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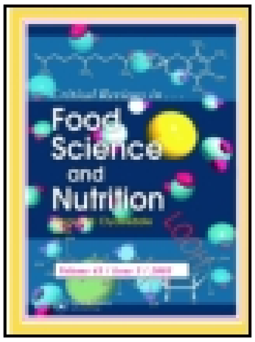

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Mango kernel fat fractions as potential healthy food ingredients: A review

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Abstract

Mango kernel fat (MKF) has been reported to have high functional and nutritional potential. However, its application in food industry has not been fully explored or developed. In this review, the chemical compositions, physical properties and potential health benefits of MKF are described. MKF is a unique fat consisting of 28.9-65.0% of 1,3-distearoyl-2-oleoyl-glycerol with excellent oxidative stability index (58.8-85.2 h at 110 °C), making the fat and its fractions suitable for use as high-value added food ingredients such as cocoa butter alternatives, *trans*-free shortenings, and a source of natural antioxidants (e.g., sterol, tocopherol and squalene). Unfortunately, the long period of dehydration of mango kernels at hot temperature results in the hydrolysis of triacylglycerols. The high levels of hydrolysates (mainly free fatty acids and diacylglycerols) limit the application of MKF in manufacturing these food ingredients. It is suggested that the physico-chemical and functional properties of MKF could be further improved through moderated refining (e.g., degumming and physical deacidification), fractionation, and interesterification.

Keywords

Mango kernel fat; cocoa butter alternative; *trans*-free fat; antioxidant; health benefit

Introduction

Mango belongs to the family of Anacardiaceae and has been known as the "king of fruits" (Dar et al., 2016). The main cultivated species is *Mangifera indica* L. Recently some wild species like *Mangifera sylvatica* Roxb and *Irvingia gabonensis* are also called mango because of their improved quality as high-value added food ingredients (Akhter, Mcdonald and Marriott, 2016; Yamoneka et al., 2015). Mango is one of the most important fruits worldwide, with 37-45 million tons produced annually from 2010 to 2014 (FAO, 2017). Although the fruit is cultivated in more than 100 countries, India, China, Thailand, Indonesia, and Mexico are the top five main mango-producing countries, whose annual output account for 62-75% (nearly 28 million tons) of the global yield (FAO, 2017).

In general, mango pulp has been processed into various snacks (e.g., juice, jam, pickle, dried fruit and jelly) in the food industry (Bhardwaj and Pandey, 2011). However, large amounts of the seeds and their kernels are considered low-value agricultural products or even discarded as waste (Torres-Leon, et al., 2016). In the past decade, increased number of researchers focused on the mango kernels because they have been reported as a source of high-quality specialty lipids and micronutrients (Nadeem, Imran and Khalique, 2016). Production of value-added products like chocolate fats, *trans*-free shortenings, and natural antioxidants using mango kernel fat (MKF) will contribute to the utilization of waste mango seeds, promote the development of healthy food, and further generate substantial economic gains. The average fat content of the mango kernels is

7.3-13.7% (Jahurul et al., 2015). In this regard, about 0.03-0.43 million tons of MKF could be produced annually if the kernels are collected properly. The amount is generally higher than that of most functional oils (about 0.05 million tons, e.g., tea seed, grape seed, and safflower seed oils) which are of major interest to the current lipid industry (Wang, 2014). The potential use of MKF also meets the demand for producing cocoa butter alternatives (CBAs, 0.025-0.050 million tons) according to the European Union Directive (2000/36/EC), which have chemical and physical characteristics similar to cocoa butter (CB).

This review summarizes the MKF compositions (especially their triacylglycerol compositions/isomers, micronutrient levels and thermal behaviors) reported worldwide and examines its potential use as healthy food ingredients and natural antioxidant source for the manufacture of high-value foods. Future applications are also suggested to exploit the full potential of this fat.

Chemical compositions and physical properties

Fat contents

The fat contents, depending on the mango varieties cultivated in different countries, constitute 3.7-13.7% of the total mass of the dried kernels (Table 1). In general, the mangoes used for extracting fats weigh from 200 to 1000 g based on the varieties. However, some individual varieties from years of introduction or breeding show lower mass (< 150 g), and no kernels

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(including fats) are found in their seeds (Jin et al., 2016a; Lakshminarayana, Rao and Ramalingaswamy, 1983). Such varieties are excluded from this review.

Iodine values (IVs) and slip melting points (SMPs)

IV and SMP are the most important indices for edible fats and oils. The potential applications of fats and oils are determined by analyzing both indices. IV is a measure of the saturation level of the fats. A lower value indicates a higher content of saturated fatty acids and reflects a higher SMP. As shown in Table 1, the IVs of MKF extracted from selected areas range from 40.9-60.7 g/100g, and the SMPs range from a low of 23.5-30.0 °C for the India mango varieties to a high of 35.8-39.1 °C for the Malaysia varieties. Both indices indicate that MKF is semi-solid at room temperature, and the values are comparable to those of palm oil (Table 1: IV, 50.6-55.1 g/100g; SMP, 30.8-37.6 °C), suggesting fractionation is the best technique to achieve full utilization of MKF as with palm oil (Shahidi, 2005).

Fat compositions

Triacylglycerols (TAGs) are the major constituent (84.9-92.7%) of MKF, followed by free fatty acids (0.5-7.5%), diacylglycerols (DAGs, 2.0-5.8%), monoacylglycerols (tr-0.8%) and micronutrients (e.g., sterol, tocopherol and squalene, < 1.5%). Most other vegetable fats and oils including CB and palm oil have similar fat compositions as shown in Table 1, while the prime differences among them are located in their TAG compositions and micronutrient levels.

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The TAG composition is a key factor in preparing different specialty fats, while the micronutrient has an important role in improving the shelf life of lipid-containing foods. Both of them will be discussed in detail in the next sections.

It is worth noting that the free fatty acid levels of most MKF varieties are too high (Table 1, > 1%) to be consumed directly (max. 0.3%, see Codex Stan 210-1999, 2015). Ali, Gafur, Rahman and Ahmed (1985) reported some Bangladesh varieties with significantly higher free fatty acid contents of 30.0-37.0 %. Long-time drying process of mango kernels at hot temperature might be responsible for this problem. The kernels are generally sun-dried for 2-3 days after the pulps are removed, and then for about 12 h at 60 °C before extracting the fat (Ali et al., 1985; Muchiri et al., 2012). High levels of free fatty acids results in the acceleration of oxidation during storage or in smoke formation during frying (Hamm, Hamilton and Calliauw, 2013). Therefore, refining should be involved in the MKF processing to remove free fatty acids.

TAG compositions and positional isomers

Table 1 also gives the information about the TAG and *sn*-2 fatty acid compositions of MKF. It has been reported that the fatty acids incorporated at the *sn*-2 position of the TAG molecules are more closely related to their applications (Hayes and Pronczuk, 2010). Obviously, oleic is the main *sn*-2 fatty acid and varies among the cultivated fields from 78.3 to 89.9% (Table 1), which is comparable to that of CB (82.8%). In this regard, the most commonly reported species in MKF are symmetrical monounsaturated TAGs, mainly 1,3-distearoyl-2-oleoyl-glycerol (StOSt, 28.9-55.4%) and 1-palmitoyl-2-oleoyl-3-stearoyl-glycerol (POSt, 5.7-19.8%), which are preferred in the manufacture of chocolate as CB (Jin et al., 2016a; Pembe, 2017; Sonwai, et al., 2014). In particular, StOSt-rich fats can solve the softening problem of CB by modifying the solid fat content (SFC), and further improve bloom inhibition and decrease tempering time during the chocolate production (Beckett, 2000). These fats are usually considered as cocoa butter improvers (CBIs), an enhancement of CBA. There is increasing scientific interests in preparing similar TAG species by exploring new sources and developing modification techniques like fractionation and interesterification. Some special mango varieties were found in Bangladesh (e.g., *Mangifera sylvatica*) and in Vietnam. The StOSt content in these fats were as high as 65.0-66.3%, indicating they are ideal ingredients for producing the natural CBIs without further modification (Akhter et al., 2016; Tran et al., 2015). Jin et al. (2017a) selectively fractionated ordinary MKF to produce the third stearin (improving the StOSt content from 44.0% to 69.2%) as CBI using 2-methylpentane based isohexane. Further mass spectral analysis indicated that the *sn*-StOSt type accounted for 82% of the total StOSt/StStO. However, fat extracted from wild mango (*Irvingia gabonensis*) in Congo showed significant difference in TAG composition compared to those presented in Table 1. It contained only 0.9% stearic acid and 4.3% oleic acid, but 37.1% lauric acid and 49.8% myristic acid (Yamoneka et al., 2015), which is a typical medium chain fatty acid-rich fat.

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Micronutrients

Although the micronutrient levels of MKF are relatively lower than other lipid constituents, their roles in preventing lipid oxidation and health promotion should not be ignored (Shahidi, 2005). Sterol, tocopherol and squalene are the major unsaponifiables in MKF (Gunstone, 2011). As shown in Table 1, sterol is the most abundant micronutrient, fluctuating between 0.38% and 1.03%; it is followed by squalene (0.02-1.06%) and tocopherol (0.01-0.33%). Their levels vary considerably with the regions of cultivation. For instance, the tocopherols in China and Tanzania varieties are generally lower than 0.1%, while the content of Egyptian MKF reached 0.33%. For most vegetable fats and oils, sterol and tocopherol are the most common nutrients. What makes the MKF different is that a higher level of squalene was found in it. Squalene is generally present in marine mammalian oils and certain vegetable oils like olive oil (0.10-1.20%), but in smaller quantities (<0.03%) in other vegetable oils (Shahidi, 2005). As reported by Jin et al. (2016a), the squalene contents of 8 China-specific mango varieties were more than 0.03% among the 11 studied samples. Therefore, most of the MKF could be used as squalene additives during food processing.

Thermal properties and crystal forms

Thermal properties of MKF, mainly SFC, melting and crystallization behaviors, have received lots of attention because of their important roles in the formulation of CBAs and different

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shortenings. The thermal properties of the fats are related to their polymorphic forms and lattice packings. In general, β crystalline form and triple-chain length structure, the most stable form, contributes to the highest melting point and to preventing fat bloom, which are preferred in the manufacture of chocolate (Beckett, 2000). However, MKF was found to crystallize into a mixture of β, β′, sub-β and pseudo-β′ forms under isothermal crystallization for 60 min at 20 °C (Sonwai et al., 2014). Similarly, at least two unstable polymorphs (between α to β crystal forms) were observed in the partially stabilized MKF sample (Solís-Fuentes and Durán-de-Bazúa, 2004). High levels of di- and tri-unsaturated TAGs (e.g., POO=1.8-10.8%, StOO=11.2-32.2%, and OOO=2.5-9.6%, Table 1) present in MKF might be responsible for its difficult and long-time stabilization. This could be examined from the melting/crystallization curves and SFC profile. For instance, the MKF melting curve is generally wider than that for CB. Jahurul et al. (2014b) and Solís-Fuentes et al. (2004) reported a single MKF melting peak which started at -15.9--13.0 °C and ended at 36.1-42.2°C with a lower enthalpy (67.7-70.1 J/g), whereas Solís-Fuentes et al. (2004), Jeyarani and Yella (1999), and Maheshwari and Reddy. (2005) reported that the values in CB were -11.0 °C and 31.5-36.5 °C with a higher enthalpy (80.0-128.2 J/g). Analogously, although MKF and CB showed similar steep SFC profiles, the values of MKF were significantly lower than that of CB from 0 and 25 °C (Sonwai et al., 2014; Jin et al., 2017a). In addition to the low-melting TAGs, researchers pointed out that the presence of DAGs (2.0-5.8%, Table 1) could also delay the transition of symmetrical monounsaturated TAGs into a more stable crystal form, resulting in lower melting properties and difficulties in the tempering (Ray, Smith, Bhaggan, Nagy and Stapley, 2013; Wahnelt, Meusel and Tulsner, 1991). Therefore, further studies were carried out to prepare tailored MKF fractions through the removal of these interfering constituents by multi-stage fractionation (Jin et al., 2016c; Jin et al., 2017a).

Potential health benefits of MKF

Lipids form the basic structural and functional constituents of cells and are also important ingredients in foods. The most attractive potential option is the use of MKF as a typical *trans*-free source. Adverse health effects of *trans* fatty acids present in partially hydrogenated fats and oils is well known (Kwon, 2015). It is necessary to find alternative fats (non-hydrogenated solid fats) that are characterized by high stability and desirable texture to fully replace such *trans* fats-containing products (Gupta, Rathi and Bradoo, 2003). MKF is semi-solid at room temperature as indicated before. Its *trans*-free characteristic makes it suitable as healthy shortenings which is discussed in the next section.

Although some anti-nutritional micro-substances (e.g., cyanide, tannins, trypsin inhibitors) are found in mango kernels, they generally tend to accumulate in the protein during the fat extraction (Diarra, 2014). No studies showed that MKF contains any allergenic and toxic compounds (Solís-Fuentes and Durán-de-Bazúa, 2011). Rukmini and Vijayaraghavan (1984) examined the edible safety and nutritional value of MKF by feeding rats balanced diets with 10% of the fat content. Results showed that the total lipids levels, serum/liver total cholesterol, liver TAG type and histopathological evaluations of the MKF-fed group were comparable to those in the control group. Furthermore, the food efficiency ratio, growth rate, and the retention of nutrients were also similar in MKF- and control-fed groups.

Edible uses of mango kernel fat

High free fatty acid content and dark color make MKF unsuitable for direct consumption. Conventional refining processes including alkali refining and bleaching were carried out according to the report by Narasimha Char, Reddy and Thirumala Rao (1977). As shown in Table 2, most of the free fatty acids and pigments were removed after alkali refining and bleaching. The free fatty acid level (0.09%) of refined MKF meets the edible demand according to the Codex Stan 210-1999 (2015). There were no significant changes in IVs and melting points during the refining, indicating the fatty acid compositions remain the same. In addition, nearly half of the non-saponifiable matter was lost, which is undesirable because there are lot of micronutrients in it.

Refined MKF is suggested to be fractionated into suitable fractions having physico-chemical properties closer to some value-added fats like CB and super palm olein by one- or multi-stage fractionation (Tran et al., 2015; Jin et al., 2016c; Jin et al., 2017a). The typical

MKF fractions are presented in Figure 1, and their uses in food manufacturing processes are also shown in this section (Table 3).

Cocoa butter alternatives (CBAs)

The biggest advantage of MKF is that its characteristics closely resemble those of CB. According to the European Union Directive (2000/36/EC), MKF is one of the only 6 fats which are allowed to be used in chocolate fat production. As shown in Figure 1, MKFS-I, MKFS-II, MKFS-III and MKF-MF are the main fractions that are used in preparing CBAs, and the optimal formulas are listed in Table 3. Although palm mid-fraction (PMF) and palm stearin have been widely mixed with the MKF fractions to produce CBAs, their effects on CB or chocolate are largely unknown and requires further research. For CB and MKF stearins (StOSt-rich fats), isosolid diagrams showed accepted compatibility in only certain ratios if adequate tempering techniques (4-5 °C, 15 days) were applied to the fats to achieve β forms (Solís-Fuentes et al., 2004; Jin et al., 2017a). Studies on shea butter hard fraction indicated that PMF could improve the miscibility of binary blends containing StOSt-rich fat and CB (Beckett, 2000). Therefore, ternary blends consisting of PMF, MKF stearins and CB are being prepared to produce high-quality CBAs in our laboratory.

Trans-free shortenings

Unlike the β structure in CBAs, the β′ crystal form is in high demand to produce shortenings designed for cakes and breads because of its smooth consistency and good aeration property (Yella

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Reddy et al., 2001; Beckett, 2000). However, most of the reported studies (Table 3) were focused on the non-fractionated MKF that is usually a mixture with at least four forms, i.e., β, β′, sub-β and pseudo-β′ (Sonwai et al., 2014), which might limit the application of MKF. As a reference, different palm oil fractions have been successfully used for manufacturing different shortenings by current food processing industry (Sue, 2009). Jin et al. (2016c) found that MKF olein was rich in di- and tri-unsaturated TAGs, and showed similar thermal properties to palm olein. It is therefore recommended as ingredient in producing shortenings, frying and cooking fats. Furthermore, its oleic acid accounted for about 76.2% of the total *sn*-2 fatty acids, indicating it could be modified by interesterification with palmitic and/or stearic acid to produce other specialty fats. Bebarta, Jhansi, Kotasthane and Sunkireddy (2013) also reported that medium chain and behenic fatty acids could be incorporated to modify the MKF for use as frying oils, salad dressings and bakery fats.

Anti-oxidative substances

MKF is considered as a natural antioxidant with potential health benefits compared to the synthetic antioxidants. Jafari, Gharachorloo and Hemmaci (2014) found that the oxidative stability index of MKF was as high as 58.8-85.2 h (110 °C, air flow 20 L/h), while other vegetable fats and oils (e.g., partially hydrogenated soybean oil, peanut oil and butter) showed significantly lower values from 3.8 to 25.9 h even at low air flow (110 °C, 9 L/h) (Akoh, 1994). Similar results were obtained by Momeny, Vafaei and Ramli (2013). They concluded that the 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity of MKF (40.33%) was slightly higher than that of PMF (37.98%) at 50% concentration. Further analyses showed that fatty acid compositions and sterols (especially β-sitosterol) were the predominant compounds that affect the oxidative stability of MKF (Jin et al., 2017b). It is well known that fats with more saturated fatty acids are high in oxidative stabilities compared with those of unsaturated fatty acid-rich oils. For individual sterol, the number and location of the double bonds in its skeleton and the presence of an ethylidene group in its side chain improve the antioxidant capacity (Winkler and Warner, 2008). β-Sitosterol containing two double bonds in the skeleton has been proved to be more active in protecting the fats and oils, especially at high temperature (Singh, 2013). However, these micronutrients tend to accumulate in the MKF oleins during the fractionation (Jin et al., 2017b), but the finding widens the potential applications of MKF oleins.

Although all the reported studies concluded (Table 3) that MKF could improve the oxidative stabilities of fats/oils-containing foods, most of these results referred to crude MKF. As discussed before, it is necessary to remove free fatty acids by refining because only refined MKF is permitted in the manufacture of food. The fatty acid compositions generally show no remarkable change during the chemical refining (Zhu et al., 2016). However, most of the non-saponifiable matters (including micronutrients) are lost during refining. Our previous study found that 40-70% micronutrients (including sterol, squalene and tocopherol) were washed away with soaps during the hydrated degumming and neutralization process (Jin et al., 2017b). In addition, deodorization is also a technological step that leads to the sterol loss (Gutfinger and Letan, 1974). The loss might reduce the antioxidant ability of refined MKF. In this regard, moderated refining techniques should be developed to reduce micronutrient loss and improve the final fat quality. More specifically, only degumming and physical deacidification are suggested if the degummed fat shows light color and fresh flavor (Wang and Jin, 2016). Further bleaching or decoloration and deodorization are not required. Reduction of the phosphorus content to less than 5 mg/kg during the degumming is important to meet the demands of the next steam refining or molecular distillation, which are used for removing free fatty acids (Kaimal et al., 2002).

Other uses

MKF was also successfully modified as rhamnolipid, a kind of swelling agent or condiment used in the food industry, by the effect of *Pseudomonas aeruginosa* DR1 (Sathi Reddy, Yahya Khan, Archana, Gopal Reddy and Hameeda, 2016). The new application also indicates that the micro-substances of MKF should not be ignored but rather explored.

Conclusion

It is well documented that MKF is a potential source of specialty fat and healthy food components due to their unique TAG compositions, *trans*-free fat features, and high oxidative stabilities. However, MKFs extracted from different areas showed significant differences in chemical

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compositions (especially the StOSt percentages) and physical properties. Therefore, more research is needed to identify the characteristics of different mango source-fats to classify their application. The high free fatty acid content of crude MKF suggests that refining is necessary in processing the fat, but the process should be moderated to prevent squalene, sterol, tocopherol, and other antioxidants losses. MKF and its stearins are considered as ideal CBA ingredients that has been examined in recent reports, but their effects on chocolate formulas remains to be determined and reported. MKF oleins, as a byproduct of MKF fractionation, exhibited similar physicochemical properties to that of palm oil oleins, making it suitable for manufacturing various shortenings and for frying/cooking. MKF could also be modified by interesterification to produce CBAs based on their high contents of *sn*-2 oleic acid. Furthermore, studies on the nutritional benefits of MKF and antioxidant effects of incorporating MKF and their fractions in foodstuffs are necessary.

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Figure caption

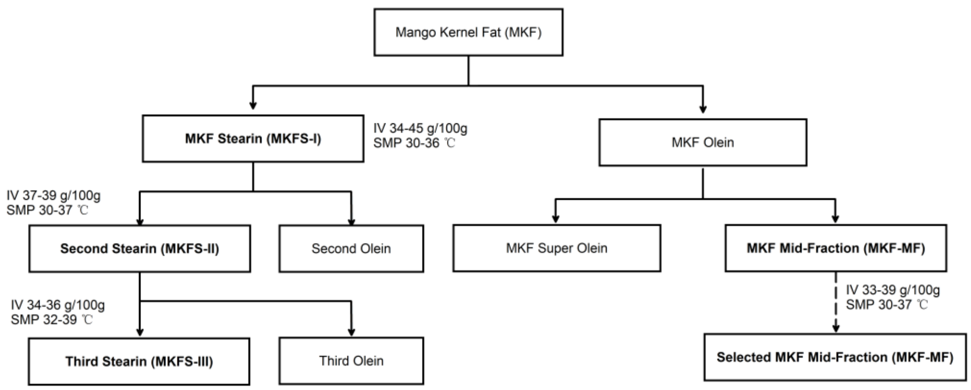

Figure 1 Typical mango kernel fat fractions and their physical properties

MKF, mango kernel fat; MKFS-I, the first stearin of mango kernel fat; MKFS-II, the second stearin of mango kernel fat; MKFS-III, the third stearin of mango kernel fat; MKF-MF, the mid-fraction of mango kernel fat; IV, iodine value; SMP, slip melting points (Baliga and Shitole, 1981; Jin et al., 2016c; Jin et al., 2017a).

Tables

Table 1 Chemical compositions of mango kernel fats extracted from various countries, cocoa butter, and palm mid-fraction [a]

	MKF [b]								CB [b]	Palm oil [b]
	China	Tanzania	Thailand	Zaire	India	Egypt	Kenyan	Malaysia		
Fat in kernel (%)	5.7-11.1	9.2-10.5	--- [c]	6.8-12.6	3.7-12.6	12.3	8.5-10.4	6.4-13.7	---	---
IV (g/100g)	42.2-60.7	41.7-43.5	40.9	46.6-57.7	---	53.2	51.1-56.8	42.9-52.7	34.2-40.7	50.6-55.1
SMP (°C)	25.5-32.1	29.1-30.5	35.7	30.5-35.8	23.5-30.0	30.5	25.0-33.0	35.8-39.1	30.0-35.0	30.8-37.6
Fat composition (%)										
Triacylglycerol	85.1-92.7	84.9-91.8	---	---	---	88.4	---	---	>90.0	>85.0
Diacylglycerol	2.5-5.8	2.0-4.2	---	---	---	3.1	---	---	1.1-2.8	6.6-6.7
Monoacylglycerol	tr-0.3	0.1-0.8	---	---	---	0.8	---	---	---	0.2-0.3
Free fatty acid	2.5-6.6	3.1-7.5	---	1.9-2.5	1.1-4.4	1.2	2.3-3.8	1.6-2.6	1.1-2.3	<5.0
Sterol	0.38-0.71	0.42-0.84	---	---	1.03	0.63	---	---	---	0.04-0.06
Tocopherol	0.01-0.09	0.10-0.13	---	---	---	0.33	---	---	0.01-0.03	0.06-0.10
Squalene	0.02-0.09	0.07-0.20	---	---	---	1.06	---	---	---	0.02-0.05
Triacylglycerol composition (%)										
PPP	tr [d]	tr	tr	---	---	---	---	---	tr	6.9-7.2
POP	1.2-2.8	1.0-1.7	8.9	---	1.1	---	---	6.9	13.6-15.5	27.2-30.6
POSt	13.1-19.8	13.2-16.2	5.7	---	17.3	---	---	14.8	33.7-40.5	3.7-4.2

POO	1.8-7.8	3.7-8.7	10.8	---	---	---	---	---	1.5-6.2	20.7-23.1
StOSt	30.0-55.4	28.9-45.7	29.4	---	38.1	---	---	39.3	23.8-31.2	tr-0.2
StOO	11.2-23.3	20.2-32.2	14.6	---	---	---	---	---	2.7-9.5	1.6-2.0
OOO	3.2-8.6	4.6-9.6	2.5	---	---	---	---	---	tr-1.0	5.1-5.4
StLSt	tr	tr	14.6	---	---	---	---	---	1.4-2.0	tr
StOA	0.9-4.1	1.0-1.9	tr	---	---	---	---	---	0.8-1.3	tr
sn-2 Fatty acid composition (%)										
P	1.1-2.0	1.0-2.1	---	tr-0.5	---	---	---	---	4.7	---
St	1.3-6.9	1.3-5.2	---	0.6-0.9	---	---	---	---	4.7	---
O	78.3-84.4	80.8-85.7	---	85.2-89.9	---	---	---	---	82.8	>58.3
L	8.3-14.8	10.0-10.9	---	7.8-13.0	---	---	---	---	6.6	>18.4
A	1.1-1.7	1.1-1.2	---	tr	---	---	---	---	tr	---

[a] MKF, mango kernel fat; CB, cocoa butter; IV, iodine value; SMP, slip melting point; P, palmitic; St, stearic; O, oleic; L, linoleic; A, arachidic.

[b] China: Jin et al., 2016a. Tanzania: Pembe, 2017. Thailand: Sonwai, Kaphueakngam and Flood, 2014. Zaire: Van Pee, Boni, Foma and Hendrikx, 1981. India: Lakshminarayana, et al., 1983; Jeyarani, Subramanian, Sneha, Sudha and Negi, 2015; Dhara, Bhattacharyya and Ghosh, 2010; Tran et al., 2015. Egypt: Abdalla, Darwish, Ayad and El-Hamahmy. 2007a. Kenyan: Muchiri, Mahungu and Gituanja, 2012. Malaysia: Jahurul et al., 2014a; Jahurul et al., 2014b. CB: Jin et al., 2016; Beckett, 2000; Shahidi, 2005; Davis and Dimick, 1989. PMF: Shahidi, 2005; Ping, 2010.

[c] ---, not analyzed.

[d] tr, trace, <0.05%

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Table 2 Quality changes during the conventional refining of MKF [a]

	Conventional refining steps		
	Crude fats	Alkali refining	Bleaching
Free fatty acid (%)	5.00	--- [b]	0.09
Iodine value (g/100g) [c]	50.0	---	50.0
Melting point (°C)	38.0	---	38.0
Lovibond color [c]	14Y+1.4R (Brown)	4.5Y+0.4R (Yellow)	0.4Y+0.0R (White)
Non-saponifiable matter (%)	1.5	---	0.7

[a] Narasimha et al., 1977.

[b] ---, not analyzed.

[c] Lovibond color, in 0.635 cm cell.

Table 3 Potential edible uses of mango kernel fat and its fractions [a]

Substrate	Result	Reference
Cocoa butter alternatives (CBAs)		
MKF was blended with CB from 0-100% by weight with and without stabilization.	Softening effects were observed with the mixtures containing 60-80% of MKF. The compatibility was improved after stabilization.	Solís-Fuentes et al., 2004
Binary blends were prepared by mixing MKFS-I and MKF-MF with equal amounts of CB, respectively.	Both blends showed miscibility at 25-40 °C. The blend consisting of MKFS-I and CB was recommended as CBI.	Baliga et al., 1981
MKF and MKFS-I were blended with CB from 0-100% by weight, respectively.	Mixtures containing 30% MKF/MKFS-I and 70% CB increased the heat resistance of dark chocolate.	Tran et al., 2015
MKFS-II was blended with CB in proportions of 15/85, 30/70 and 45/55 by weight.	The blends consisting of 30-45% MKFS-II and 55-70% CB were considered as CBIs in terms of melting/crystallization properties.	Jin et al., 2016c
MKFS-III was blended with CB at ratios from 95/5 to 20/80 with and without stabilization.	The tempered blends consisting of 20-50% MKFS-III and 50-80% CB showed acceptable compatibility at 20-28 °C.	Jin et al., 2017a
MKF was blended with PMF in the ratios of 90/10, 80/20, 70/30, 60/40 and 50/50 by weight.	The mixture containing 80% MKF and 20% PMF was recommended as CBE because it was fully compatible at 20 °C.	Sonwai et al., 2014
MKF was blended with PMF in the ratios from 95/5 to 50/50 by weight.	The blends containing 70-85% MKF showed similar thermal properties to those of commercial CB.	Jahurul et al., 2014b
MKF was blended with palm stearin in the ratios from 95/5 to 50/50 by weight.	The blends containing 75-90% MKF had physico-chemical properties close to those of commercial CB. They were recommended as CBI because they showed harder SFC at 20.0-37.5 °C.	Jahurul et al., 2014c Jahurul et al., 2014d
MKF-MF was blended with PMF in the ratios of 90/10, 80/20 and 70/30 by weight.	The blend ratio 90/10 (MKF-MF/PMF) was the best compared to the other mixtures because it resembled CB in terms of thermal properties.	Jin et al., 2016b
MKF was blended with PMF in the ratios from 40% to 60% and then was modified by interesterification.	Interesterified blending of 50% MKF and 50% PMF exhibited similar physical properties to CB.	Momeny et al., 2013
trans-Free shortenings		
MKF or MKF-MF was blended with mahua fat or its stearin to prepare	Formulations containing 20% MKF-MF and 80% mahua fat stearin or 40% MKF and 60% mahua fat (including	Yella Reddy and Jeyarani,

trans-free bakery shortenings	5-7% fully hydrogenated peanut oil) were good cakes/biscuits shortenings. Formulation containing 50% MKFS-I and 50% mahua fat with addition of 5%-7% of fully hydrogenated oil was puff pastry shortening.	2001
MKF was blended palm oil from 70% to 100% to prepare muffin margarines	Muffin margarine were prepared from 70 % MKF and 30 % palm oil. Its textural and chemical characteristics were similar to bakery margarine.	Jeyarani et al., 2015
MKF was blend with palm hard fraction and then was modified by interesterification.	The interesterified blend with 50% MKF and 50% palm hard fraction showed similar solid fat contents to those of commercial hydrogenated bakery shortenings and vanaspati.	Khatoon and Reddy, 2005
MKF was blended with palm stearin and then was modified by interesterification.	The binary blends with 60-70% MKF and 30-40% palm stearin showed short melting ranges that were not suitable as bakery shortenings, but the characteristics were improved in the interesterified mixtures.	Shetty, Reddy and Khatoon, 2014
Anti-oxidative substances		
Crude MKF (1%, 5% and 10%) was added to tallow fat as a natural antioxidant.	Samples were placed at 90 °C for 0-120 h. The results showed MKF could significantly increase the induction periods of tallow.	Jafari et al., 2014
MKF was added to watermelon oil at four concentrations of 5%, 10%, 15% and 20 %.	Samples were stored at 25-28 °C for 3 months. Results showed the induction period of watermelon oil containing MKF was significantly improved.	Azeem, Nadeem and Sajid, 2015
Mango kernel extract (0.04%) and MKF (3-5%) were added to sunflower oil as frying antioxidants.	The oxidative stability of frying oil and the characteristics of related potato chip were improved by addition of 0.04% mango kernel extract and 5% MKF.	Abdalla et al., 2007b
Catechin mixture containing 1-3% MKF was added to edible oil.	Edible oil fortified with 1-3% MKF showed similar antioxidant ability to that containing 300 mg/kg BHT.	Zein, El-Bagoury and Kassab, 2005
Crude MKF (2.5, 5.0, 7.5 and 10.0%) was added to butter.	Samples were stored at 25 and 55 °C for 6 months, respectively. Addition of MKF at all levels significantly improved the oxidative stabilities of butter oil.	Nadeem et al., 2017
Crude MKF and BHT were added to sunflower oil, respectively	1% crude MKF exhibited similar antioxidant ability to 200 mg/kg BHT against the oxidation of sunflower oil.	Youssef, 1999
Other uses		

MKF was used as a carbon source for producing rhamnolipid biosurfactant using *P. aeruginosa* DR1	MKF together with glucose was used to produce di-rhamnolipid-rich product, and it showed good antifungal activity against various phytopathogens.	Sathi Reddy et al., 2016

[a] MKF, mango kernel fat; MKFS-I, the first stearin of mango kernel fat; MKFS-II, the second stearin of mango kernel fat; MKFS-III, the third stearin of mango kernel fat; MKF-MF, the mid-fraction of mango kernel fat; CB, cocoa butter; PMF, palm mid-fraction; CBE, cocoa butter equivalent; CBI, cocoa butter improver; BHT, butylated hydroxytoluene.