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Assessment of composition, color, and oxidative stability of mango (*Mangifera indica* L.) kernel fats from various Ivorian varieties

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Abstract

Seven mango seeds of Ivorian varieties, that is, *Amelie*, *Kent*, *Keitt*, *Brooks*, *Palmer*, *Dadiani*, and *Djakoumankoun* were collected from Northern Ivory Coast as wastes from local processing factories and local markets; their kernels were then quickly separated and sun-dried to ensure lipases inactivation. This study was carried out to elucidate (1) the variability in the proximate composition (protein, ash, and fat content) of the so-obtained kernels and (2) the characteristics of the extracted fat including acidity, peroxide value, unsaponifiable matters, phospholipid content, iodine value, fatty acid (FA), and triacylglycerol (TAG) composition, sterol content, oxidative stability, color, and carotenoid content. It was found that the fat content ranged from 4.9% to 9.6% (dry matter) depending on the variety. Whatever the variety, oleic (O, 35.9%–47%) and stearic acid (St, 30.3%–48.3%) were the most abundant FA. A wide range of variation in TAG composition was however observed: the major were StOSt (23.9%–45.9%), StOO (15.5%–25.8%), and StLSt (10.4%–12.5%). A classification of the seven varieties based on their FA, TAG, and sterol content, was established using multivariate analysis: principal component analysis (PCA) and cluster analysis (CA). According to their main FA and TAG, the seven varieties may be grouped into four clusters: cluster I = *Amelie*, cluster II = *Keitt, Palmer*, and *Kent*, cluster III = *Brooks* and *Dadiani* and, cluster IV = *Djakoumankoun*.

KEYWORDS
fatty acid composition, Ivorian varieties, mango kernel fat, oxidative stability, phospholipids, sterols composition, triacylglycerol

INTRODUCTION

Mango (*Mangifera indica* L.), a member of Anacardiaceae family is one of the most important fruits worldwide and is cultivated in more than 100 countries at both tropical and subtropical latitudes, especially in Asia, and is widely distributed in the world. It is the second most widespread tropical crop, behind bananas, in terms of production and area used to cultivate it (Muchiri et al., 2012). In Ivory Coast, mango is the most popular fruit and its cultivation has developed considerably in recent years, with about 180,000 tons per year, according to PPAAO/WAAPP (2017). Ivory Coast is the largest African supplier of mangoes to Europe and the third largest in the world behind Brazil and Peru (CBI, 2019). The main growing areas are concentrated in the north of the country, particularly in the departments of Korhogo, Ferkéssédougou, Sinématiali, and Boundiali. Thus, Mango is the most valuable fruit of the northern regions of Ivory Coast. Over 1000 mango varieties are available worldwide (Jahurul et al., 2015). About 30 varieties grow in Ivory Coast, among which can be distinguished some traditional and some grafted cultivars, of which only about 15 are grown for

commercial purpose. The best known commercial cultivars are *Amélie*, *Kent*, *Keitt*, *Palmer, Smith, Brooks*, *Valencia, Ruby, Zill*, and *Julie* (Agroforesterie Côte d'Ivoire, 2017). The latter have global acceptance due to their taste profile, aroma, and nutritional components.

The major component of the mango fruits is the pulp which is consumed fresh or is processed into a range of products including dried mango, mango chutney, syrup, jam, and mango juice. After consumption or industrial processing of the pulp, high amounts of mango seed are generated and unexploited. Mango seed contains a kernel made of approximately 3.7%–15% fat (on dry matter basis), which can be considered a valuable oleiferous source for the recovery of edible fats. Several studies reported values between 6.8% and 12.6% (dry matter basis) for African varieties (Abdalla et al., 2007; Muchiri et al., 2012; Van Pee et al., 1981); Lakshminarayana et al. (1983) reported lower contents for some varieties from India (3.7%-var. *Black Andrews*), while Nzikou et al. (2010) reported a content up to 15% for a Congolese variety (*Kibangou*). The fat content depends upon the variety and geographical origin, while the extraction yield depends on the extraction method (Solís-Fuentes & del Carmen Durán-de-Bazúa, 2020; Torres-León et al., 2016). Mango kernel fat (MKF) is toxicologically safe and contains high micronutrient levels, in particular phenolic compounds, tocopherols, and sterols (Jahurul et al., 2017; Jin et al., 2016). The fat has attracted a remarkable interest for its biological activities and qualities as natural food and functional food ingredients in the manufacturing of confectionary and chocolate products and for remarkable antioxidant activities in some food systems (Abdalla et al., 2007; Jahurul et al., 2014; Jin et al., 2017). Previous studies reported a variety and origin dependent chemical composition of MKFs (Jahurul et al., 2014; Jin et al., 2016; Lieb et al., 2019; Solís-Fuentes & Durán-de-Bazúa, 2004; Sonwai et al., 2014). Kassi et al. (2019) reported physicochemical properties (acid value, iodine value, peroxide value, saponification value, density, unsaponifiable matter, and fatty acid composition [FAC]) of 10 MKF (var. *Ruby, Kent, Retard, Key, Assabony, Smith* "*tête de chat*," *Smith* "*normal*," *Palmer, Governeur*, and *Aravia*) from central Ivory Coast. However, to the best of our knowledge, nothing has been reported yet regarding MKF of specific varieties from the north Ivory Coast, which is the most important diversity area.

Therefore, this study focused on the extraction and chemical characterization of MKF extracted from seven specific northern Ivorian varieties to investigate how such MKF may differ from each other and the reported MKF in terms of chemical compositions, color, and oxidative stability.

EXPERIMENTAL PROCEDURES

Raw material and sample preparation

Ripe mango seeds of five grafted or commercial varieties *Kent, Amelie, Brooks, Palmer, Keitt* were kindly supplied by local mango processing factories in Korhogo Province, Ivory Coast, and two local mango varieties were collected in the same area and manually depulped to obtain the seeds. The local variety *Dadiani* was collected directly under the mango trees in the fields and along the roads; while the local variety *Djakoumankoun* was acquired at the local market. All fruits and seeds were obtained between May and June 2021. The recovered seeds directly underwent a heat treatment (cooking at 98 ± 2°C under atmospheric pressure for 15 min) to ensure lipases inactivation, and were sun-dried for 2 days. Afterwards, the mango seeds were manually peeled to obtain the kernels which were sun-dried for 2 weeks. Samples were then sent to the laboratory of Food Science and Formulation (TERRA, Uliège GxABT, Belgium), where they were ground to a powder (particle size of 1 mm) using a high-speed lab mill (FRITSCH, 19.1020/00426, ROHS, Oberstein, Germany). The powder was kept in a closed plastic container under vacuum and stored at 4°C until use.

Proximate composition of mango seed kernels

Moisture (AOCS, Da 2a-48) and ash content (AOCS, Ba 5a-49) were determined according to the AOCS official methods (AOCS Methods, 2009), nitrogen content (N) by Dumas combustion method (Rapid N Cube e Elementar analyzer system, Villeurbanne, France), and calculating the crude proteins by $N \times 6.25$. The total fat content was determined automatically using a Soxtherm extraction system (Type S306 AK/S306 A, Gerhardt, Konigswinter, Germany) using *n*-hexane as extraction solvent. All the chemical analyses were carried out in triplicate.

Mango kernel fat extraction

A maceration extraction method was applied to extract the fat in order to preserve the physical properties of the fat on the one hand and improve the yield on the other hand: 200 mL of hexane was added to 100 g of sample. The whole was then heated (40°C) with stirring for 90 min. The extracts obtained were centrifuged at 7000 rpm at 30°C for 15 min using a centrifuge (Jouan C312, France) and finally filtered on filter paper (Whatman N°1, Ø125 mm). The extraction was repeated three times and the collected filtrates were combined in a flask; afterward the solvent was removed

using a rotary evaporator (Büchi Labortechnik AG, Flawil, Switzerland). Traces of residual solvent were further removed by nitrogen flushing. All fats were extracted in triplicate. The extracted fats were stored in the dark at −20°C until further analyses.

Physicochemical characterization of MKF

Chemical characteristics of the fats

Free fatty acid (FFA; AOCS, Cd 3d-63), peroxide value (PV; AOCS, Cd8-53), and iodine value (IV) (AOCS, Cd 1b-87) were determined according to the AOCS official methods (AOCS Methods, 2009).

Color evaluation and carotenoids content

The color of the crude fats was analyzed by CIE Lab color system ($L^*a^*b^*$) using a Colorflex EZ model 45/0 LAV colorimeter (Kruikebe Associates Laboratory, Elscolab, Belgium). In this coordinate system, the value L^* is a measure of lightness of material, ranging from 0 for black to 100 for white, the value a^* ranges from −100 for green to +100 for red, and the value b^* ranges from −100 for blue to +100 for yellow. Carotenoids content was determined according to MPOB test method p2.6:2004 (2004).

Determination of phosphorus content

Phosphorus was determined according to the AOCS official method (AOCS-Ca 12-55) by ashing the sample in presence of zinc oxide, followed by the spectrophotometric measurement of phosphorus as a blue phosphomolybdic. The equivalent phosphatide content was then calculated by using the conversion factor 30 (AOCS, 2009).

Unsaponifiable matter and sterols composition

Unsaponifiable matter was determined according to the *American Oil Chemists' Society* (AOCS) standard method (AOCS-Ca 6b-53) using diethyl ether for extraction (AOCS Methods, 2009). The composition and content of sterols were determined by capillary column gas chromatography according to the IOC method for olive oil sterols analysis (IOC, 2017a).

Fatty acid composition by gas chromatography

Fatty acid (FA) composition determination was carried out by using a Trace GC Ultra gas chromatograph (GC; Thermo Fisher Scientific, Belgium) fitted with a flame ionization detector (FID), as described by Mtibaa et al. (2021). The FA methyl esters were prepared according to AOCS Ce 2-66 method (AOCS Methods, 2009), and were analyzed in GC-FID using a Stabliwax DA column (Restek Corporation, USA) of 30 m × 0.25 μm × 0.25 μm (length × thickness × diameter). The injection was performed in splitless mode (splitless time: 0.85 min) at 250°C. Helium was used as carrier gas with a flow rate of 1 mL/min in constant flow. The temperature program was set as follow: 50°C (hold of 1 min) to 150°C at 30°C/min and to 240°C (hold for 10 min) at 5°C/min. FID was set at 250°C. The identification of FA methyl ester was performed by comparison of their retention times with those of pure reference.

Triacylglycerol composition

Triacylglycerol (TAG) analysis was performed with an HPLC Infinity II 1260 (Agilent Technologies, Inc., Santa Clara, CA, USA) system, equipped with a refractive index detector (RID) and a C18 column (RP-18 LiChroCART 250-4 5 μm, 250 mm × 4 mm, Merck, Darmstadt, Germany) according to the IOC method for olive oil TAGs analysis (IOC, 2017b), both set at a temperature of 30°C. The mobile phase was a mixture of acetone/acetonitrile 57/43 vol/vol with a flow rate of 1.5 mL/min; injection volume 20 μL. TAGs were identified by their equivalent carbon numbers and comparison with olive oil of known TAG composition. The content of each TAG was reported in terms of the relative proportion.

Oxidative stability index

Oxidative stability index (OSI) was determined according to the AOCS (Cd 12b-92) method (AOCS Methods, 2009).

Statistical analysis

Univariate analyses were performed in triplicate and the results are expressed as average ± standard deviation. Analysis of variance and Tukey's test were performed using Minitab 21 software (Minitab, Inc., Coventry, UK). A $p < 5\%$ was considered as statistically significant difference. Principal component analysis (PCA) and cluster analysis (CA) were performed to discriminate the seven varieties according to their main FA, TAG, and sterol composition similarities. Multivariate analysis was performed using RStudio software (version 2023.03.0).

RESULTS AND DISCUSSION

Proximate composition

The proximate composition of the kernel of the seven studied varieties of mango are summarized in Table 1. The moisture content in the dried kernels ranged from 7% to 10%. *Palmer* had the highest mean moisture content (10%) while *Keitt* had the lowest (7.2%).

Crude fat contents ranged from about 5–10 g/100 g dry matter depending on varieties. *Djakoumankoun* had the highest fat content (9.6 g/100 g dry matter) while *Amelie* had the lowest (5 g/100 g dry matter). As stated above the MKF content varies widely in the literature and all the Ivorian mango varieties studied fall into this range, which is between 3.7% and 15%. Among the seven varieties studied, five have been found in Kenya, Costa Rica, Brazil, and China. Therefore, their crude fat content was compared with values reported for MKFs of the same varieties. The fat content for the *Kent* variety (7.6 g/100 g) was slightly higher than that reported by Kassi et al. (2019) (7 g/100 g) in Ivory Coast, while this value was lower than that reported by Muchiri et al. (2012) (10.4 g/100 g) in Kenya. The *Brooks* variety (9.3 g/100 g) was also higher than that of Kassi et al. (2019) (7.8%). The fat content for the *Palmer* variety (8.1 g/100 g) was lower than that showed by Kassi et al. (2019) (10.6%), while Lieb et al. (2019) showed the lowest value (7.3%) for the Brazilian variety. The *Keitt* variety (7.5 g/100 g) was comparable to the same variety grown in China (8.4%) (Jin et al., 2016) and Brazil (7.8%) (Lieb et al., 2019). Variation in fat content may be due to differences in growing conditions (origin, soil, climate), ripening stage and in the extraction method used.

Protein content in the seven mango kernel varieties ranged from 4.5 to 5.7 g/100 g of dry matter. *Brooks* variety had the highest protein content (5.7 g/100 g), while mango kernel of *Kent* variety had the lowest (4.7 g/100 g). The protein content obtained for the seven varieties were comparable to some mango varieties cultivated in Kenya and India (Dhingra & Kapoor, 1985; Muchiri et al., 2012).

The ash content of the defatted cake ranged from 1.6 to 2.6 g/100 g of dry matter. *Amelie* had the highest ash content (2.6 g/100 g) while *Brooks* had the lowest one (1.6 g/100 g). The ash content observed for the seven mango kernel varieties studied were comparable to other varieties grown in Egypt, Zaire, and Kenya (Abdalla et al., 2007; Lakshminarayana et al., 1983; Muchiri et al., 2012).

Physicochemical characterization of extracted MKFs

Acidity (%)

Acidity measures the level of breakdown of triglycerides in oils by the action of lipases. The FFA content (expressed as oleic acid) of the fats of the seven mango seed kernel varieties studied ranged from 0.9% to 4.6%, with *Amelie* having the highest value and *Brooks* the lowest (Table 2). Values were compared to those reported in mango seed kernels of the same varieties. FFA for *Kent* (1.6%) and *Brooks* (0.9%) were lower than those reported by Kassi et al. (2019) for the same varieties grown in Ivory Coast, which were respectively 13.6% and 2.7%. The same observation was found for the *Kent* variety reported by Muchiri et al. (2012) in Kenya (3.8%). These values were significantly different ($p \leq 0.05$). Otherwise, FFAs observed in this work are in the range of the low values reported for MKF, ranging from 0.8% to 7.5% (Lakshminarayana et al., 1983; Muchiri et al., 2012; Solís-Fuentes & del Carmen Durán-de-Bazúa, 2020). High FFA content could be due to post-harvest handling practices of mango seed kernels, such as the lack of a suitable heat treatment, storage method, and duration. Proper care throughout the entire process of harvesting, pretreatment, and storage are necessary to ensure a satisfactory final product. Hence, all samples met the quality standards required (FFA ≤2) of the codex Alimentarius (1999) commission for crude fats, except *Amelie* and *Keitt*.

Peroxide value

The peroxide value is a useful measure of oil/fat quality as it provides an indication of the rancidity level of oils

TABLE 1 Proximate composition of mango seed kernels.

	Mango variety						
Parameter	**Kent**	**Brooks**	**Palmer**	**Keitt**	**Amelie**	**Dadiani**	**Djakoumankoun**
Moisture (%)	9 ± 0.01^{c}	9.4 ± 0.01^{b}	10 ± 0.06^{a}	7.2 ± 0.09^{e}	7.8 ± 0.20^{d}	7.7 ± 0.18^{d}	7.7 ± 0.06^{d}
Crude protein (g/100 g)	4.5 ± 0.07^{c}	5.7 ± 0.10^{a}	5.4 ± 0.07^{ab}	4.9 ± 0.12^{bc}	4.8 ± 0.27^{c}	5.4 ± 0.14^{ab}	5.0 ± 0.04^{bc}
Crude fat (g/100 g) (Soxtherm)	7.6 ± 0.06^{d}	9.3 ± 0.03^{b}	8.1 ± 0.02^{c}	7.5 ± 0.02^{d}	5 ± 0.05^{e}	9.4 ± 0.02^{b}	9.6 ± 0.01^{a}
Ash (g/100 g)	2.2 ± 0.02^{b}	1.6 ± 0.03^{d}	2.3 ± 0.07^{b}	2.2 ± 0.09^{b}	2.6 ± 0.01^{a}	1.9 ± 0.01^{c}	2.5 ± 0.01^{a}

Note: Difference from 100% is probably carbohydrates. Each value is a mean of triplicates ± SD. Values represent means ± standard deviations ($n = 3$). Significant differences of means ($p \leq 0.05$) within a row are indicated by different letters.

TABLE 2 Physicochemical characteristics of mango kernel fats.

Parameter	Mango variety						
	Kent	Brooks	Palmer	Keitt	Amelie	Dadiani	Djakoumakoun
FFA (%, as oleic acid)	1.6 ± 0.08^{c}	0.9 ± 0.01^{e}	1.8 ± 0.05^{b}	2.1 ± 0.04^{b}	4.6 ± 0.08^{a}	1.2 ± 0.08^{de}	1.3 ± 0.07^{d}
Peroxide value (mEq O_2/kg)	0.1 ± 0.01^{b}	0.1 ± 0.03^{ab}	0.1 ± 0.04^{ab}	0.1 ± 0.01^{b}	0.3 ± 0.07^{a}	0.1 ± 0.01^{b}	0.1 ± 0.01^{b}
Iodine value (g I_2/100 g)	55.3 ± 0.22^{b}	47.3 ± 0.35^{e}	55.2 ± 0.01^{b}	53.3 ± 0.03^{c}	60.4 ± 0.58^{a}	49.8 ± 0.12^{d}	42.7 ± 0.06^{f}
Oxidative stability index (OSI, h)	46.9 ± 1.30^{d}	29.0 ± 0.08^{e}	18.6 ± 0.06^{f}	28.7 ± 0.14^{e}	112.4 ± 0.17^{a}	77.1 ± 0.90^{c}	90.5 ± 0.28^{b}

Note: Values represent means ± standard deviations ($n = 3$). Significant differences of means ($p \leq 0.05$) within a row are indicated by different letters.

and fats. The peroxide values of the MKFs obtained in this study ranged from 0.1 to 0.3 mEq O_2/Kg with *Amelie* having the highest value (Table 2). The Codex Alimentarius (1999) Commission has set a maximum allowed peroxide value of 10 mEq O_2/kg; therefore, as all the oils extracted in this study had a peroxide value of less than 10 mEq O_2/kg oil, they are suitable for consumption.

Iodine value

The IV of the MKFs of the seven varieties studied ranged from 42.7 to 60.4 g I_2/100 g (Table 2). *Amelie* had the highest iodine value while *Djakoumankoun* had the lowest. Fat obtained from *Amelie, Palmer, Kent*, and *Keitt* showed higher IV, which were respectively 60.4, 55.2, 55.3, 53.3 g I_2/100 g and they were semisolid at 20°C. For other varieties, the IV were lower (42.7–49.8 g I_2/100 g) and they were all solid in the same conditions. The IV of MKFs reported in the literature widely differ from one region to another and are variety-dependent, with values ranging from 22.9 to 60.7 g I_2/100 g. The seven Ivorian mango varieties studied fall into this range. However, interestingly, the IV range observed for the Ivorian varieties is very large compared to those of the Colombian varieties (22.9–32.6 g I_2/100 g), Tanzanian varieties (41.7–43.6 g I_2/100 g), Zairian varieties (46.6–57.8 g I_2/100 g), Malaysian varieties (42.9–52.7 g I_2/100 g), and Kenyan varieties (51.1–56.9 g I_2/100 g) (Hernández et al., 2016; Jahurul et al., 2014; Muchiri et al., 2012; Van Pee et al., 1981), while this range is comparable to that of Chinese varieties (42.2–60.7 g I_2/100 g; Jin et al., 2016). Furthermore, IV of MKF of the seven varieties studied were compared with the values reported for MKFs of the same varieties. IV for *Kent* variety (55.3 g I_2/100 g) was in the same range (51.1 g I_2/100 g) as that reported by Muchiri et al. (2012) in Kenya. On the contrary, IV of *Palmer* (55.2 g I_2/100 g) was considerably higher than the value (37.8 g I_2/100 g) reported by Kassi et al. (2019) in Ivory Coast and IV of the *Keitt* variety (53.3 g I_2/100 g) was in the same range (49.5 g I_2/100 g) as the one reported by Jin et al. (2016) in China. These differences are obviously related to the differences in the FA composition of the fats. Indeed, IV is related to the unsaturation degree of a fat: a higher IV corresponds to a higher unsaturated FA content.

Phosphorus content

The determination of the phospholipid content in a vegetable oil is necessary to grade the quality of the oil (Chen et al., 2014; Chew & Nyam, 2020). As shown in Table 3, the phospholipids content of the seven MKFs varied from 0.6% to 2.6%. *Brooks* had the lowest phospholipid content, while *Amelie* exhibited the highest one. There were significant differences ($p \leq 0.05$) between the samples, except between *Kent* and *Djakoumankou* varieties. The phospholipid contents obtained for the seven varieties were lower than the values (2.7%–3.6%) found by Rashwan (1990) and Abdalla et al. (2007) for Egyptian varieties (*Goleck, Pairi, Hindi, Zebda, Balady*, and *Succary*), using lipid class fractionation. By contrast, Ali et al. (1985) reported lower value (0.1%–0.8%) of phospholipids for 10 Bangladesh varieties (*Brindaboni, Fazli, Kalabau, Kanchamitha, Kuipahari, Lakhanvoge, Lengra, Mohanvoge, Misrakanta Ranipasand*) using also the lipid class fractionation technique. Hemavathy et al. (1987) also found lower value (1%) for *Alphonso* variety grown in India. On the other hand, the findings of this study rank MKFs in the category of oils with high phospholipid values (1%–3%) such as soybean, rapeseed, and sunflower oil (Chew & Nyam, 2020).

Unsaponifiable content and sterol composition

The composition of unsaponifiable of vegetable oils, including sterols, tocopherols, and squalene, is of great importance as nutritional supplements and antioxidants for fats and oils (Gunstone, 2011). The unsaponifiable content obtained for the seven Ivorian MKFs in the present study ranged from 0.5% to 5.7% (Table 3). *Amelie* had the highest unsaponifiable content, while *Kent* had the lowest. In addition, except for *Amelie*, no significant

TABLE 3 Phospholipids, unsaponifiable matter, sterol composition, and content.

Parameter	Mango variety						
	Kent	Brooks	Palmer	Keitt	Amelie	Dadiani	Djakoumankoun
Phospholipids (%)	1.8 ± 0.01^{b}	0.6 ± 0.01^{e}	1.6 ± 0.01^{c}	1.3 ± 0.01^{d}	2.3 ± 0.01^{a}	2.1 ± 0.01^{f}	1.8 ± 0.01^{b}
Unsaponifiable (%)	0.8 ± 0.01^{b}	1 ± 0.26^{b}	1 ± 0.02^{b}	1 ± 0.01^{b}	5.7 ± 0.42^{a}	0.5 ± 0.01^{b}	1 ± 0.02^{b}
Sterol composition (mg/kg)							
Campesterol	300.1 ± 0.02^{b}	323.2 ± 0.02^{e}	248.3 ± 0.01^{c}	683 ± 0.01^{d}	535.4 ± 0.01^{a}	383.2 ± 0.01	300 ± 0.02
Stigmasterol	549.8 ± 0.01^{b}	516.5 ± 0.08^{e}	402.7 ± 0.01^{c}	948.4 ± 0.02^{d}	1190.8 ± 0.01^{a}	485.7 ± 0.01^{f}	639.5 ± 0.02^{g}
ß-Sitosterol	3120.5 ± 0.01^{b}	2673 ± 0.01^{e}	2079.8 ± 0.02^{c}	5356 ± 0.02^{d}	4855 ± 0.1^{a}	2763 ± 0.1^{f}	2204.5 ± 0.01^{g}
D5-Avenasterol	68.3 ± 0.01^{a}	35.8 ± 0.03^{d}	54 ± 0.02^{b}	136.6 ± 0.01^{c}	0	105.4 ± 0.01^{e}	58 ± 0.02^{f}
24-Methylene-cholesterol	0	6.9 ± 0.07^{b}	1.2 ± 0.01^{d}	9.5 ± 0.01^{a}	0	4.3 ± 0.01^{c}	0
Total sterol	4038.7 ± 0.06^{b}	3555.3 ± 0.15^{e}	2785.8 ± 0.06^{c}	7133.2 ± 0.05^{d}	6881.2 ± 0.03^{a}	3741.7 ± 0.04^{f}	3201.1 ± 0.06^{g}

Note: Values represent means ± standard deviations ($n = 3$). Significant differences of means ($p \leq 0.05$) within a row are indicated by different letters.

difference was found between the other samples. The mean unsaponifiable matter content for *Kent* was comparable to values reported by Kassi et al. (2019) for the same variety in Ivory Coast (0.9%), while it was lower than those reported by Muchiri et al. (2012) and Gaydou and Bouchet (1984) for the same variety grown respectively in Kenya (2.7%) and Bangladesh (2.8%). *Brooks* value (1%) was lower than the value reported by Kassi et al. (2019) for the same variety. Regarding the *Amelie* variety, the content (6%) was higher than the value reported by Gaydou and Bouchet (1984) for the same variety (1.8%) grown in Bangladesh. However, the unsaponifiable matter content for *Amelie* was comparable to the value reported for *Pancha varnam* variety (5.3%) cultivated in India (Lakshminarayana et al., 1983). Jin et al. (2017) reported that sterols constitute the majority of the unsaponifiable fraction in MKFs, making up 72.4% of total micronutrients and could be one important factor that affects the oxidative stabilities in MKFs. The sterol content and composition of the seven MKFs studied are listed in Table 3. Significant differences ($p \leq 0.05$) in sterol contents of the studied MKFs were found: the total sterol content of the seven MSK fats varied from 3201 to 7133 mg/kg, with *Keitt* having the highest content and *Palmer* the lowest one. The total sterol content for *Keitt* (7133 mg/kg) was higher than the value reported for MKFs of the same variety grown in China (3837 mg/kg; Jin et al., 2016). However, the sterol contents for *Keitt* and *Amelie* were comparable to values reported for *Xiangya* (7085 mg/kg), *Okrong* (6926 mg/kg), *Zihua* varieties (6369 mg/kg) cultivated in China and to Ranipasand (7000 mg/kg), Mohanvoge, *Brindaboni* and *Kanchamitha* varieties (6000 mg/kg) cultivated in Bangladesh (Ali et al., 1985; Jin et al., 2016). The content of the *Kent* variety (4039 mg/kg) was comparable to the *Guifei, Chiin Hawang, Biantao*, and *Guire* varieties (4007–4392 mg/kg) grown in China and to *Kalabau* and *Misrankanta* varieties (4000 mg/kg) cultivated in Bangladesh (Ali et al., 1985; Jin et al., 2016). Those of *Brooks*, *Dadiani*, and *Djakoumankoun* varieties were comparable to the *Lengra* and *Lakhanvoge* varieties (3000 mg/kg) cultivated in Bangladesh. Besides the varieties, the geographic origin (agronomic and climatic conditions) and extraction method could be the reasons for the different sterol levels. Among the sterols found in all the MKFs studied, β-sitosterol, campesterol, and stigmasterol were the dominant, accounting for more than 90%. This result was comparable to varieties grown in China (Jin et al., 2016), India (Dhara et al. (2010), and Madagascar (Gaydou & Bouchet, 1984). β-Sitosterol was the main sterol of MKFs, like for virgin olive oil. In addition, 24-methylene-cholesterol and D5-avenasterol were also found in smaller quantities in most of the samples. No cholesterol was detected in all studied MKFs. However, Jin et al. (2016) reported that other compounds, such as 24-methylenecycloartanol,

lupeol, and α-amyrin were present in small amounts in Chinese MKFs. By contrast, cholesterol was found in some Malagasy mango varieties at levels ranging from 1 to 9.3 (Gaydou & Bouchet, 1984), which is high for vegetable oil according to the Codex standard (1999). Gaydou and Bouchet (1984) indicated that the sterol composition of MKFs was quite similar to that of cocoa butter. As the stigmasterol/campesterol ratio has been used to detect adulteration of cocoa butter, in the case of the MKFs studied this ratio ranged from 1.3 to 2.2. This ratio was lower than that of cocoa butter (2.8–3). Thus, this characteristic could be used to for detection of extraneous oils in MKFs.

Fatty acid composition

The FA profiles of the seven MKFs are summarized in Table 4. Six FA: 16:0, 18:0, 18:1n9, 18:2n6, 18:3n3, 20:0 were detected in the fats extracted from mango seed kernels of all the varieties. Oleic (18:1n9—O) and stearic (18:0—St) acids were the most abundant FA, together ranging from 74.2% to 84.3% of the total FA in *Amelie* and *Djakoumankoun*, respectively. The FAC of the seven MKFs varied considerably depending on the mango varieties. However, among them, *Kent, Palmer*, and *Keitt* exhibited similar content of all FA detected with no significant difference ($p < 0.05$), excepted 16:0 (P). The FAC of the varieties studied here were compared with those reported in MKFs for the same varieties. The *Kent* variety has a higher content of St and lower content of O compared to that showed by Kassi et al. (2019) (31% and 58%, respectively) in Ivory Coast, while Muchiri et al. (2012) reported similar content of O (46.4%) and lower content of St (30.5%) for the same variety cultivated in Kenya. The content of P (9.4%) was comparable to those reported by Kassi et al. (2019) and Muchiri et al. (2012). The linoleic acid (18:2—L) content (6.2%) was lower than the value (10.4%) reported by Muchiri et al. (2012) in Kenya, while this FA was not found for the same variety by Kassi et al. (2019) in Ivory Coast. *The Keitt* and *Palmer* varieties showed similar FA profiles with the same varieties grown in Costa Rica and Brazil, respectively (Lieb et al., 2019). For *Brooks* variety, the contents in 16:0, 18:0, and 18:2 were comparable to those reported by Kassi et al. (2019) for the same variety in Ivory Coast, while 20:0 was higher than the one showed by the latter (0.8%). These variations of FAC in MKFs are due to the different growing conditions such as soil, climate, and geographical origin. Indeed, for the same country (Ivory Coast), our studied area (Korhogo, North) is characterized by a sub-humid and dry tropical climate with an average temperature of 27°C, average rainfall of 1364 mm per year and by a ferrallitic soil highly desaturated with a PH between 6 and 7, while that of Kassi et al. (2019) (Yamoussoukro, central) is characterized by a equatorial transition climate with an average temperature of 26°C, a rainfall of 1147 mm per year and by clay, granite, and sandy soils with pH of 5.8. (Beaudou & Sayol, 1980; Kouakou et al., 2017; Kouamé et al., 2014; Yao-Kouamé & Allo, 2008).

In the seven MKFs studied, different tendencies were observed with the two most abundant FA. Oleic acid predominated in *Amelie, Keitt, Kent*, and *Palmer* varieties (44%–48%), followed by stearic acid (30.3%–35.6%), while for *Dadiani* and *Brooks* these two FA had comparable contents. In contrast, *Djakoumankoun* had a higher content of stearic acid (48.3%) than oleic acid (35.9%). Compared to oleic and stearic acids, the proportion of palmitic acid was much lower (8.3%–13.4%) in the seven MKFs. *Amelie* had the highest content of palmitic acid (13.4%), while *Djakoumankoun* had the lowest one (8.3%). Both lower and higher values were found respectively in *Bobbili panasa* (3%) and *Andrew* (18%) varieties cultivated in India (Lakshminarayana et al., 1983). The essential FA such as linoleic and linolenic were both the highest in *Amelie* (9.6% and 1.1%, respectively), while they were the lowest in *Djakoumankoun* (4.9% and 0.3%) and *Brooks* (5.2% and 0.2%, respectively). It was noted that *Amelie* variety stood out for its significantly higher proportion of these essential FA. Its proportion of polyunsaturated FA (PUFAs—10.7%) was higher compared to those of other samples assessed herein (5.2%–6.8%), this is the reason why the IV is higher for *Amelie* compared to the other varieties. This content of PUFA was close to that of *Falan* variety (11.2%) from Thailand reported by Lieb et al. (2019). By contrast, Sonwai et al. (2014) and Jahurul et al. (2014) have previously reported eminently lower proportions PUFAs in Thai and Malaysian mango kernel fats, 4.3% and 4.4%, respectively. For the arachidic acid, the proportion ranged from 1.7% to 2.3% for the seven MKFs studied with *Djakoumankoun* having the highest value and *Palmer* having the lowest. Overall, the total content of saturated fatty acids (SAFA) was higher in *Djakoumankoun, Brooks* and *Dadiani* (59%, 53.4%, and 52%, respectively), and lower in *Amelie* (45.4%), whereas the total content of UnSAFA was higher in *Palmer*, *Amelie*, and *Kent* (54.7%, 54.6%, and 53.7%, respectively) and lower in *Djakoumankoun* (41.1%). Lastly, the investigated FA profiles of the seven promising MKFs are different from each other and suggest a differentiation into four sub-groups based on SAFA contents: very high SAFA (*Djakoumankoun*), high SAFA (*Brooks and Dadiani*), half-high SAFA (*Keitt*), and low SAFA (*Palmer, Kent* and *Amelie*). This will be further confirmed by PCA and CA (see Section 3.2.10 and Figure 1A,B).

TABLE 4 Fatty acid composition of MKFs (% total fat means ± SD).

	Present study ($n = 3$) MKF (maceration extraction)						
Fatty acids (%)	**Kent**	**Brooks**	**Palmer**	**Keitt**	**Amelie**	**Dadiani**	**Djakouman-koun**
16:0 (P)	9.4 ± 0.04^{bc}	8.7 ± 0.4^{c}	9.4 ± 0.16^{bc}	10.6 ± 0.03^{b}	13.4 ± 0.9^{a}	9.5 ± 0.2^{bc}	8.3 ± 0.12^{c}
18:0 (St)	35.1 ± 0.01^{c}	42.5 ± 0.57^{b}	34.3 ± 1.79^{cd}	35.6 ± 1.02^{c}	30.3 ± 2.27^{d}	40.6 ± 0.08^{b}	48.3 ± 0.02^{a}
20:0 (A)	1.8 ± 0.08^{bc}	2.2 ± 0.21^{bc}	1.7 ± 0.15^{c}	1.7 ± 0.13^{c}	1.7 ± 0.23^{c}	1.7 ± 0.05^{c}	2.3 ± 0.02^{b}
SAFA	46.3 ± 0.13^{e}	53.4 ± 0.76^{bc}	45.4 ± 1.09^{e}	48 ± 0.92^{de}	45.4 ± 1.61^{e}	52 ± 0.06^{cd}	59 ± 0.09^{a}
18:1n9 (O)	47 ± 0.03^{a}	41.2 ± 0.66^{cd}	48 ± 1.62^{a}	45.5 ± 0.52^{ab}	44 ± 0.66^{bc}	41.4 ± 0.01^{cd}	36 ± 0.09^{e}
18:2n6 (L)	6.2 ± 0.23^{b}	5.2 ± 0.06^{bc}	6.3 ± 0.37^{b}	6.1 ± 0.12^{b}	9.6 ± 1.91^{a}	6.4 ± 0.02^{bc}	4.9 ± 0.02^{b}
18:3n3 (Ln)	0.5 ± 0.07^{b}	0.2 ± 0.05^{b}	0.5 ± 0.11^{b}	0.4 ± 0.02^{b}	1.1 ± 0.36^{a}	0.3 ± 0.02^{b}	0.3 ± 0.02^{b}
PUFA	6.7 ± 0.09^{c}	5.4 ± 0.10^{e}	6.8 ± 0.47^{b}	6.5 ± 0.10^{d}	10.7 ± 2.27^{a}	6.7 ± 0.04^{c}	5.2 ± 0.01^{f}
UnSAFA	53.7 ± 0.13^{a}	46.6 ± 0.76^{cd}	54.7 ± 2.09^{a}	52 ± 0.92^{ab}	54.6 ± 1.67^{a}	48.1 ± 0.06^{bc}	41.1 ± 0.09^{e}

Note: Significant differences of means ($p \leq 0.05$) within a row are indicated by different letters.
Abbreviations: A, arachidic; L, linoleic; Ln, linolenic; MKF, mango kernel fat; O, oleic; P, palmitic; PUFA, polyunsaturated fatty acid; SAFA, saturated fatty acid; St, stearic; UnSAFA, unsaturated fatty acid (sum of PUFA with oleic acid).

Triacylglycerol composition

The separation efficiency of the applied chromatographic method resulted in the identification of 22 TAGs in MKFs assessed here, including 9 mono-, 8 di-, and 5 triunsaturated TAGs and the composition is presented in Table 5. It is important to note that no trisaturated TAGs were observed in none of the seven MKFs. The analysis revealed significant differences in TAGs composition. The major TAG found in MKFs of the seven varieties studied were StOSt (23.9%–45.8%), StOO (15.5%–25.8%), and StLSt (10.4%–12.5%), also the MKFs contained appreciable amounts of OOO (2.5%–8.4%) and StOP (3%–5%). In the literature, only 10–14 TAGs have been previously reported in Thai and Chinese mango kernel fats (Jin et al., 2016; Sonwai et al., 2014). Holčapek et al. (2005) identified more than 53 TAGs in MKF, including 13 detected at very low abundance (<0.01%) and 18 were composed of the minor fatty acids 17:0, 19:0, 20:1n9, 22:0, 23:0, 24:0, 25:0. Unfortunately, the mango variety and origin were unspecified in their study. Recently, Lieb et al. (2019) identified 32 TAGs in Latin America varieties, among which LnLnLn, LLnLn, OLnLn, PLnLn, and OAA were detected at low abundance (<1%). Studies on TAG composition of MKF showed variation in major TAGs. Jin et al. (2016) identified StOSt, StOO, and POSt as main TAGs in MKFs from 11 Chinese varieties, whereas StOSt, StLSt, and StOO were the major TAGs in Kaew variety cultivated in Thailand (Sonwai et al., 2014). In contrast, Lieb et al. (2019) reported StStO, StStL, PStL, StOL, and PStO to be the major TAGs in Thai varieties *Falan*, *Nam Dok Mai*, and *Maha Chanook*. TAG profiles of MKFs of the seven varieties studied were compared to those reported in mango kernel seed of the same varieties. The TAG profile of *Keitt* was very different from that reported by Lieb et al. (2019) for the same variety grown in Costa Rica, while it resembles that of the same variety grown in China, containing a higher StOSt (46.5%) and lower StOO (17.6%) contents (Jin et al., 2016). The TAG profile of *Palmer* was also very different from that reported by Lieb et al. (2019) for the same variety grown in Brazil, in which StStO, StOL, and StStL were found to be the main TAGs. On the other hand, Lieb et al. (2019) reported a difference in major TAGs between local (*Falan, Nam dok mai*) and grafted (*Maha chanook*) varieties grown in Thailand, while this trend was the same for both local and grafted varieties studied. In the present study, monounsaturated TAGs prevailed in all the MKFs (51.2%–74.7%), followed by di- (21.4%–36.1%) and triunsaturated TAGs (3.9%–13.3%), thus being in accordance with Jin et al. (2016), Sonwai et al. (2014), and Lieb et al. (2019). Of the seven studied varieties, *Djakoumankou, Brooks*, and *Dadiani* had the higher content of monounsaturated TAGs (74.7%, 63.9%, and 60.9%, respectively), mainly comprising StOSt and StLSt, while *Kent, Amelie*, and *Palmer* had significant lower contents (51.6%, 53.2%, and 54.1%, respectively). Conversely, *Kent, Amelie*, and *Palmer* had significantly higher contents of diunsaturated and triunsaturated TAGs, while *Djakoumankoun, Brooks*, and *Dadiani* contained lower contents. Thus, based on TAG composition, particularly on the major TAG content, the varieties studied could be classified into high-StOSt rich fat (45.8%, only *Djakoumankoun*), half-StOSt rich fat (32.9%–37%, *Dadiani* and *Brooks*), low-StOSt rich fat (26.3%–29.7%, *Kent, Palmer*, and *Keitt*) and very low (23.9%, only *Amelie*). This will be further confirmed by PCA and CA (see Section 3.2.10 and Figure 1C,D). Finally, the different TAGs composition indicates that MKFs of the seven varieties could provide diversified applications.

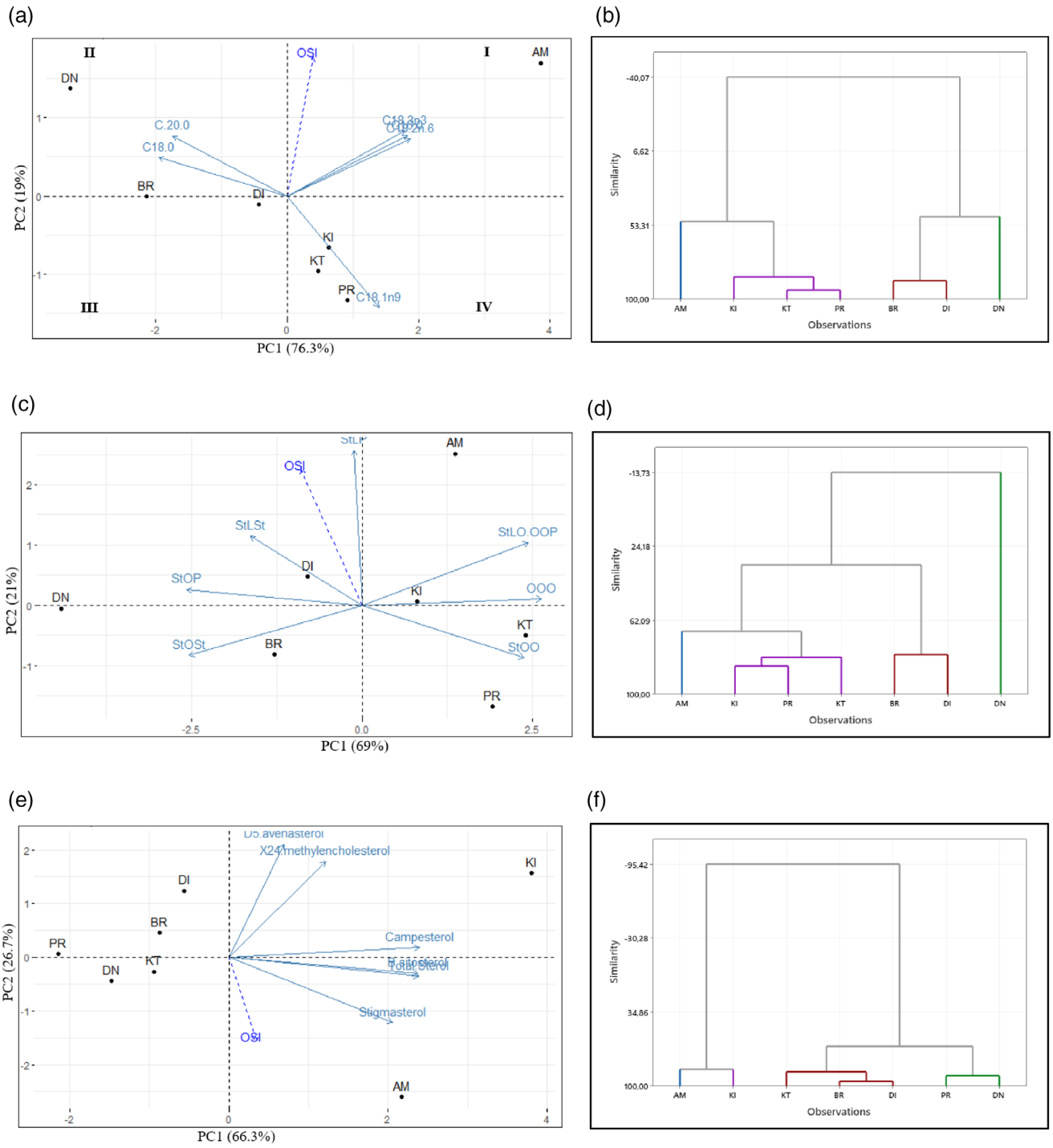

FIGURE 1 Principal component and cluster analysis of mango kernel fat of seven varieties from Ivory Coast. (a, b) Fatty acid composition; (c, d) triacylglycerol composition; (e, f) sterol composition. *Kent* (KT), *Brooks* (BR), *Palmer* (PR), *Keitt* (KI), *Amelie* (AM), *Dadiani* (DI), *Djakoumankoun* (DN).

Color and carotenoids content

The total carotenoids content (expressed as β-carotene) of the seven MKFs is given in Table 6. Significant differences ($p \leq 0.05$) were found: the total carotenoids content varied from 1 to 42 ppm, with *Amelie* having the highest content and *Djakoumankoun* and *Brooks* the lowest one. The color of the MKF was estimated by LAB. Table 6 shows color parameters of crude MKFs. Significant differences ($p \leq 0.05$) were observed between the color coordinates, with a predominance of yellow pigment shown by positive and relative high values of b^*. The fats ranged in color from light pale yellow to dark golden yellow. *Djakoumankoun* and *Brooks*

TABLE 5 Triacylglycerol composition in mango kernel fat (as average of two replicates).

TAG composition (%)	Kent	Brooks	Palmer	Keitt	Amelie	Dadiani	Djakoumankoun
LLL	0.2	0.1	0.1	0.1	0.3	0.1	tr
OLLn	0.1	0.1	0.1	tr	0.2	tr	tr
OLL	1.3	0.9	0.9	1.1	1.9	1	0.6
OOL	2.3	1.6	2.2	2.1	3.1	1.8	0.9
OOO	8.4	4.8	7.9	7.3	7.8	4.8	2.5
PLLn	0.1	0.1	0.11	0.1	0.3	0.1	0.1
PLL	0.2	0.1	0.8	0.1	0.4	0.1	0.1
POLn	0.4	0.3	0.3	0.5	0.5	0.3	0.2
StLO+OOP	10.1	7.5	8.9	9.3	10.9	8.7	5.2
StLL+POL	2.3	1.8	1.9	2.1	3.5	2	1.3
AOO	2.2	2	2,3	2.2	2.5	1.7	1.5
StOO	25.8	20.7	25.5	22.6	20.8	22.9	15.5
PLP	0.5	0.3	0.3	0.4	1	0.4	0.4
PLnP	tr	tr	tr	tr	0.1	tr	tr
StLP	2	1.9	1.9	2	2.7	2	2.16
POP	1.5	1.3	1.3	1.7	2.6	1.5	1.2
StOP	3.5	4.6	3.3	3.4	3.9	4.6	6
StLSt	10.5	11.7	11.4	12.2	11.5	12.5	12
StOSt	26.3	37	29.7	29.4	23.9	32.9	45.8
AOSt	2.2	3.5	2.8	3.4	2.6	2.6	4.3
Monounsaturated TAGs (SUS)	51.6	64	54.1	57.2	53.2	60.9	74.6
Diunsaturated TAGs (SUU)	36.1	28.7	34.7	32.3	33.5	31.5	21.4
Triunsaturated TAGs (UUU)	12.4	7.4	11.2	10.5	13.3	7.6	4
Trisaturated TAGs (SSS)	0	0	0	0	0	0	0

Note: ≤0.05.
Abbreviations: A, arachidic; L, linoleic; Ln, linolenic; O, oleic; P, palmitic; S, saturated; St, stearic; tr, trace; U, unsaturated.

fats displayed a light pale-yellow color ($b^* = 19–21$) with a lightness (clarity) value of 69.3 and 68.8 respectively, while *Dadiani, Kent, Palmer*, and *Keitt* displayed a very light golden yellow color ($b^* = 27–47$) with a similar lightness (clarity; $L^* = 67.8$, 67.4, 66.3, and 64.2, respectively) to the others. A dark golden yellow color ($b^* = 57.5$) was particularly displayed by *Amelie* with the lowest clarity ($L^* = 57.2$). The differences are linked to the carotenoid pigments, which are more concentrated in *Amelie* (42 ± 1.7 ppm; see Table 6).

Oxidative stability

Oxidative stability is an important quality parameter of vegetable fats and oils for potential food applications and is expressed as the period of time necessary to reach the critical oxidation point during processing and storage (Pawar et al., 2014). Oxidative Stability Index (OSI) is a measurement of the resistance of lipid molecules to oxidation and is associated with oil stability. It is a predictive analysis technique that can be used to compare different oils to predict their respective shelf lives. *OSI* of the seven MKFs studied was tested by determining their induction time (*IT*) by Rancimat system under accelerated oxidation conditions at 110°C. The OSI values of the seven varieties ranged between 18.6 and 112.4 h, with *Amelie* having the highest value and *Palmer* the lowest one (Table 2). The *OSI* values observed were significantly different. Nadeem et al. (2017) reported *OSI* value of 62.5 h at 120°C for *Chaumsa* variety cultivated in Pakistan using Rancimat system. Abdel-Razik et al. (2012) showed a higher OSI value 148.4 h at 100°C for *Zebda* variety grown in Egypt by also using Racimat system. Differences may be due to the differences in the FA composition and test conditions (temperature, air flow). However, these findings indicated that some of the MKFs have a great oxidative stability. It is well known that oxidative stability of fat depends upon FA composition and the occurrence of natural antioxidant substances. Fats rich in polyunsaturated fatty acids (PUFA) have much lower oxidative stability than that of fats rich in monounsaturated fatty acids (MUFA) and SAFA. However, although *Amelie* had the highest PUFA content (10.7%, Table 5), it exhibited the highest oxidative stability.

TABLE 6 Color and carotenoid content of mango kernel fat.

Samples	Parameters CIELAB			β-Carotene (ppm)
	*L**	*a**	*b**	
Kent	66.3 ± 0.01^{f}	-3 ± 0.01^{b}	27.6 ± 0.02 ^{d}	7.7 ± 0.93^{c}
Brooks	68.8 ± 0.02^{c}	−4 ± 0.01 ^{d}	20.5 ± 0.01^{e}	1 ± 0.01^{a}
Palmer	67.4 ± 0.01^{e}	−4 ± 0.03 ^{d}	31.9 ± 0.01^{c}	6.1 ± 0.53^{c}
Keitt	64.2 ± 0.01^{g}	−3.2 ± 0.06^{c}	46.5 ± 0.02^{b}	9.6 ± 0.95^{c}
Amelie	57.2 ± 0.02^{h}	5.1 ± 0.04^{a}	57.5 ± 0.04^{a}	42 ± 1.7^{d}
Dadiani	67.8 ± 0.02^{d}	−4 ± 0.02 ^{d}	27.5 ± 0.03 ^{d}	3.2 ± 0.55^{b}
Djakoumankoun	69.3 ± 0.01^{b}	−4.1 ± 0.01^{e}	19.6 ± 0.03^{f}	1 ± 0.01^{a}

Note: Values represent means ± standard deviations ($n = 3$). Significant differences of means ($p \leq 0.05$) within a row are indicated by different letters.

This is undoubtedly linked to a higher level of antioxidant compounds in *Amelie*. Therefore, this revealed that micronutrients are predominantly present in MKFs with high unsaturated fatty acid content to confer protection against oxidation. Jin et al. (2017) reported that sterol could be the main factor that affected the oxidative stabilities in MSK fats. Thus, the differences in oxidative stability observed in the MKFs studied might be affected by the sterol species and concentrations present in the fat, besides the FA compositions.

Multivariate analysis

Using PCA and CA, the seven Ivorian mango kernel varieties studied may be explicitly distinguished according to their main FAC, TAG, and sterol composition. The corresponding loading and score plots are illustrated in Figure 1. For the main FAC, a screen plot (Figure 1A) shows that the two main principal components (PCs) explain 95% of the variability in the data set. PC1 accounted for 76% of the total variance and was mostly explained by 18:0 (negative loading), opposed to 16:0, 18:2n6, and 18:3n3 variables (positive laoding). The residual variance of PC2 (19%) mostly showed negative loading for 18:1n9. The loading projection on the PC1-PC2 axes showed four quadrants (I, II, III, and IV) in Figure 1A. The quadrant I, with the vectors of 16:0, 18:2n6, and 18:3n3 showing a positive correlation, includes only the *Amelie* variety. Quadrant II is particularly descriptive of a negative contribution of PC1 and a positive contribution of PC2. It comprises only *Djakoumankoun* variety, which possess high 18:0 and 20:0 content, but lower content of 18:1n9 compared to the other varieties. Quadrant III is described by a negative contribution from PC1 and PC2, and contains mostly *Brooks* and *Dadiani* varieties, which have a medium content of 18:0 and 18:1n9 relative to other varieties in sample set. Lastly, quadrant IV is especially described by a positive contribution of PC1 and negative contribution PC2. It predominately contains *Kent*, *Palmer*, and *Keitt* varieties, which possess high 18:1n9 content and lower 18:0 content compared to the other varieties. When the OSI was used as an illustrative variable in this study, it can be seen that OSI increases along the positive direction of PC2, while 18:1n9 content increases along the negative direction of PC2. In other words, there is an increase in OSI as the 18:1n9 content decreases. The observed groups generated from PC were explicitly differentiated through the high similarity level of 86 by applying CA, allowing to distinguish four clusters (groups; Figure 1B). The cluster I was formed only by *Amelie*, cluster II by *Keitt*, *Kent*, and *Palmer*, cluster III by *Brooks* and *Dadiani*, and cluster IV contained only *Djakoumankoun*.

For the main TAG, the first two PCs explaining 90% of the total variance among samples were selected for the analysis. PC1 accounted for 69% of the variance and was mostly explained by positive loadings for TAG like OOO, StOO, and StLO+OOP, and by negative loadings for StOSt and StOP (Figure 1C). PC2 was most described by StLP (positive loading). The score plot of PC1-PC2 projection revealed that the seven samples could be differentiated from the content of these significant variables. Thus, the varieties *Kent* and *Palmer* contain high content of StOO and OOO, but low content of StOP and StOSt. The variety *Amelie* is characterized by high content of StLP, StLO+OOP, and OOO, but lower content of StOSt compared to the other varieties. The variety *Keitt* has a medium content of OOO and StOO, but low content of StOSt. The varieties *Brooks* and *Dadiani* contain medium content of StOSt and StOP, and low content of OOO. The variety *Djakoumankoun* is especially characterized by higher content of StOP and StOSt, but lower content of OOO, StOO, and StLO+OOP. Moreover, when the samples were clustered, the dendrogram (Figure 1D) showed that the seven varieties may be grouped into four main clusters with a similarity level of 80. The cluster I was made only by *Amelie*, cluster II by *Keitt, Palmer*, and *Kent*, cluster III by *Brooks* and *Dadiani* and, cluster IV contained only sample *Djakoumankoun*.

Regarding their main sterols and total sterols, the first two dimension of PCA express 93% of the total

variance among samples. PC1 accounted for 66.3% of the variance and was mostly explained by only positive loadings for campesterol, β-sitosterol, stigmasterol, and total sterol. PC2 was mostly explained by D5-avenasterol and 24-methylene-cholesterol, both with positive loadings (Figure 1E). The two-dimensional PCA score plots of the data showed that the seven varieties could be easily distinguished from each other by the content of these significant variables. *Amelie* is characterized by high content of stigmasterol, medium content of β-sitosterol and total sterol, but lower content of D5-avenasterol and 24-methylene-cholesterol. *Keitt* is particularly described by higher content of total sterol and in all sterol species except for stigmasterol, for which the content is medium. The varieties *Kent*, *Brooks*, and *Dadiani* have medium content of β-sitosterol and total sterol, while varieties *Djakoumankoun* and *Palmer* have the lower one. Moreover, four clusters could be created with a similarity level of 88. The cluster I was formed by samples *Amelie*, cluster II by *Keitt*, cluster III by *Kent, Brooks*, and *Dadiani*, cluster IV by *Palmer* and *Djakoumankoun* (Figure 1F).

On another note, Figure 1E revealed that two variables (D5-avenasterol and 24-methylene-cholesterol) had an inverse correlation with OSI on PC2. This means that lower contents of D5-avenasterol and 24-methylene-cholesterol are characteristic of samples with higher OSI. Thus, this result strengthens the evidence that sterol species and concentration may be an important determinant of MKF oxidative stability.

CONCLUSION

Ivorian mango seed kernels are an interesting potential source of edible fat. The extracted MKFs are suitable to formulate food components, and seems interesting for specialty fatty products due their high StOSt content. Whatever the variety, Ivorian MKF is rich in oleic (O) and stearic (St) acids, with three main TAGs: StOSt, StOO, StLSt. All varieties contained high content of sterols, among which β-sitosterol, campesterol, and stigmasterol were the most abundant. However, significant differences in chemical compositions and properties were found among the varieties studied. Multivariate statistical analysis (PCA, CA) allowed to classify them into groups of similar characteristics based on main components of the fats: FA, TAG, and sterols composition. For major and total sterols, four groups were clearly distinguished: cluster I made of samples *Amelie*, cluster II: *Keitt*, cluster III: *Kent, Brooks*, and *Dadiani*, cluster IV: *Palmer* and *Djakoumankoun*. According to their main FA and TAG, the seven varieties may be grouped into four clusters: cluster I = very low-StOSt fat: *Amelie*, cluster II = low-StOSt fats: *Keitt*, *Palmer*, and *Kent*, cluster III = medium-StOSt fats: *Brooks* and *Dadiani*, and cluster IV = high-StOSt fat: *Djakoumankoun*.

The huge differences observed in the TAG composition within the different groups should be expressed in the thermal properties (crystallization and melting behavior, polymorphism) of the fats, which will be the target of our further investigation.

AUTHOR CONTRIBUTIONS

Sabine Danthine, Taofic Alabi, Alfred Kouakou Kouassi: Conceived the study. **Sabine Danthine, Alfred Kouakou Kouassi:** Designed the study. **Alfred Kouakou Kouassi:** Wrote the first draft of the manuscript. **Mohamed Cissé, Alfred Kouakou Kouassi:** Carried out the research. **Giorgia Purcaro, Sabrina Moret, Erica Moret analyzed:** Chromatography data. **Taofic Alabi, Christophe Blecker:** Provided funding. All authors contributed to and approved the final draft of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

ETHICS STATEMENT

No human or animal subjects were used in this research.

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