds with advanced antioxidant properties. The results from their study demonstrated that the TPC of the bambangan ranged from 5.96–103.3 mg gallic acid equivalent/g (Table 4). Bambangan kernel contained the highest TPC, peel had the second highest TPC, and flesh had the lowest TPC (Bakar et al., 2009; Ibrahim et al., 2010; Tangah et al., 2017). The major polyphenols in bambangan kernel are phenolic acids, and approximately 90% of the total polyphenols are non-flavonoid compounds (Bakar et al., 2009). The results showed that the bambangan kernel is a natural source of polyphenols. It is important to determine the free phenolic content of the oil extracted from bambangan kernel for quality control (Hassan, Ismail, Abdulhamid, & Azlan, 2011). Bambangan kernel has a slightly lower TPC compared to mango kernel. In mangos, kernel contained the highest TPC, peel contained the second highest TPC, and flesh contained the lowest TPC (Abbasi et al., 2015; Soong & Barlow, 2004).

Bakar et al. (2010a) determined the phenolic acid content of bambangan flesh, peel, and kernel. Table 5 shows the four phenolic acids, gallic, *p*-coumaric, caffeic, and chlorogenic acids, that were measured in different parts of bambangan and mango fruits. Bambangan kernel shows a higher level of phenolic acid content, especially gallic, *p*-coumaric and chlorogenic acid, than peel and flesh. Gallic acid is a potential source of functional food ingredients because of its high antioxidant capacity reported by Sethiya, Trivedi, and Mishra (2014). A high caffeic acid content has been found in bambangan peel. Lower phenolic acid contents have been found in bambangan flesh, with *p*-coumaric, caffeic, and chlorogenic acids, than in the peel and kernels. Gallic acid was found only in the peel and kernel of the bambangan. No gallic acid has been detected in bambangan flesh.

Abbasi et al. (2015) and Ongphimai, Lilitchan, Aryusuk, Bumrungpert, and Krisnangkura (2013) determined the phenolic acid contents of mango flesh, peel, and kernels. Their results showed that the phenolic acid content of peels are significantly higher than in flesh, except for chlorogenic acid. The chlorogenic acid in mango flesh and peel is higher than in the flesh and peel of bambangan. Gallic acid in mango kernel has been reported to be higher than in its peel and flesh and kernels are the richest source of other phenolic acid contents. However, no chlorogenic acid has been detected in mango kernel. The *p*-coumaric and caffeic acids in mango flesh, peel, and kernel are lower than bambangan, as shown in Table 5. On the other hand, mango contains higher gallic and chlorogenic acid contents than bambangan. The results presented in the literature show that the phenolic acid contents of bambangan and mango fruits and their co-products exhibit significant variation. These variations could be due to environmental factors, agricultural practices, genetic characteristics, and the maturation stage of the fruit.

3.3. *Dietary fibres in bambangan fruit and its co-products*

The demand for fruit waste co-products as a source of dietary fibre (DF) continues to rise. These sources have high nutritional quality, large quantities of DF, low caloric content, potent antioxidant activity, high levels of fermentability, water and oil holding capacity, and swelling. The food industry seeks products that contain high fibre levels to support human health (Al-Sheraji et al., 2011; Hassan, Ismail, Hamid, et al., 2011). The DF of bambangan wastes, such as peel, was investigated by Hassan, Ismail, Hamid, et al. (2011). They found that bambangan peel contained 33.4%, 38.8%, and 72.3% (dry matter) of soluble, insoluble, and total dietary fibre (TDF), respectively. Mannose, arabinose, and glucose were the major neutral sugars in the soluble and insoluble dietary fibres of bambangan peel. The pulp of the bambangan fruit was reported to contain 9%, 79%, and 88% (as % dry matter) of soluble, insoluble, and total dietary fibre, respectively. Soluble dietary fibre (SDF) is composed of mannose (1.51%), arabinose (0.72%), glucose (0.39%), rhamnose (0.16%), erythrose (0.14%), galactose, xylose, and fucose with 5.8% uronic acid (neutral sugar), whereas insoluble

Table 4
Total phenolic and carotenoid contents of different parts of bambangan and other fruits.

Samples	Total phenolic contents (mg GAE/g)	Total carotenoid content (mg β-carotene equivalent/100 g)	References
Bambangan			
Flesh	5.96	20.04	Khoo et al. (2010); Bakar et al. (2009)
Peel	22.93–98.0	13.09	Bakar et al. (2009); Khoo et al. (2010); Hassan et al. (2011a)
Kernel	103.3		Bakar et al. (2009)
Mango[a]			
Flesh	0.41-5.58	0.27–2.80	Abbasi et al. (2015); Septembre-Malaterre et al. (2016); Siriamornpun and Kaewseejan (2017)
Peel	28.05		Abbasi et al. (2015)
Kernel	117.0		Soong and Barlow (2004)
Mango[b]	0.78–6.5		Chen et al. (2014); Park et al. (2015)
Mango co-products (peel and pulp)	0.55		Martínez et al., 2012
Apple[b]	0.57–5.2		Chen et al. (2014); Park et al. (2015)
Apple peel	3.1–5.89		Wolfe, Wu, and Liu (2003)
Orange[b]	1.26–2.5		Chen et al. (2014); Park et al. (2015)
Pomegranate peel	9.38–21.18		Ambigaipalan, de Camargo, and Shahidi (2016)
Avocado peel	12.6		Ayala-Zavala et al. (2011)
Banana pulp	0.12–3.0	0.03	Chen et al. (2014); Park et al. (2015); Septembre-Malaterre et al. (2016); Siriamornpun and Kaewseejan (2017).
Banana peel	9.18		Subagio, Morita, and Sawada (1996); Ayala-Zavala et al. (2011)
Papaya	0.33–0.41	1.57–1.92	Septembre-Malaterre et al. (2016);
Passion fruit	2.87	3.83	Septembre-Malaterre et al. (2016);
Grape[b]	0.31–5.5		Chen et al. (2014); Park et al. (2015)
Guava peel	58.7		Ayala-Zavala et al. (2011)
Genipap peel	187.7		Omena et al. (2012)
Siriguela peel	112.2		Omena et al. (2012)
Umbu peel	52.5		Omena et al. (2012)
			Park et al. (2015)
Litchi[b]	1.31–2.52		Chen et al. (2014); Saikia et al. (2016)
Pineapple[b]	0.09	0.05	Septembre-Malaterre et al. (2016); Saikia et al. (2016)
Olive[b]	0.07		Saikia et al. (2016)
Watermelon[b]	0.03–0.1		Chen et al. (2014); Saikia et al. (2016)

[a] Mango variety ripe (Da Tainang, Xiao Tainang, Nam Dokmai, Khiew Sawoey, Kaew).
[b] Fresh weight.

Table 5
Phenolic acid contents of bambangan and other fruits.

Samples	Gallic acids (mg/100 g DW)	*p*-Coumaric acids (mg/100 g DW)	Caffeic acids (mg/100 g DW)	Chlorogenic acids (mg/100 g DW)	References
Bambangan					
Flesh	N.D	2.95	2.68	0.58	Bakar et al. (2010a); Hassan et al. (2011a)
Peel	2.09–3.07	1.26–19.90	44.05	0.03–0.82	
Kernel	23.66	30.11	15.0	1.41	
Mango[a]					
Flesh	2.11	–	0.89	1.24	Abbasi et al. (2015); Ongphimai et al. (2013)
Peel	16.57	–	14.43	4.40	
Kernel	54.25	0.08	0.02	ND	
Calabura peel	3.14–3.82				Rotta, Haminiuk, Maldaner, and Visentainer (2017).

N.D. – not detected at concentration tested; DW-dry weight.
[a] Mango variety (Namdok-mai, Shuixian, Xiao Tainang, Jidan).

dietary fibre (IDF) is composed of arabinose (18.47%), glucose (4.46%), mannose (3.15%), rhamnose (1.65%), galactose (1.20%), xylose (0.99%), and fucose (0.26%) with 15.5% uronic acid and 33.1% klason lignin (Al-Sheraji et al., 2011). Storage polysaccharides could be a source of the high amount of mannose in SDF and IDF of the bambangan fruit. Hemicelluloses such as xyloglucans, arabinoxylans, glucuronoxylans and pectic substances associated with the cell wall matrix in bambangan fibres are responsible for the low amount of rhamnose, xylose, and galactose (Al-Sheraji et al., 2011). The TDF of bambangan peel was higher (72.3% dry matter) than guava peel (49% dry matter) (Jiménez-Escrig, Rincón, Pulido, & Saura-Calixto, 2001), mango peel (51.2% dry matter) (Ajila, Leelavathi, & Rao, 2008), banana peel (50% dry matter) (Wachirasiri, Julakarangka, & Wanlapa, 2009), cocoa co-products (51.88 to 56.70% dry matter) (Martínez et al., 2012), passion fruit seed and pulp (PFSP) (53.51% dry matter) (López-Vargas, Fernández-López, Pérez-Álvarez, & Viuda-Martos, 2013), and orange peel (57% dry matter) (Chau & Huang, 2003). The TDF contents of bambangan co-products were comparable to that of the co-products of other tropical fruits such as Indian mango peel (78% dry matter) (Ajila, Bhat, & Rao, 2007), passion fruit (albedo) (71.79% dry matter) (López-Vargas et al., 2013), and lime (70.76% dry matter) (Peerajit, Chiewchan, & Devahastin, 2012). A possible explanation for the high TDF content in bambangan fruit may be its low starch content (Al-Sheraji et al., 2011).

SDF has a high hydration capacity, swells to form viscous solutions and can also adsorb and retain nutrients (minerals, non-polar

Table 6
Physicochemical properties of bambangan seed fat, cocoa butter, and its alternatives.

Physicochemical properties	Bambangan seed fat	Cocoa butter	Illipe butter	Palm oil	Sal fat	Shea butter	Kokum butter	Mango seed fat[a]
Palmitic acid	8.4–15.8	24.1–27.9	18–21	–	4.8–5.5	3.4–5.4	1.6–5.3	4.87–10.93
Stearic acid	36.4–40.4	33.3–37.6	39–46	–	43.2–44.2	35.7–43.5	62	24.22–47.62
Oleic acid	39.2–44.5	32.7–36.5	34–37	–	41.0–42.4	44.47–49.6	35.6–41.5	37.01–58.59
Linoleic acid	4.9–5.4	2.5–3.6	1.6	–	1.7–2.5	6.11–7.8	0.4–1.7	3.66–10.4
SFAs	48.3–56.2	57.4–65.5	57–67		48.0–49.7	38.1–48.9	63.6–67.3	29.09–58.55
MUFAs	39.2–44.5	32.7–36.5	34–37		41.0–42.4	44.47–49.6	35.6–41.5	37.01–58.59
PUFAs	4.9	2.5–3.6	1.6		1.7–2.5	6.11–7.8	0.4–1.7	3.66–10.4
Iodine value (g I/100 g fat)	38.7–50.3	32–35	29–38	56.3	31.0–49.0	52–59.5	34.7–36.7	42.9–52.7
Saponification value (mg KOH/g)	169.7–191.5	192–199	188–204	126.2	198.3	190	189	189.9–190.7
Acid value (%)	2.81–4.3	1.04–1.1	0.38–1.47	10.04	1.20[b]	3.62	–	3.2-5.2
Peroxide value (µEq/g)	0.9–2	1–1.1	–	2	–	1.2	–	1.7
Refractive index	1.458–1.4594	1.4546–1.4571	–	1.455	–	–	–	1.4562–1.4597
References	Azrina et al. (2015); Haron and Said (2004); Jahurul, Leykey, et al. (2018a)	Jahurul et al. (2013); Padilla, Liendo, and Quintana (2000)	Firestone (1999); Gunstone (2011). Jahurul et al. (2013)	Ekop, Etuk, and Eddy (2007)	Vedaramana, Puhanb, Nagarajanc, Ramabrahmama, and Velappana (2012); Jahurul et al. (2013); Kamalakar, Manoj, Prasad, and Karuna (2015)	Okullo et al. (2010); Enweremadu and Alamu (2010); Jatto, Yuanfa, Shan, Wang, and Aworh (2010); Jahurul et al. (2013); Zhang, Ma, Huang, and Wang (2017).	Raju and Reni (2001); Jeyarani and Reddy (2010).	Jahurul et al. (Jahurul et al., 2015, Jahurul, Zaidul, Norulaini, Sahena, & Mohd Omar, 2014); Yatnatti, Yijayalakshmi, and Chandru (2014); Muchiri et al. (2012)

[a] Mango variety (Kent, Kagege, Dodo, Boribo, Apple, Arumanis, Chokonan, Elephant, Sala, and Waterlily).
[b] Acid value mg/g.

molecules, and glucose, etc.). On the other hand, IDF can adsorb and retain water within its fibrous matrix and adsorb other components, such as SDF, without forming viscous solutions (Al-Sheraji et al., 2011; Martínez et al., 2012). Based on the results obtained by Al-Sheraji et al. (2011), bambangan pulp and peel could be used as a functional ingredient in confectioneries and in the preparation of low-fat, high-fibre, dietetic products. Further research is needed to investigate the anti-nutritional compounds as well as the sensory properties of the bambangan fruit and its co-products.

3.4. Carotenoids in bambangan fruit and its co-products

Carotenoids are responsible to the yellowish pigments of bambangan pulp. This substance plays an important role in biological functions such as antioxidant activity, cell communication, body metabolism, immune system function, provitamin A activity, and the protection of skin from UV damage (Van de Berg et al., 2000). Carotenoids have anticancer properties because they act as antioxidant agents that prevent cell damage from free radicals and are capable of removing radical species (Cano & Ancos, 1994). Carotenoids prevent or inhibit lipid peroxidation, which would cause the formation of free radicals (Septembre-Malaterre, Stanislas, Douraguia, & Gonthier, 2016). β-carotene has been found to have cardio-protective and antioxidant capacities (Khoo et al., 2010). Moreover, it is extensively used as an antioxidant preservative and as a colorant in the food industry. Hence, the retention of carotenoids during postharvest processes or processing methods is important for the maintenance of nutrient contents and the quality of food products.

Khoo et al. (2010) determined the carotenoid contents of bambangan pulp and peel. The results showed that the α- and β-carotene contents of bambangan pulps are significantly higher than the peels (Table 4). Bambangan peel extract contained 4.2 and 13.1 mg/100 g of α- and β-carotene, respectively. However, there were 7.96 mg/100 g of α-carotene and 20.04 mg/100 g of β-carotene in bambangan pulp extracts. Moreover, 2.5 and 2.7 mg/100 g of 9-cis-β-carotene were identified in bambangan peel and pulp extracts, respectively. The other cis-isomers of β-carotene ranged from 2.87 to 3.74 mg/100 g found in the bambangan fruit peel and pulp extracts. Chen, Tai, and Chen (2004) found that mango pulp contained 0.9 to 9.2 mg/100 g of total carotenoids. Vijayanand, Deepu, and Kulkarni (2015) determined the total carotenoids in Indian Sindura, Mallika, and Totapuri mango pulp extracts. Their results showed that mango pulp contains total carotenoids in the range of 1.79 to 7.15 mg/100 g.

Recently, carotenoid contents of tropical fruit pulps such as banana, litchi, mango, papaya, passion fruit, and pineapple were analysed by Septembre-Malaterre et al. (2016). Their results showed that passion fruit, American mango, and papaya contain significantly higher levels of carotenoids than those from the José mango (0.57 mg/100 g), litchi (0.57 mg/100 g), pineapple, and banana. It can be clearly seen that carotenoid content greatly varies depending on the food matrix. Moreover, carotenoid content varies according to the fruit cultivar; for example, carotenoid content was 5-fold higher in the American mango than in the José mango. The carotenoid level of tropical fruits is associated with changes in the expression of genes involved in carotenoid biosynthesis pathways in response to environmental stimuli integrating photooxidative stress and light signalling cascades (Septembre-Malaterre et al., 2016). In addition, variations in carotenoid content found in tropical fruits could be due to environmental factors, such as temperatures or solar radiation, and agricultural practices, such as soil irrigation frequency or cultivation modes. (Rodriguez-Amaya, Kimura, Godoy, & Amaya-Farfan, 2008; Septembre-Malaterre et al., 2016). Recently, Crizel, Hermes, Rios, and Flôres (2016) determined the total carotenoids in pineapple, papaya, and olive co-product powders. Their results showed that papaya powder contains higher amounts of carotenoids (15.56 mg/100 g) than pineapple (2.02 mg/100 g) and olive co-products powders (1.64 mg/100 g). Avocado and banana peels have been reported to contain total carotenoids of 1.52 and 0.4 mg/100 g, respectively (Wang, Bostic, & Gu, 2010). In another study, mango peel has been reported to contain high amounts of total carotenoids in the range of 36.5 to 54.7 mg/100 g (Ajila et al., 2007). The carotenoid content of bambangan fruit and its co-products was higher than most tropical fruits and their co-products. Therefore, carotenoid-rich bambangan peels and pulp could be a potential source of functional foods.

4. Physicochemical properties of bambangan kernel fat (BKF)

BKF has been extracted using solvents (petroleum ether and *n*-hexane) and its physicochemical properties were studied by Azrina et al. (2015) and Jahurul, Leykey, et al. (2018a). In another study, Jahurul, Soon, et al. (2018b) optimized the total BKF yield using response surface methodology and determined its antioxidant properties. Although BKF has traditionally been extracted with organic solvents (petroleum ether and *n*-hexane), the adverse effects of these solvents on human health and the environment have encouraged fat extraction with green techniques, such as supercritical fluids. Jahurul et al. (2015) reported that the mango seed fat obtained by supercritical fluids can be considered premium grade. Table 6 shows the physicochemical properties of BKF, cocoa butter, and its alternatives. The fat extracted from the bambangan kernel shows potential for being a cocoa butter equivalent (Azrina et al., 2015; Jahurul, Leykey, et al., 2018a). Palmitic, stearic, oleic, and linoleic acids are the major fatty acids in BKF that are comparable to that of commercial cocoa butter. The high levels of saturated fatty acids (SFAs) mostly present in BKF are palmitic and stearic acids. However, BKF has a lower palmitic acid content than cocoa butter and a comparatively higher percentage of stearic acid. The results showed that the saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) of BKF were 56.2%, 39.2%, and 4.9%, respectively. These SFAs, MUFAs, and PUFAs in cocoa butter ranged from 57.4 to 65.5%, 32.7 to 36.5%, and 2.5 to 3.6%, respectively. BKF (44.1%), sal fat (42.1 to 45.2%), illipe butter (34 to 37%), kokum butter (40.8%), and mango fat (47%) are the fats that contain a similar degree of unsaturated fatty acids (MUFAs and PUFAs) as cocoa butter (35.2 to 40.1%) (Jahurul et al., 2013). This high similarity in fatty acids indicates that the BKF could be a potential cocoa butter alternative.

Based on the results, BKF has the closest iodine value with mango seed fat, Illipe butter, and shea butter but is higher than cocoa butter. Thus, the iodine value of BKF can be reduced by controlled the hydrogenation process to that desired for cocoa butter (Muchiri et al., 2012). Table 6 shows the saponification value of BKF. It can be clearly seen from Table 6 that the saponification value of BKF is relatively lower than cocoa butter, and is comparable with illipe and shea butter. Thus, cocoa butter has a slightly shorter carbon chain than BKF. When the saponification value is measured along with the iodine value, it may able to indicate the quality and characterize the types of fats. Hence, BKF contains a long chain of unsaturated fatty acids.

It can be observed from the results in Table 6 that BKF contains a high acid value when compared with cocoa butter. However, the acid value of BKF is comparable with shea butter and mango seed fat. Cocoa butter is the fat that contains the lowest oxidation rate among all the cocoa butter alternative fats. BKF, palm oil, and shea butter have a more than 2 μEq/g peroxide value (Table 6). Cocoa butter has a lower peroxide value than BKF. This could be because the BKF was extracted by a solvent (petroleum ether) which was heated during extraction, thus the heat may cause the fat to undergo oxidation. However, the acidity of BKF can be reduced by chemical or physical refining (Muchiri et al., 2012). According to Al-Neshawy and Al-Eid (2000), the addition of an antioxidant, such as butylated hydroxytoluene, to fats may reduce the oxidation process in long-term storage. The refractive index of BKF, cocoa butter, and its alternatives are shown in Table 6. The refractive index of BKF is closest to cocoa butter. The refractive indices of several fat samples do not deviate much from each other, and are consistently read at 1.45. Recently, Jahurul, Leykey, et al. (2018a) determined the solid fat content (SFC) of BKF. They reported that the SFC of BKF is high from 10 to 20 °C, whereas it is low at 25 °C and above. The authors claimed that the SFC of BKF is similar to mango seed fat (Jahurul, Zaidul, Norulaini, Sahena, Jaffri & Omar et al., 2014; Solís-Fuentes & Durán-de-Bazúa, 2004; Sonwai, Kaphueakngam, & Flood, 2012). The unique composition of fatty acids, the iodine value, the peroxide value, the acid value, and the saponification value make the chemical characteristics of BKF comparable with the chemical characteristics of commercial cocoa butter. Therefore, BKF could be used in the food industry as a cocoa butter substitute. Research on the blending of BKF with other fats and their compatibility is necessary.

5. Health effects of bambangan kernel extract

Bakar et al. (2013b) reported that bambangan kernel has the ability to protect against oxidative damage caused by *tert*-butyl hydroperoxide in the human liver cancer cell line (HepG2). Their results demonstrated that bambangan kernel extract and quercetin performed cytoprotective activity in HepG2 cell lines, with EC_{50} values of 1.2 and 5.3 μg/mL, respectively. In addition, bambangan kernel extract has been suggested to exert anticancer effects against breast cancer cells (Bakar et al., 2010b).

Bakar et al. (2010b) and Abdullah, Mohammed, Abdullah, Mirghani, and Al-Qubaisi (2014) studied the cytotoxic activities of bambangan and mango kernels, respectively. The results showed that the extracts of bambangan kernel have higher cytotoxic activities than mango kernel. The IC_{50} values of bambangan kernel extracts for MCF-7 and MDA-MB-231 cell lines were 23.0 μg/mL and 30.5 μg/mL, respectively. However, the cytotoxic activities of mango kernel extracts were 15 μg/mL in MCF-7 cell lines and 30 μg/mL in MDA-MB-231 cell lines. The high cytotoxic activities in bambangan kernel are due to the presence of multiple bioactive compounds. Bambangan kernel contains high levels of phenolic compounds, such as gallic acid, sinapic acid, chlorogenic acids, and flavonoids, which are able to inhibit the proliferation and growth of breast cancer cells (Indap, Radhika, Motiwale, & Rao, 2008; Manthey & Guthrie, 2002; Noratto, Porter, Byrne, & Cisneros-Zevallos, 2009). The cytotoxic activities of mango kernel extracts are just slightly lower than bambangan kernel. Mango contains phenolic compounds such as mangiferin and xanthine glycoside, which are active cytotoxic agents (Masibo & He, 2008). These phenolic compounds perform antiproliferative activities when reacting with other compounds additively, antagonistically and/or synergistically (Yang, Liu, & Halim, 2009).

Bakar et al. (2009) determined the effect of the cytotoxic properties of bambangan kernel. The results showed that bambangan kernel display high antioxidant properties with higher DPPH free radical scavenging activity and ferric reducing ability than other fruit parts. Plant extracts with high antioxidant properties have been shown to have cytotoxic effects on different cancer cell lines (Boivin et al., 2009; Ju, Lee, Hwang, & Kim, 2004). Bambangan fruit, with high antioxidant properties and TPCs, demonstrated cytotoxic effects against the proliferation of cancer cells (Bakar et al., 2010b). The presence of major bioactive substances, such as methyl gallate, suggest the anticancer, antimicrobial, and antioxidant potential of bambangan kernel (Ahmad et al., 2015).

In another study, Bakar et al. (2010a) determined the cytotoxic activity of extracts from flesh, kernel, and peel of bambangan against human liver cancer cells (HepG2), human colon cancer cells (HT-29), and human ovarian cancer cells (Caov3). The results showed that bambangan kernel has a strong cytotoxic activity against three of the cancer cells tested, whereas bambangan peel displays high cytotoxic activity against the liver and ovarian cancer cells. Among the cell lines reported by Bakar et al. (2010a), bambangan kernel was revealed to have the strongest inhibitory activity towards ovarian cancer cells (92.0 IC_{50} μg/mL), followed by colon (63.0 IC_{50} μg/mL), and liver cancer cells (34.5 IC_{50} μg/mL). However, bambangan peel showed higher cytotoxic activity against ovarian cancer cells (55.0 IC_{50} μg/mL) and liver cancer cells (36.5 IC_{50} μg/mL). There was no cytotoxic effect of bambangan peel on colon cancer cells observed by Bakar et al. (2010a). Based on the results obtained by Bakar et al. (2010a), bambangan kernel could be used as a promising anticancer agent.

6. Conclusions

Like mango, bambangan is a tropical fruit tree of great economic importance. It is nutritious and has various biological properties, due to the presence of various bioactive compounds (phytochemicals, antioxidant properties, fibre, phenolic acids, flavonoids, and carotenoids). Therefore, the consumption of bambangan fruit is recommended. It can be concluded that all parts of the bambangan fruit can be used for the development of antioxidant-rich drinks and high-fibre food products, and as potent antioxidant. To determine the efficacy of bambangan fruit extracts at treating diseases, in vivo and human clinical studies are needed. Moreover, comprehensive studies are needed to determine if BKF can be blended with other fats to make cocoa butter alternatives.

Conflict of interest

None to declare.

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