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Review

Mango (*Mangifera indica* L.) by-products and their valuable components: A review

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ABSTRACT

The large amount of waste produced by the food industries causes serious environmental problems and also results in economic losses if not utilized effectively. Different research reports have revealed that food industry by-products can be good sources of potentially valuable bioactive compounds. As such, the mango juice industry uses only the edible portions of the mangoes, and a considerable amount of peels and seeds are discarded as industrial waste. These mango by-products come from the tropical or subtropical fruit processing industries. Mango by-products, especially seeds and peels, are considered to be cheap sources of valuable food and nutraceutical ingredients. The main uses of natural food ingredients derived from mango by-products are presented and discussed, and the mainstream sectors of application for these by-products, such as in the food, pharmaceutical, nutraceutical and cosmetic industries, are highlighted.

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1. Introduction

Mango (*Mangifera indica* L.) fruit belongs to the family of *Anacardiaceae* in the order of *Sapindales* and is grown in many parts of the world, particularly in tropical countries. Over 1000 mango varieties are available worldwide. Of the available varieties, only a few are grown on commercial scales and traded (Solís-Fuentes & Durán-de-Bazúa, 2011). Presently, mango is cultivated on an area of approximately 3.7 million ha worldwide. According to Muchiri, Mahungu and Gituanja (2012), mango fruit occupies the 2nd position as a tropical crop, behind only bananas in terms of production and acreage used. It has been well documented that mango fruits are an important source of micronutrients, vitamins and other phytochemicals. Moreover, mango fruits provide energy, dietary fibre, carbohydrates, proteins, fats and phenolic compounds (Tharanathan, Yashoda & Prabha, 2006), which are vital to normal human growth, development and health. Each part of a mango tree, such as its leaves, flowers, bark, fruit, pulp, peel and seeds contains essential nutrients that can be utilized. Fig. 1 shows the nutritional and functional compounds in mango by-products.

Mango puree, slices in syrup, nectar, leather, pickles, canned slices and chutney are the main industrial products obtained from mango fruits. The major by-products from mango processing are peels and seeds. Depending on the cultivars and products made, its industrial by-products, namely peels and seeds, represent 35–60% of the total weight of the fruit (Larrauri, Rupérez, Borroto & Saura-Calixto, 1996). Therefore, extensive research on mango by-products has been performed in the past decade. This research has revealed that mango by-products, such as peels and seeds, contain high levels of various health-enhancing substances, such as phenolic compounds, carotenoids, vitamin C and dietary fibre (Ajila, Aalami, Leelavathi & Prasada Rao, 2010; Ajila, Naidu, Bhat & Prasada Rao, 2007; Aziz, Wong, Bhat & Cheng, 2012; Kim et al., 2010; Sogi, Siddiq, Greiby & Dolan, 2013). In the past decade, fats from mango seeds have been extracted, fractionated, and evaluated for quality by many researchers (Abdalla, Darwish, Ayad & El-Hamahmy, 2007; Ali, Gafur, Rahman & Ahmed, 1985; Dorta, González, Lobo, Sánchez-Moreno & Ancos, 2014; Gaydou & Bouchet, 1984; Jahurul, Zaidul, Norulaini, Sahena, Rahman & Mohd Omar, 2015; Jahurul et. al., 2013; Jahurul, Zaidul, Norulaini, Sahena, Jaffri & Omar, 2014a). Mango seed fat has attracted considerable interest from scientists due to its unique physicochemical characteristics, which are similar to those of cocoa butter (Hemavathy, Prabhakar, & Sen, 1988; Jahurul et al., 2014a; Muchiri et al., 2012).

Recently, Mirabella, Castellani, and Sala (2014) reported that 39% of food waste is produced by the food manufacturing industries in developed countries. They also reported that these wastes are used as raw material for new products and applications. Food by-products represent a growing problem as the plant material is prone to microbial spoilage, which may cause odours and other environmental problems (Joshi & Attri, 2006; Laufenberg, Kunz, & Nystroem, 2003; Van Dyk, Gama, Morrison, Swart, & Pletschke, 2013). For example, approximately $10 million is spent annually on the disposal of only apple pomace in the USA (Shalini & Gupta, 2010). In another study, Schieber, Stintzing, and Carle (2001) reported that the costs to dry, store and ship food by-products are economically limiting factors. This review examines the potential uses of mango by-products from industrial manufacturing and processing.

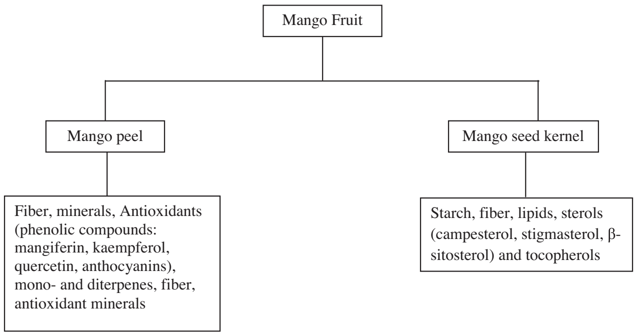

Fig. 1. Nutritional and functional compounds in mango by-products.

Table 1
Top five mango production, exporting and importing countries in the world (2001–2005).

Countries	Mango production statistics (1000 metric tonnes)					
	2001	2002	2003	2004	2005	2003–2005 (%)
India	10,060	10,640	10,780	10,800	10,800	38.58
China	3273	3513	3571	3582	3673	12.90
Thailand	1700	1700	1700	1700	1800	6.20
Mexico	1577	1523	1362	1573	1679	5.50
Indonesia	923	1403	1526	1438	1478	5.29
World total	17,533	18,779	18,939	19,093	19,430	68.47
Mango exporting statistics (1000 metric tonnes)						
Mexico	195	195	216	213	195	22.64
India	46	42	179	156	223	20.25
Brazil	94	104	138	111	114	13.18
Pakistan	52	48	60	82	49	6.94
Netherlands	43	33	58	51	69	6.42
World total	430	422	651	613	650	69.43
Mango importing statistics (1000 metric tonnes)						
United States	238	263	278	276	261	32.70
Netherlands	70	71	91	76	98	10.62
United Arab Emirates	46	52	62	58	51	6.82
Saudia Arabia	36	35	40	42	51	5.32
China	34	38	47	57	19	4.91
World total	424	459	518	509	480	60.37

Source: FAOSTAT (2007).

2. World production, export and import of mango fruit

The production, trade and consumption of mango fruits have increased significantly both domestically and internationally, due to the attractive nutritional value of the fruits. Thus, mangoes are commercially cultivated in more than 103 countries worldwide and production is increasing each year due to increasing consumer demand. Approximately 77% of the world's mangoes are produced in Asian countries, while 13% and 9% are produced in the Americas and African countries, respectively (FAOSTAT, 2007). The Food and Agriculture Organization (FAO, 2007) estimate that the world's production of mango fruits is over 26 million tonnes annually. The top five mango-producing countries are shown in Table 1. Approximately 68.5% of the world's mangoes are currently produced by these five countries. From 2003 to 2005, India was the largest mango producer, accounting for 38.6% of the mangoes produced, followed by China (12.9%), Thailand (6.2%), Mexico (5.5%) and Indonesia (5.3%). The other major mango growing countries are Pakistan, Brazil, the Philippines, Nigeria and Egypt (FAOSTAT, 2007). Recently, Masibo and He (2009) reported that among the world's mango-producing countries, India was the largest producer, accounting for 54.2% of the mangoes produced worldwide.

According to FAOSTAT (2007), approximately 912,853 metric tonnes of mangoes were exported worldwide in 2005. The top five mango-exporting countries are also shown in Table 1. From 2003 to 2005, approximately 69.4% of the world's mangoes were exported by these five countries. Mango exports have increased steadily due to increasing consumer demand. Mexico (22.6%) was the largest mango exporter in the world, followed by India (20.3%), Brazil (13.2%), Pakistan (6.9%) and the Netherlands (6.4%). Although India was the largest mango producer, it was surpassed by Mexico in terms of mango exports. Mexico and India together dominated the world mango exports from 2003 to 2005.

Table 1 shows the top five mango importing countries and it can be clearly observed that the world's mango imports increased steadily. From 2003 to 2005, approximately 60.4% of the world's mango imports were imported by five countries. The USA alone imported approximately 32.7% of the world's mangoes during that period and was the major importer of mangoes. Other prominent mango-importing countries were the Netherlands (10.6%), the United Arab Emirates (6.8%), Saudi Arabia (5.3%) and China (4.9%). Mango imports in China dramatically decreased in 2005, which may have been due to an increase in domestic production. China imported 57 metric tonnes of mango fruits in 2004 which decreased to 19 metric tonnes in 2005.

3. Mango fruit peels

Mango peels are considered to be by-products from industrial processing or consumption of the fruit. The peel composes approximately 7–24% of the total weight a mango fruit (Iqbal, Saeed, & Zafar, 2009; Kim et al., 2012). Recently, mango peels have attracted considerable attention in the scientific community due to their high content of valuable compounds, such as phytochemicals, polyphenols, carotenoids, enzymes, vitamin E and vitamin C, which have predominant functional and antioxidant properties (Ajila et al., 2007). Moreover Sogi et al. (2013) reported mango peels as a rich source of dietary fibre, cellulose, hemicellulose, lipids, protein, enzymes and pectin. These valuable compounds are also beneficial for human health. Mango peels can be utilized for the production of valuable ingredients (i.e., dietary fibre and polyphenols) for various food applications, as has been reported by many researchers (Ajila et al., 2007; Ajila, Rao, & Rao, 2010; Aziz et al., 2012). Currently, mango peel flour is used as a functional ingredient in many food products, such as noodles, bread, sponge cakes, biscuits and other bakery products (Aziz et al., 2012). Mango peels also contain fats (2.16–2.66%) (Ajila et al., 2007).

Ajila, Aalami, et al. (2010) studied the effects of mango peel added to macaroni and its effect on the cooking properties, firmness, nutraceutical and sensory characteristics of the macaroni. Their results suggested that the incorporation of mango peel powder improved the nutritional quality of the macaroni without affecting its cooking, textural or sensory properties. The effect of mango peel powders at differing amounts (5%, 10%, 15% and 20%) and mango kernel powders at 20%, 30%, 40% and 50% on the rheological, physical, sensory and antioxidant properties of biscuits was evaluated by Ashoush and Gadallah (2011). The results showed the possibilities of improving the nutritional quality and antioxidant properties of biscuits by incorporating mango peels and kernel powders.

3.1. Bioactive compounds in mango peel

Two major valuable compounds, namely ethyl gallate and penta-O-galloyl-glucoside, have been isolated from mango peels by Jiang, He, Pan, and Sun (2010). Their results showed that these compounds possess potent hydroxyl radical ($^{\cdot}OH$), superoxide anion ($O_2^{\cdot-}$) and singlet oxygen ($^1O_2$) scavenging activities. They concluded that mango peel waste could be utilized in both an experimental and clinical sense. Meanwhile, pharmaceutical studies have indicated that gallate-type compounds, such as penta-O-galloyl-glucoside, show various bioactivities, including anti-tumor (Lizarraga et al., 2008), antioxidant (Hatano et al., 1989), anti-cardiovascular (Ignarro, Balestrieri, & Napoli, 2007) and hepatoprotective effects (Eun-Jeon, Zhao, Ren-Bo, Youn-Chui, & Hwan, 2008). Engels, Gänzle, and Schieber (2012) analyzed gallotannins from mango kernels and reported the effects of methanolysis on their antibacterial activity and iron binding capacity by a fast liquid chromatography mass spectroscopy method. Their results showed that methanolysis led to the degradation of highly galloylated tannins and yielded penta-O-galloylglucose and methyl gallate. Due to the compositional changes during degradation, there was no effect found on the antimicrobial activity of the extracts where iron binding capacity increased with the amounts of methyl gallate (Engels et al., 2012).

Ajila et al. (2007) determined the major antioxidants, such as polyphenols, anthocyanins and carotenoids, in Indian Raspuri and Badami (ripe and raw) mango peel extracts. Moreover, they examined the antioxidant activity of these mango peel extracts. Their results showed that ripe peels contained higher amounts of anthocyanins (360–365 mg/100 g) and carotenoids (194–436 μg/g) compared to raw peels, while raw mango peels had high polyphenol content (90.18–109.7 mg/g). Mango peel extracts were proven to be a good source of polyphenols, anthocyanins and carotenoids, and thus, they may be used in nutraceutical and functional foods.

The carbohydrate composition and bound phenolics in the dietary fibre of mango peels were determined by Ajila and Rao (2013). The total dietary fibre content ranged from 40.6% to 72.5%. The results also showed that galactose, glucose and arabinose are the major neutral sugars in insoluble and soluble dietary fibres. The bound polyphenolic and flavonoid contents ranged from 8.1 to 29.5 and 0.101 to 0.392 mg/g, respectively. They reported that the bound phenolic acids were gallic, protocatechuic and syringic acids, and kaempferol and quercetin were the major flavonoids in the peels. The mango peel, which is rich in dietary fibre and bound phenolics, can be used in functional foods, as reported by Ajila and Rao (2013). The antioxidant and tyrosinase inhibitory properties of extracts from mango seed kernels were studied by Maisuthisakul and Gordon (2009). They found that the mango seed kernel extracts contained phenolic components with a high antioxidant activity and also possess a tyrosinase inhibitory activity. They reported that the extracts had the most effective antioxidants, which had the highest radical-scavenging, metal-chelating and tyrosinase inhibitory activity. In conclusion, they recommended that mango seed kernel extracts are suitable for use in food, cosmetic, nutraceutical and pharmaceutical applications.

Dorta, Lobo, and González (2012) studied the effects of different drying methods on the polyphenol and chlorophyll contents as well as the antioxidant activity of mango peels and seeds. They found that freeze-drying allowed the peels and seeds to be stabilized without diminishing their antioxidant activity. Oven-drying treatment had the most negative effect on the antioxidant capacity of the mango by-products (peels and seeds). They concluded that the freeze-drying method can improve the antiradical capacity of the mango peel against ABTS^{*+} and scavenge capacity of free radicals and inhibit lipid peroxidation in the mango kernel. In another study, Dorta et al. (2014) identified the phenolic compounds in the extracts of powdered food ingredients obtained from peels and seeds of three mango varieties (Keitt, Sensation and Gomera 3) cultivated in the Canary Islands (Spain) using high-performance liquid chromatography–electrospray ionization–quadrupole-time of flight–mass spectrometry (HPLC–ESI–QTOF–MS). They reported that bioactive phenolic compounds from mango by-products have been successfully separated and identified using the HPLC–ESI–QTOF–MS technique (Gallates and gallotannins; flavonoids, mainly quercetin derivatives; ellagic acid and derivatives; xanthines, principally mangiferin; benzophenones and derivatives, such as maclurin derivatives). Moreover, their results also highlighted the importance of mango by-products, such as peels and seeds, as a source of natural bioactive phenolic compounds.

Ajila et al. (2010) formulated macaroni products enriched with mango peel powder. They also examined the quality of the products including the cooking characteristics, polyphenol, carotenoid and dietary fibre contents and the free radical scavenging activity. For this study, mango peels were incorporated into macaroni at three different levels (2.5%, 5.0% and 7.5%). The total dietary fibre, polyphenols and carotenoid content in their formulated macaroni increased from 8.6% to 17.8%, 0.46 to 1.80 mg/g and 5 to 84 µg/g, respectively. Their results also showed that the cooking loss and firmness of the macaroni increased from 5.84% to 8.71% and 44 to 73.45 gf, respectively, after incorporating the mango peel powder. They concluded that improving the nutritional quality of macaroni without affecting its textural and sensory properties is possible. In another study, Ajila, Leelavathi, and Prasada Rao (2008) prepared soft dough biscuits using different levels (5.0%, 7.5%, 10.0%, 15.0% and 20.0%) of mango peel powder. The results show that wheat flour incorporated with mango peel powder yielded dietary fibre-enriched biscuits with improved antioxidant properties.

Yang and Li (2013) demonstrated that the derivative of mango peel extract could be a novel biological route for the synthesis of silver nanoparticles. Their results showed that non-woven fabrics loaded with biosynthesized silver nanoparticles displayed excellent antibacterial activity. They recommended these nanoparticles as a promising candidate for many medical applications. Amid, Shuhaimi, Zaidul, and Manap (2012) investigated the feasibility of employing ATPS alcohol/salt to purify serine protease on mango peels. In their study, the highest partition coefficient (64.5) and selectivity (343.2) for the serine protease purification value were achieved in an ATPS of 16% (w/w) 2-propanol, 19% (w/w) potassium phosphate and 5% (w/v) NaCl at pH 7.5. They concluded that the serine protease from mango peels could be an excellent choice for applications in the food, detergent, biotechnology and pharmacology industries.

Table 2 shows the most bioactive compounds, such as phenolic compounds, carotenoids, vitamin C and dietary fibre, present in mango peels. It has been well documented that these compounds contribute to lowering the risk of cancer, Alzheimer's disease, cataracts and Parkinson's disease, among others (Ayala-Zavala et al., 2011). The antioxidant and radical scavenging activities of these bioactive compounds have been shown to delay or inhibit the oxidation of DNA, proteins and lipids (Ayala-Zavala et al., 2011). Sogi et al. (2013) determined the antioxidant activity, total phenolics and functional properties of mango peels and kernel wastes. They also evaluated different drying methods of mango wastes and assessed their impact on the antioxidants, nutrients and functional properties. Freeze-dried mango by-products showed higher antioxidant contents than mango products dried with hot air, vacuum and infrared techniques. They reported that cabinet-dried mango by-products can be used in food products to enhance their nutritional and antioxidant properties. Mango by-products were proven to be a good source of phytochemicals that exert antioxidant properties and can be utilized in several food applications. Future studies would be necessary to focus on optimize various quality parameters and the evaluation of such products.

Recently, the antioxidant and anti-proliferative activities of mango peels and flesh were investigated by Kim et al. (2010). Furthermore, the cytoprotective effect of extracts from mango peels and flesh on oxidative damage induced by H_2O_2 in a human hepatoma cell line (HepG2) was also evaluated in this study. It was observed that mango peels contained more flavonoids and polyphenols than the flesh and also exhibited good antioxidant activity. The results also showed that treatment of HepG2 cells with mango peel extracts inhibited DNA damage. Thus, mango peels exhibited good antioxidant activity, which shows their potential as a functional food or supplemental ingredient. On the other hand, they concluded that these findings necessitate extensive studies on the chemical profiles and mechanistic actions of the antioxidant and anti-proliferative activities in mango by-products and these studies are currently underway in their lab.

4. Mango fruit seed

Like mango peels, mango seeds are also discarded as by-products during industrial processing of the fruit. Depending on the varieties, the kernel represents 45–85% of the seed and approximately 20% of the whole fruit (Arogba, 1997; Hemavathy et al., 1988; Solís-Fuentes & Durán-de-Bazúa, 2011). On a dry basis, the kernel contains 7.1–15% crude fats (Abdalla et al., 2007; Ali et al., 1985; Gunstone, 2011; Jahurul et al., 2013, 2014a). This fat has attracted considerable interest from scientists due to its unique physical and chemical characteristics, which are similar to those of cocoa butter, illipe, shea, kokum and sal butter (Hemavathy et al., 1988; Jahurul et al., 2013; Jahurul et al., 2014a; Muchiri et al., 2012). It is a promising, safe and natural source of edible fats, as it does not contain any trans fatty acids (Solís-Fuentes & Durán-de-Bazúa, 2011).

4.1. Fat contents in different mango fruit varieties

Many researchers have extracted and fractionated mango fats using solvents to subsequently evaluate their quality (Abdalla et al., 2007; Ali et al., 1985; Dorta et al., 2014; Gaydou & Bouchet, 1984). Recently, Jahurul et al. (2014a) extracted mango fats from several mango varieties using supercritical carbon dioxide (SC-CO_2). They also studied the physicochemical properties of the SC-CO_2 extracted mango fats. Table 3 shows the total fat content in different mango varieties.

Table 2
Functional compounds found in mango by-products.[a]

Mango by-products	Total phenolics (mg/100 g)	Ascorbic acid (mg/100 g)	Carotenoids (µg/100 g)	Fibre (%)	References
Peel	5467–9020	–	8100–19,400	–	Ajila, Rao, et al. (2010)
Peel	7010–9260	–	–	–	Kim et al. (2010)
Peel	7000.0	–	–	–	Larrauri et al. (1996)
Peel	810–2950			40.6–72.5	Ajila and Rao (2013)
Peel	2032–3185	68.49–84.74	1880–4050	–	Sogi et al. (2013)
Kernel	11,228–20,034	61.22–74.48	370–790	–	Sogi et al. (2013)
Peel	5467–10,970	18.8–39.2	36,500–394,500	3.28–7.4	Ajila et al., (2007)
Peel	9620		309,200	–	Ajila et al. (2008)
Kernel	112	–	–	–	Abdalla et al. (2007)
Peel	47,830–79,530	–	–	–	Dorta et al. (2014)
Kernel	28,330–44,760	–	–	–	Dorta et al. (2014)

[a] Dry weight basis.

Table 3
Total mango fat (%) and their fatty acid compositions from different studies.

Variety	Origin	Total fat (%)	Fatty acids					References
			$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{20:0}$	
6 varieties	Malaysia	7.6–13.7	6.95–10.93	32.8–47.62	37.01–47.28	3.66–6.87	1.77–2.43	Jahurul et al. (2014a)
Mixed variety	Egypt	12.3	5.8	38.3	46.1	8.2	–	Abdalla et al. (2007)
Manila variety	Mexico	11.3	9.29	39.07	40.81	6.06	2.48	Solís-Fuentes and Durán-de-Bazúa (2004)
Kaew variety	Thailand	7.28	5.4	46.6	41.1	3.8	1.7	Sonwai et al. (2012)
4 varieties	Kenya	8.5–10.4	4.87–10.57	24.22–32.80	46.37–58.59	6.73–10.4	0.62–1.64	Muchiri et al. (2012)

Table 4
Triglyceride compositions of mango seed fat from different studies.

Variety	Origin	TG Types							References
		POS	SOS	SOO	POO	POP	SOA	OOO	
		11	40	23	5	–	4	5	Gunstone (2011)
Kaew variety	Thailand	5.7	29.4	14.6	10.8	8.9	–	2.5	Sonwai et al. (2012)
Waterlily	Malaysia	14.76	39.28	–	–	6.89	–	–	Jahurul et al. (2014b)

SOS (1,3-distearoyl-2-oleoyl-glycerol), SOO (1-stearoyl-2,3-dioleoyl-glycerol), POS (1-palmitoyl-2-oleoyl-3-stearoyl-glycerol), POO (1-palmitoyl-2,3-dioleoyl-glycerol), SOA (1-stearoyl-2-oleoyl-3-arachidoyl-glycerol), OOO (1,2,3-trioleoyl-glycerol), POP (1,3-dipalmitoyl-2-oleoylglycerol).

Table 5
The physicochemical properties of mango fats from different studies.

Variety	Iodine value (g iodine/100 g fat)	Saponification value (mg KOH/g fat)	Acid value (%)	Slip melting point (°C)	References
6 varieties	42.9–52.69	189.9–190.7	3.23–5.12	35.8–39.1	Jahurul et al. (2014a)
4 varieties	51.08–56.79	188.8–195.9	4.49–7.48	25–33	Muchiri et al. (2012)
Mixed variety	53.15	192.16	1.22	30.5	Abdalla et al. (2007)
Kaew variety	40.9	185.4	–	35.7	Sonwai et al. (2012)
Manila variety	41.76	189.0	–	–	Solís-Fuentes and Durán-de-Bazúa (2004)

4.2. Fatty acid compositions

Mango fats are a rich source of palmitic ($C_{16:0}$), stearic ($C_{18:0}$), oleic ($C_{18:1}$) and linoleic ($C_{18:2}$) acids. The stearic and oleic acids are the dominant fatty acids. In addition to these fatty acids, arachidic, behenic, lignoceric and linolenic acids are minor fatty acids present in mango fats. The fatty acid constituents of mango fats varied considerably with the mango varieties. Table 3 shows the major fatty acid compositions of mango fats. The fatty acid constituents and other physicochemical properties of mango fats make it a valuable fat that is comparable to commercial cocoa butter (Jahurul et al., 2014a; Muchiri et al., 2012; Sonwai, Kaphueakngam, & Flood, 2012).

4.3. Triglyceride compositions

Triglycerides are complex mixtures of a variety of fatty acids, which are the major constituents in fats and oils. The triglyceride compositions of mango seed fat from different studies are shown in Table 4. The major triglycerides found in mango seed fat are 1,3-distearoyl-2-oleoyl-glycerol (SOS) (29.4–40%), 1-stearoyl-2,3-dioleoyl-glycerol (SOO) (14.6–23%), 1-palmitoyl-2-oleoyl-3-stearoyl-glycerol (POS) (5.7–14.76%) and 1,3-dipalmitoyl-2-oleoylglycerol (POP) (6.89–8.9%). Multiple researchers have reported that blending of SOS-rich fats into chocolate products can increase the solid fat content, inhibiting fat bloom and decreasing the tempering time slightly (Jeyarani & Reddy, 1999; Maheshwari & Reddy, 2005; Reddy & Prabhakar, 1994). The compositions of the triglycerides, particularly SOS, in mango seed fat (MSF) are well established. Therefore, SOS-rich MSF could be used as a suitable raw material for the production of temperature-resistant hard butter in countries with hot climates (Jahurul et al., 2014c).

4.4. Physicochemical properties of mango fats

The physicochemical properties of mango seed fats, shown in Table 5, have been evaluated to explore their potential applications. The iodine value of mango seed fats in different varieties varied from 40.90 to 56.79 (g iodine/100 g fat). The iodine value of the Kaew variety (40.90) cultivated in Thailand was the lowest, while the Kagege mango variety (56.79) cultivated in Kenya was the highest (Muchiri et al., 2012; Sonwai et al., 2012). The authors also reported that the iodine values of different mango varieties cultivated in India, Bangladesh, Egypt, Mexico and Malaysia were comparable. The saponification values ranged from a low of 185.4 (mg KOH/g fat) for the Thailand Kaew mango variety to a high of 197.0 (mg KOH/g fat) for the Bangladeshi Ranipasand mango variety. The acid values varied from 1.22% for the Egyptian mango variety to 7.48% for the Kenyan Kent mango variety. The melting point of mango seed fats from different countries ranged from 25 to 47 °C. Recently, Jahurul et al. (2014a) and Muchiri et al. (2012) reported that the physicochemical characteristics (i.e., iodine value, saponification value, acid value and melting point) of mango seed fats are similar to that of Borneo illipe, shea butter, tallow and cocoa butter. The physicochemical characteristics of mango seed fats are slightly higher or lower than the corresponding characteristics in cocoa butter; thus, controlled hydrogenation, chemical or physical refining, and natural blending processes could be used to increase or reduce cocoa butter characteristics to desired values.

4.5. Thermal behavior of mango seed fats

The thermal behavior of fats, particularly those in several prepared food products, is an important area of study. The thermal behavior of palm kernel oil (PKO), palm oil (PO), mango seed fat,

Table 6
Essential and non-essential amino acid profiles (g/100 g) of mango seed kernel from different studies.

Essential amino acids												Non-essential amino acids						References
Leu	Iso	Met	Phe	Lys	Thr	Tyr	Val	Try	His	Cys	Arg	Asp	Glu	Ser	Pro	Gly	Ala	
6.9	4.4	1.2	3.4	4.3	3.4	2.7	5.8		5.5		7.3	6.5	18.2	3.3	3.5	4.0	4.2	Abdalla et al. (2007)
7.0	4.0	2.2	2.8	5.4	4.0	4.1	5.0	1.0	2.4	2.4	6.1	9.6	12.3	7.6		3.3	5.9	Arogba (1997)
8.8–9	3.8–4.6	1.8	1.9–2.0	4.4–5.3	4.3–4.4	1.8	3.7–3.8	2–2.1	1.5		3.4–3.6	11.3–12.0	8.5	7.0–7.1	3.4	8.0–8.3	6.0–6.9	Elegbede et al. (1995)

Leu (leucine), Iso (isoleucine), Met (methionine), Phe (phenylalanine), Lys (lysine), Thr (threonine), Tyr (tyrosine), Val (valine), Try (tryptophan), His (histidine), Cys (cysteine), Arg (arginine), Asp (aspartic), Glu (glutamic), Ser (serine), Pro (proline), Gly (glycine), Ala (alanine).

kokum butter, sal fat, shea butter, illipe fat and their blends has received a lot of attention given their valuable role in cocoa butter formulations and its widespread use in confectionaries (Calliauw et al., 2005; Jahurul et al., 2014b, 2014c; Maheshwari & Reddy, 2005; Olajide, Ade-Omowaye, & Otunola, 2000; Reddy & Prabhakar, 1994; Zaidul, Norulaini, Omar, & Smith, 2007). Jahurul et al. (2014b, 2014c) and Solís-Fuentes and Durán-de-Bazúa (2004) studied the fusion and crystallization profiles of mango seed fats. The authors also compared the thermal behavior of mango seed fat with that of commercial cocoa butter. Jahurul et al. (2014b) reported that a single melting peak which started at −12.98 °C and ended at 36.07 °C, whereas Solís-Fuentes and Durán-de-Bazúa (2004) reported values of −15.94 °C and 42.23 °C. For the crystallization of mango seed fat, Jahurul et al. (2014b) reported a single peak starting at 16.18 °C and ending at −24.32 °C, whereas Solís-Fuentes and Durán-de-Bazúa (2004) reported values of 14.64 °C and −24.27 °C. They concluded that the melting and crystallization profiles of mango seed fat closely resemble those for cocoa butter.

4.6. Cocoa butter alternatives from mango seed fat

Many researchers have produced cocoa butter alternatives from mango seed fat (Jahurul et al., 2014b, 2014c; Solís-Fuentes & Durán-de-Bazúa, 2004; Sonwai et al., 2012). Recently, Jahurul et al. (2014b) formulated cocoa butter substitutes by blending MSF and palm oil mid-fraction (POMF). Ten blends of MSF/POMF with different ratios (95/5, 90/10, 85/15, 80/20, 75/25, 70/30, 65/35, 60/40, 55/45 and 50/50) have been studied using various chromatographic and thermal techniques. Their results showed that the POP, SOS and POS were predominant triglycerides in certain blends, which are similar to the components in commercial cocoa butter. In these blends, melting started at −14.10 °C and ended at 36.82 °C, whereas crystallization started at 14.71 °C and ended at −27.26 °C. The melting and crystallization curves had exotherms/endotherms indicative of the high and low melting fractions of the blends that were similar to the curves for commercial cocoa butter. They also reported that the solid fat content (SFC) of certain blends resembles the SFC of commercial cocoa butter between 10 and 20 °C. In another study, Solís-Fuentes and Durán-de-Bazúa (2004) studied the thermal behavior of mango seed fat and cocoa butter mixtures. They reported that the isosolid diagrams showed the compatibility of mixtures of mango seed fat and commercial cocoa butter, even more so than mixtures of cocoa butter with milk fat, lauric fats or hydrogenated cottonseed oil (Solís-Fuentes & Durán-de-Bazúa, 2004).

A cocoa butter equivalent (CBE) was produced from MSF and POMF blends by Sonwai et al. (2012). Five fat blends with different ratios of MSF/PMF (90/10, 80/20, 70/30, 60/40 and 50/50) were characterized. In the studied blends, palmitic, stearic and oleic acids were the main fatty acid components, similar to commercial cocoa butter. Their results also showed that the physicochemical properties, such as the triglyceride compositions, iodine value, saponification value, slip melting point and acid value of certain blends, were close to those of cocoa butter. They also reported that the crystallization curve, polymorphic structure, crystal morphology and bloom behavior of the mixed fats were not significantly different from those of cocoa butter.

Recently, Jahurul et al. (2014c) produced a heat-tolerant cocoa butter replacer (CBR) from mango seed fat and palm stearin. In their study, the blending effects of mango seed fat and palm stearin on formulating hard CBRs were investigated. Their results showed that the melting and crystallization properties and solid fat content of blends containing 80–90% mango seed fat and 10– 20% palm stearin were close to commercial cocoa butter. The melting peak temperatures increased and shifted towards higher temperatures with palm stearin. The melting peak started at −13.4 °C and ended at 36.9 °C for blend 2 with 10% palm stearin and at −16.5 °C and 40.0 °C for blend 5 with 25% palm stearin. The crystallization thermogram profiles of blends having 95–80% mango seed fat showed a single exothermic peak was similar to the commercial cocoa butter at different onset and offset temperatures. However, onset and offset crystallization temperatures were ranged from 16.4 to 16.9 °C and from −24.6 to −22.6 °C, respectively for these blends. They also studied the relationships between SFC and the temperature of the mango seed fat and palm stearin blends. Certain blends showed a higher SFC from 20 to 25 °C that did not drop to 0% at 37.5 °C, but shifted such that the drop occurred above 40 °C. The authors reported that these blends could be used to produce temperature-resistant hard butter in countries with hot climates. The results of their study also suggested that certain blends of mango seed fat and palm stearin could be used to prepare CBRs without significantly altering the physical and chemical properties of the product.

4.7. Amino acid profiles

There is a lack of information on the mango kernel amino acid profiles compared with reports on the fatty acid and triglyceride compositions. The protein content of the mango seed kernels is low compared to wheat, maize and barley. Although mango seed kernels contain a small amount of crude protein (6.7% on the dry basis), the quality of the protein is high because it is rich in all of the essential amino acids. Many researchers (Abdalla et al., 2007; Arogba, 1997; Elegbede, Achoba, & Richard, 1995; Lasztity, EL-Shtel, Abdel-Samei, Hatour, & Labib, 1988) reported that most of the essential amino acids in mango seed kernels were at higher levels than in the FAO/WHO reference protein (Food, 1993). Table 6 shows the essential and non-essential amino acids of mango seed kernels in different studies. The essential amino acids, such as leucine and arginine, were the dominant amino acids, followed by valine, histidine, lysine, isoleucine, threonine and phenylalanine. Different studies indicated that the amino acid composition of mango seed kernels depends on the mango variety. Among all of the amino acids determined to be in mango seed kernels in different studies, the lowest percentage was found for methionine and tryptophan. Recently, Abdalla et al. (2007) found that all of the essential amino acids except methionine, threonine and tyrosine were at higher levels in mango seed kernels compared to the FAO/WHO reference protein (Food, 1993).

5. Conclusion

It has been well documented that mango by-products, such as peels and seeds, contain high levels of various health-enhancing substances (i.e., phenolic compounds, carotenoids, vitamin C and dietary fibre). Mango seed fat has attracted considerable interest from scientists due to its unique physicochemical characteristics, which are similar to those of commercial cocoa butter. It can be concluded that mango fruit by-products are potential sources of natural food ingredients. The recovery and utilization of valuable compounds from mango by-products is an important challenge for scientists. Meanwhile, the utilization of mango by-products, such as peels and seeds, has become an important aspect in waste management to contribute to more sustainable production in the food and pharmaceutical industries. This review presents the recovery of bioactive compounds with antioxidant and antimicrobial activities from byproducts originating from mango fruit processing. These valuable compounds in mango by-products could have a greater application in the food industry. Comprehensive studies are needed that not only include the recovery of valuable compounds, but also specific applications to ensure industrial exploitation and sustainability of the final product. Furthermore, the sensorial and nutritional aspects of the food products containing mango seed fat from mango by-products should be studied.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodchem.2015.03.046.

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