Functional characteristics, nutritional value and industrial applications of Madhuca longifolia *seeds: an overview*

Mohamed Fawzy Ramadan, Adel Abdelrazek Abdelazim Mohdaly, Adel M. A. Assiri, Monier Tadros & Bernd Niemeyer

Journal of Food Science and Technology

ISSN 0022-1155
Volume 53
Number 5

J Food Sci Technol (2016) 53:2149-2157
DOI 10.1007/s13197-015-2095-6

Springer

J Food Sci Technol (May 2016) 53(5):2149–2157
DOI 10.1007/s13197-015-2095-6

REVIEW

Functional characteristics, nutritional value and industrial applications of *Madhuca longifolia* seeds: an overview

Mohamed Fawzy Ramadan[1] · **Adel Abdelrazek Abdelazim Mohdaly**[2] · **Adel M. A. Assiri**[3] · **Monier Tadros**[4] · **Bernd Niemeyer**[5]

Revised: 13 August 2015 / Accepted: 3 November 2015 / Published online: 15 November 2015

Abstract New sustainable edible oil sources are desired to achieve supply chain flexibility and cost saving opportunities. Non-traditional fruit seeds are being considered because their constituents have unique chemical properties and may augment the supply of nutritional and functional products. *Madhuca longifolia* Syn. *M. indica* (Sapotaceae) is an important economic tree growing throughout the subtropical region of the Indo-Pak subcontinent. Information concerning the exact composition of mahua butter (known also as mowrah butter) from fruit-seeds of buttercup or *Madhuca* tree is scare. Few studies investigated mahua butter for its composition, nutritional value, biological activities and antioxidative properties. In consideration of potential utilization, detailed knowledge on the chemical composition, nutritional value and industrial applications of mahua butter is of major importance. The diversity of applications to which mahua butter can be put gives this substance great industrial importance. This review summarizes recent knowledge on bioactive compounds, functional properties as well as food and non-food industrial applications of mahua butter.

Keywords Mowrah butter · Buttercup tree · Seed cake · Fatty acids · Sterols · Tocopherols · Biodiesel

Research Highlights
- *Madhuca longifolia* seeds could be considered as novel commercial source of vegetable fats.
- Mahua fat is characterized by various nutritional and functional properties.
- Mahua butter is also a potential alternative source of biodiesel.
- Recent knowledge on *M. longifolia* fat as well as its food and non-food applications is reviewed.

✉ Mohamed Fawzy Ramadan
hassanienmohamed@yahoo.com

1 Agricultural Biochemistry Department, Faculty of Agriculture, Zagazig University, Zagazig 44519, Egypt

2 Department of Food Science and Technology, Faculty of Agriculture, Fayoum University, Fayoum, Egypt

3 Biochemistry Department, Faculty of Medicine, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia

4 Internationales Laboratorium fuer Biotechnologie und Consulting (ILBC GmbH), 14473 Potsdam, Germany

5 Process Engineering, Especially Separation Technologies, Helmut-Schmidt-University Hamburg, 22043 Hamburg, Germany

Introduction

Seed oils and fats are increasingly being utilized for biofuels, making these oils potentially more costly and a less plentiful and reliable supply for food needs. Oil and fats market is interested in solutions that can either address these agricultural supply chain challenges. There are few plants that produce oil and fat in sufficient commercial quantity. Vegetable oils contribute about 85 % of the visible oil or fat available for consumption (Lawson 1995; Yadav et al. 2011a). Several plants are grown not only for food and fodder but also for amazing variety of novel industrial products. Search is necessary of new sources of oil plants which provide high recovery of oil or fat for nutritional, pharmaceutical applications and other uses.

The genus *Madhuca*, belonging to the family of Sapotaceae, is a multipurpose tree with its species, *Madhuca longifolia*, *Madhuca latifolia* and *Madhuca butyracea* being the most prevalent. Buttercup or mahua, *Madhuca longifolia* (Koenig) (Synonyms, *Madhuca indica* Gmelin; Family, Sapotaceae), is a large, shady, deciduous tree dotting much of the central Indian landscape, both wild and cultivated.

The tree is economically important because of widespread uses of its flowers, fruits, seeds and timber (Ramadan et al. 2006).

The tree wins in fame due to the liquor distilled from the flowers, which are used to make vinegar. The expectorant flowers are used to treat chest problems such as bronchitis. They are also taken to increase production of breast milk. The distilled juice of the flowers is considered a tonic, both nutritional and cooling. The leaves are applied as a poultice to relieve eczema. In Indian folk medicine, the leaf ash is mixed with ghee to make a dressing for wounds and burns. Mahua preparations are used for removing intestinal worms, in respiratory infections and in cases of debility and emaciation. The astringent bark extract is used for dental-related problems, rheumatism, and diabetes. *Madhuca longifolia* flowers seasonally and produces green-fleshy fruits containing three to four seeds. The buttercup fruit-seeds, generally ellipsoidally shaped (Fig. 1), measured from 1.5 to 2.0 cm and from 1.3 to 1.6 cm across the length and breadth, respectively. The medicinal properties attributed to this plant are stimulant, demulcent, emollient, heating, and astringent (Ramadan and Moersel 2006; Yadav et al. 2011a, b).

Previous phytochemical studies on *Madhuca longifolia* included characterization of sapogenins, carbohydrates, triterpenoids, steroids, saponins, flavonoids, and glycosides (Yosioka et al. 1974; Yoshikawa et al. 2000). In view of the attributed medicinal properties, new components including: madhucic acid (a pentacyclic triterpenoid), madhushazone (an untypical isoflavone), madhusalmone [(a bis(isoflavone)] (Yoshikawa et al. 2000) and four new oleanane-type triterpene glycosides (madlongisides A-D) (Siddiqui et al. 2004). Madhucosides A and B were isolated from *Madhuca longifolia* and showed significant inhibitory effects on both superoxide release from polymorphonuclear cells and hypochlorous acid generation from neutrophils (Pawar and Bhutani 2004).

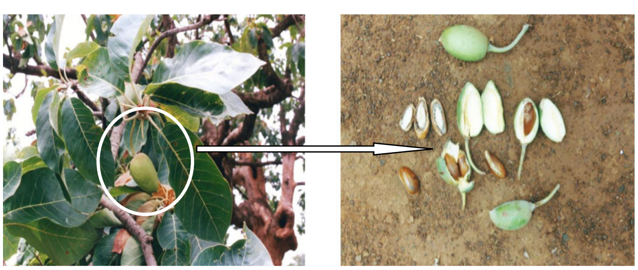

Fig. 1 Mahua tree, a deciduous tree, 10-15 m tall and with a spreading, dense, round, shady canopy. Bark is rough, brown in color, slightly cracked and fissured, inner bark red, exudes white, milky sap when cut. Leaves elliptic, 15–25 × 8–15 cm, tip pointed, base angled, texture thick, hairy beneath, nerves strong, about 12 pairs, tertiary nerves oblique, margin entire but may be wavy. Stalk 2–4 cm, reddish. Flowers in bunches at the end of the branches, white, 2 cm long, pointed, sweat scented, fleshy. Fruits ovoid, fleshy, 2–4 cm across, greenish, 1–4 seeded. Seeds elongate, 2 cm long, brown, shining

Madhuca longifolia fruit is valued for its seed which contain high quantity of lipids (ca. 50–61 %), commercially known as mahua or mowrah butter, and it has many edible, medicinal and non-food applications (Ramadan et al. 2006). This review reported on composition, nutritional value, functional properties as well as food and non-food applications of mahua lipids.

Composition and uses of mahua seeds and seed cake

The whole mahua seeds contain 50–61 % oil, 16.9 % protein, 3.2 % fiber, 22 % carbohydrates, 3.4 % ash, 2.5 % saponins, and 0.5 % tannins. Oil represents the major component which is thrice the amount of protein. The deoiled seed cake contains 30 % protein, 1 % oil, 8.6 % fiber, 42.8 % carbohydrates, 6 % ash, 9.8 % saponins, and 1 % tannins (Singh and Singh 1991). Defatting of mahua seed increased the protein, saponin and tannin levels. The levels of saponins could be reduced by treatment with isopropanol. The deoiled mahua seed cake showed good oil absorption and emulsification properties. The in vitro digestibility of mahua seed cake after treatment with isopropanol was found to be 81 %. Detoxified mahua seed flour appears to be a good source of protein for food and feed products (Singh and Singh 1991; Ramadan and Moersel 2006).

The cake is a rich source of sugars, nitrogen and proteins. The cake has been used as a low grade fertilizer, bio-pesticide, included in animal feed (up to 20 %) and in dye removal from waste waters. Various detoxification methods have also been tried for the use of cake as an improved animal feed only. Gupta et al. (2012) evaluated the use of raw as well as detoxified cake (produced from water treatment) for biogas production and mushroom cultivation. Significant enhancement in the biogas (93 %) and the mushroom yield (128 %) was obtained. In a recent study, Gupta et al. (2013) evaluated the conditions affecting biogas production from raw and detoxified mahua seed cake. Detoxified mahua seed cake produced better results compared to raw cake. Significant reduction in celluloses (34.4 %) and hemicelluloses (29.7 %) and an increase in the nutrients (NPK) of the digested slurry were obtained. It was concluded that anaerobic digestion of mahua seed cake, detoxified by simple water treatments, offers one of the viable tools for waste to energy generation. Inamdar et al. (2015) studied the effect of deoiled *Madhuca longifolia* seed cake on methane production and nutrient utilization in buffaloes. Defatted mahua seed cake reduced total gas production in comparison to control. Addition of *Madhuca longifolia*, under in vitro conditions, decreased methane production significantly.

Oil content and characteristics

In the search for new oil plants for nutritional, pharmaceutical and industrial uses, it is necessary to see that it provides a large quantity of oil or fat (Lawson 1995; Ramadan and Moersel 2006; Yadav et al. 2011b). Therefore, the oil yield is always the key factor to decide plant suitability for industrial purposes from economic point of view. As common with many other tropical fruit seeds, seed of *Madhuca longifolia* is also among the under-utilized for oil production. This could be due to the lack of technical information with regard to its properties and potential uses. Unlike many other tropical fruit seeds, the seeds of *Madhuca longifolia* show a good commercial potential as a source of vegetable oil. The fruit seeds may have 50 to 61 % oil and hence, a high possibility exists for oil recovery from the seed via commercial screw-press expellers. Castor, jatropha and *Simarouba glauca* kernels are the only oilseed sources having oil yield comparable (>50 %) to mahua while all others yield <50 % oil (Manjunath et al. 2015). The high oil content indicates the suitability of mahua seeds for industrial purposes as it reduces the production cost. Moreover, mahua butter is suitable for human consumption, in contrast, to other tree borne oilseeds like jatropha, castor and karanj which have some toxic compounds like curcurin in jatropha, ricin in castor and pongamin and karakjiin flavonoid in karanj (Yadav et al. 2011a).

The crude oil extracted from the seeds of *Madhuca longifolia* is known in India as mahua butter, which is pale yellow in color and remains as a semi-solid under the tropical temperature conditions. On the basis of iodine value IV (ca. 80), mahua butter could be classified as a non-drying oil. The IV of mahua butter is well-above from those reported for Malaysian cocoa butter or Borneo Illipe butter (Marikkar et al. 2010).

Cloud point (CP) and slip melting point (SMP)

CP and SMP are important parameters related to the nature of fatty acid and triacylglycerol (TAG) distribution of oils and fats. Marikkar et al. (2010) used acetone to fractionate mahua butter into solid and liquid fractions including high-melting fraction (HMF) and low-melting fraction (LMF). The average SMP of mahua butter was 35.5 °C, which is comparable to those of Malaysian Cocoa butter and Borneo Illipe butter (Wong 1988). The SMP value being below the physiological temperature indicates its suitability for edible applications, such as fat substitute in confectionery industry. Upon fractionation, the SMP of the solid component, HMF, was found to exceed the physiological temperature. However, its value was within the range of the commercially available palm sterine samples. The SMP of commercial stearines were found to range from 44 to 56. Hence, it may be useful as a raw-material for preparing fat blends that could be used as commercial shortenings. On the other hand, LMF remains as a liquid in all temperatures above 10 °C. The CP value of LMF is within the range found in most of the commercially available palm olein. Thus, it may have some resistance to clouding effect, particularly, if its intended use is as cooking oil for temperate climatic regions (Marikkar et al. 2010).

Solid fat content (SFC)

The SFC of mahua butter at 0 °C was 33 %, while that of Malaysian cocoa butter is 94 % (Marikkar et al. 2010). This wider difference may support the presumption that the physical nature of mahua butter is softer when compared to Malaysian cocoa butter, which is hard and brittle. It is due to the fact that high SFC means the firmness of fat as it is the solid component that imparts the plasticity and rigidity to fatty materials (Campos et al. 2002). After fractionation, the SFC profile of solid fraction was found to have a pattern similar to that of mahua butter, but the values were always higher than those of the native sample. For example, the SFC value of HMF at 0 °C was 48 % and it could be probably due to the fact that the HMF becomes enriched with more disaturated TAG molecules which may crystallize at higher temperatures (De Man 1990). On the other hand, the liquid fraction always had a lower SFC than the native sample, and tended to become zero even just below 10 °C. This could be a direct result of the enrichment of unsaturated TAG molecules in LMF. Having a lower SFC for LMF could be advantageous, if its intended use is cooking oil (Marikkar et al. 2010).

Neutral and polar lipid classes of mahua butter

Ramadan et al. (2006) used different chromatographic procedures on silica gel to obtain major lipids classes and subclasses of mahua butter. The levels of lipid classes and subclasses presented in mahua butter are presented in Table 1. Among total lipids (TL) present in the seeds, the level of neutral lipids (NL) was the highest (ca. 95.4 % of TL), followed by glycolipids GL (0.51 % of TL) and phospholipids PL (0.13 % of TL), respectively. Subclasses of NL in the mahua butter contained triacylglycerol (TAG), free fatty acids (FFA), diacylglycerol (DAG), monoacylglycerol (MAG), esterified sterols (STE) and free sterols (ST) in decreasing order. Significant amount of TAG was found (ca. 95.6 % of total NL) followed by FFA (ca. 1.3 % of total NL), while DAG, MAG and STE were recovered in a lower amounts. Subclasses of GL in the mahua butter were sulphoquinovosyldiacylglycerol (SQD), digalactosyldiglycerides (DGD), cerebrosides (CER), sterylglycosides (SG), monogalactosyldiglycerides (MGD) and esterified sterylglycosides (ESG). ESG, SG and CER were the prevalent components and made up about 97 % of the total GL. The average daily intake of GL in human has been

Table 1 Lipid subclasses of mahua butter

Neutral lipid Subclass[a]	mg/g TL	Glycolipid Subclass[b]	mg/g TL	Phospholipid Subclass[b]	mg/g TL
MAG	9.92	SQD	0.005	PS	0.076
DAG	11.9	DGD	0.061	PI	0.086
FFA	12.8	CER	1.433	PC	0.428
TAG	912	SG	1.689	PE	0.806
STE	7.93	MGD	0.076		
		ESG	1.843		

Results are given as the average of triplicate determinations ± standard deviation

TL total lipids, *MAG* monoacylglycerols, *DAG* diacylglycerols, *TAG* triacylglycerols, *FFA* free fatty acids, *STE* sterol esters, *SQD* sulphoquinovosyldiacylglycerol, *DGD* digalactosyldiacylglycerol, *CER* cerebrosides, *SG* steryl glucoside, *MGD* monogalactosyldiacylglycerol, *ESG* esterified steryl glucoside, *PS* phosphatidylserine, *PI* phosphatidylinositol, *PC* phosphatidylcholine, *PE* phosphatidylethanolamine

[a] Solvent system used in TLC development: *n*-hexane/diethyl ether/acetic acid (60:40:1, *v/v/v*)

[b] Solvent system used in TLC development: chloroform/methanol/ammonia solution 25 % (65:25:4, *v/v/v*)

reported to be 140 mg of ESG, 65 mg of SG, 50 mg of CER, 90 mg of MGD and 220 mg of DGD (Sugawara and Miyazawa 1999). Therefore, it is worthy to point out that mahua butter might be a good source of GL in diet. PL subclasses in mahua butter were separated into four major fractions via thin layer chromatography (TLC). TLC of PL fraction revealed that the predominant PL subclasses were PE (57.7 %) followed by PC (30.6 %), while PI and PS were isolated in smaller quantities.

Fatty acid composition of mahua butter

Fats and oils quality and utility are determined by its fatty acid profile. The study of fatty acid profile of mahua butter has shown that it has palmitc acid (P), stearic acid (S), oleic acid (O) and linoleic acid (L) as the main fatty acids. The results showed that the mahua butter is high in satuarated fatty acids, SFA (39.3–52.7 %) and monounsaturated fatty acids, MUFA (32.9–48.6 %), while it has low polyunsaturated fatty acids (PUFA) especially linoleic acid (9.36–15.4 %). When compared with other oilseed crops (Fig. 2) mahua fatty acid composition is similar to palm oil, cocoa butter and shea fat. Thus, the pattern of fatty acids explains the suitability of mahua butter to the formulation of cocoa butter substitutes and its uses in some cosmetic and pharmaceutical applications (Ramadan et al. 2006; Yadav et al. 2011a, b).

Vegetable oils with high saturated fatty acid levels are desired by food industry especially to avoid hydrogenation and transesterification process in production of solid fat food products such as margarine and shortening as well as avoiding the

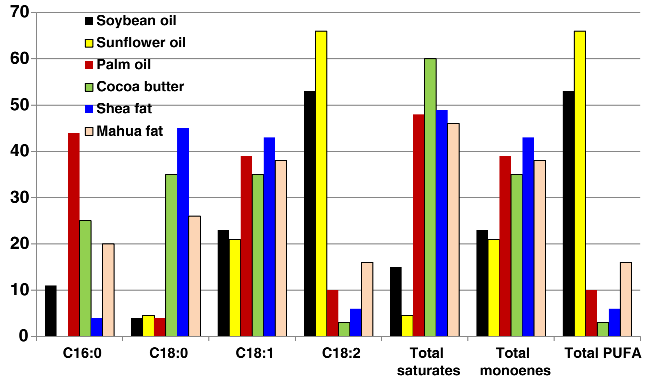

Fig. 2 Mahua butter compared to selected common seed oils and natural semi-solid fats: average levels of major fatty acids (%)

production of unwanted *trans* fatty acids. Oleic acid is the main determiner of oil quality and its high content is favored. The predominance of oleic acid in vegetable oils has been favored by nutritionists as it reduces the blood cholesterol, and hereby reducing the incidence of coronary heart disease (CHD). Compared to other oils, mahua has highest oleic acid than jatropha and neem (45 %). Moreover, oleic acid level in mahua is also higher than palm oil, sal fat and kokum when compared with other cocoa substitutes (Yadav et al. 2011a, b).

Marikkar et al. (2010) fractionated mahua butter into solid and liquid fractions using acetone into HMF and LMF. The fatty acid profile was affected by fractionation as there were considerable deviations in the fatty acid compositions of the fractions. In HMF, the SFA content increased with a concurrent decrease in its MUFA and PUFA content. Its fatty acid profile showed closer comparison to that of Malaysian cocoa butter with regard to the proportion of palmitic and oleic acids, but did not show much comparison to that of commercial palm stearine (Lipp and Ankalam 1998). This shows that there could be considerable amount of palmitic and steric acids migrating into the solid phase during crystallization. The SFA content of LMF fraction decreased with an increase in the MUFA and PUFA content. Naturally, with the departure of more palmitic and steric acids into the solid phase, the liquid phase becomes enriched with oleic acid. The liquid fraction becoming rich in oleic acid is beneficial for its use as cooking and frying medium.

Fatty acid profile of TL and lipid classes (NL, GL and PL) of mahua butter is presented in Table 2. Thirteen fatty acids were identified in mahua fruit-seed extract, wherein the analysis of FAME gave the proportion of oleic, stearic, palmitic and linoleic as the major fatty acids, which comprising together more than 98.5 % (Ramadan et al. 2006).

Oleic acid was the main fatty acid (37.3 %) followed by stearic acid (25.9 %). In mahua butter about 46 % of the fatty acids present are SFA, 37.4 % MUFA and 16.5 % PUFA. Thus, it seems that mahua butter contains the necessary amount of essential fatty acids. The predominance of monounsaturation likens mahua fat to olive oil which has been

Table 2 Fatty acid composition of mahua butter and its' lipid classes

Fatty acid	Total lipids (TL) Relative content (%)	Neutral lipids (NL)	Glycolipids (GL)	Phospholipids (PL)
C14:0	0.13	0.13	0.61	0.73
C16:0	19.6	19.6	29.3	30.5
C18:0	25.9	25.2	30.9	30.1
C18:1	37.3	37.7	26.1	25.3
C18:2	15.8	16.2	11.3	11.4
C20:0	0.21	0.23	0.19	0.18
C18:3*n*-3	0.19	0.20	0.16	0.15
C18:3*n*-6	0.17	0.18	0.12	0.10
C22:0	0.15	0.14	0.09	0.16
C20:2	0.08	0.09	0.11	0.05
C20:5 EPA	0.20	0.17	0.15	0.10
C24:1	0.13	0.07	0.22	1.02
C22:6 DHA	0.14	0.09	0.15	0.13
Total saturates	45.9	45.3	61.0	61.6
Total monoenes	37.4	37.7	26.3	26.3
Total PUFA[a]	16.5	16.9	11.9	11.9
S/U[b]	0.85	0.83	1.59	1.61

Results are given as the average of triplicate determinations ± standard deviation

[a] PUFA, Polyunsaturated fatty acids

[b] Saturation ratio = (14:0 + 16:0 + 18:0 + 20:0 + 22:0)/(18:1 + 18:2 + 18:3 + C20:2 + C20:5 + C24:1 + C22:6)

found by nutritionists to be as effective as polyunsaturated oil in reducing blood cholesterol, hence reducing the incidence of CHD. Clinical studies indicated that the substitution of MUFA for SFA results in a reduction of serum total cholesterol and LDL cholesterol without a reduction in HDL-cholesterol. The monounsaturates are, therefore, metabolically more favorable than saturated or polyunsaturated fatty acids as high levels of the latter have been associated with adverse effects (recall that some of the polyunsaturates are essential). The American Heart Association has suggested that the ratio of mono to poly should be 1.5 (Lawson 1995). A striking feature of the mahua butter was the relative high level of PUFA, especially dienes. Trienes [(γ-linolenic acid GLA, C18:3*n*-6) and (α-linolenic acid ALA, C18:3*n*-3)] as well as essential fatty acids EPA (C20:5) and DHA (C22:6), were also detected in a lower amounts or traces. Both *n*-6 and *n*-3 acids are important in prostaglandin biosynthesis. These are necessary hormone-like compounds that are mediators of the defense system (Ramadan et al. 2006).

Fatty acid profile in neutral lipids and polar lipids were relatively different, wherein the saturation ratio was lower in neutral fractions than in the corresponding polar fractions (GL and PL). Concerning SFA (especially palmitic and stearic), GL resemble PL in the higher content of SFA, while SFA were detected in lower levels in the corresponding NL. In general, fatty acid profile of mahua butter evinces the lipids as a good source of the nutritionally essential fatty acids. The fatty acid composition and high amounts of MUFA and PUFA makes the mahua butter a special component for nutritional applications.

Triacylglycerols (TAG) composition

Marikkar et al. (2010) studied TAG profile of mahua butter (Table 3). The TAG profile of mahua butter shows closer comparison to that of palm oil. Hence, it can be deduced that the combination of TAG molecules formed by palmitic, oleic and steric acids could be responsible for the semi-solid nature

Table 3 TAG profile of mahua butter

TAG	%
OOL	3.00
PLO	4.26
PPL	1.19
OOO	9.85
OOP	22.9
PPO + POP	11.9
PPP	tr.
OOS	17.8
POS	19.3
PPS	tr.
SOS	9.74

O oleic, *P* palmitic, *L* linoleic, *S* sterric, *TAG* triacylglycerol, *tr* trace amount displayed by mahua butter. It is because the combined effect of both palmitic and stearic acids in TAG molecules may tend to elevate the melting points of fatty materials (De Man 1990). Among the TAG molecules of mahua butter, OOP is the most dominant followed by POS and OOS. A fingerprint comparison with the TAG profile of Malaysian cocoa butter showed that mahua butter also had considerable amount of POP, POS, and SOS molecules. But, the proportional distribution of POP, POS, and SOS in mahua butter is not comparable to either Malaysian cocoa butter or Borneo Illipe butter (Shukla 1995). It could be a probable reason for the soft nature of mahua butter as against the usual brittle nature displayed by the other two plant-derived fats.

Minor lipid components of mahua butter

Phytosterols (ST) composition

Another distinct feature of mahua butter is the high unsaponifiable matter (UM) content (ca. 8 g/kg fat). Levels of phytosterols (ST) in vegetable oils are used for the identification of oils, oil derivatives and for the determination of the oil quality. Phytosterols are of interest due to their antioxidant activity and impact on health. Recently, ST have been added to commercial vegetable oils as an example of a successful functional food (Ramadan and Mörsel 2002). Mahua butter being characterized by a relatively high amount of ST (3.94 g/kg TL). Nine compounds were postulated, wherein the sterol marker was Δ5-avenasterol which comprised ca. 30.2 % of the total ST (Table 4). The next major components were β-sitosterol and Δ5, 24-stigmastadinol and these two components were constituted ca. 46 % of the total ST. Other components, e.g., sitostanol, campesterol, stigmasterol, lanosterol, Δ7-avenasterol and Δ7-stigmastenol, were presented at lower levels. β-Sitosterol has been most intensively investigated with respect to its physiological effects in man. Many beneficial effects have been shown for the β-sitosterol (Yang et al. 2001). Furthermore, it has been suggested that certain sterols, e.g. β-sitosterol has the beneficial effect of being hypocholesterolemic and Δ5-avenasterol can protect lipids from oxidative polymerization during frying. These sterols if recovered will have potential uses in the pharmaceutical industry for conversion into steroid derivatives.

Table 4 Phytosterols and tocopherols composition of mahua butter

Compound	mg/kg
Campesterol	37
Stigmasterol	7
Lanosterol	34
β-Sitosterol	935
Δ5-Avenasterol	1192
Sitostanol	707
Δ5, 24-Stigmastadinol	904
Δ7- Stigmastenol	31
Δ7-Avenasterol	94
α-Tocopherol	38
β-Tocopherol	189
γ-Tocopherol	1741

Tocopherols composition

Data about the composition of tocopherols are summarized in Table 4. Three of the four tocopherol isomers were present in mahua butter, wherein γ-tocopherol constituted ca. 88.8 % of the total analytes. The rest being β- tocopherol (ca. 9.6 % of total tocopherols) and α-tocopherol (ca. 1.9 % of total tocopherols). α-Tocopherol is the most efficient antioxidant of tocopherol isomers, while β-tocopherol has 25–50 % of the antioxidative activity of α-tocopherol, and γ-isomer 10–35 %. Despite general agreement that α-tocopherol is the most efficient antioxidant and vitamin E homologue in vivo, however, studies indicate a considerable discrepancy in its absolute and relative antioxidant effectiveness in vitro, especially when compared to γ-tocopherol (Ramadan et al. 2003). The nutritionally important components such as tocopherols improve stability of the oil. Tocopherols are the dietary antioxidant that has received the most attention. Vegetable oils and fats are excellent sources of tocopherols, corn, cottonseed, peanut, safflower, sunflower and soybean all runs close to 0.1 % (0.07–0.1 %). Tocopherols helps decrease incidences of heart attacks and reduce muscle damage from oxygen free radicals produced during exercise. Eipdemiologic studies, moreover, suggest that people with lower tocopherols and other antioxidant intake and plasma levels may be at increased risk for certain types of cancer and for atherosclerosis (Kallio et al. 2002). Tocopherols in vegetable oils, moreover, are believed to protect PUFA from peroxidation. Levels of tocopherols detected in mahua butter may provide to the fat nutritional value and strong stability toward oxidation (Ramadan and Moersel 2006).

Stability of mahua butter

Natural antioxidants allow food processors to produce stable products with clean labels and tout all-natural ingredients. The tests expressing antioxidant potency can be categorized into two groups: assays for radical scavenging ability and assays that test the ability to inhibit lipid oxidation under accelerated conditions (Schwarz et al. 2000). Apart from the oxidative stability of vegetable oils and fats depends on the fatty acid composition, the presence of minor fat-soluble bioactives and the initial amount of hydroperoxides. The peroxide value

(0.24 meq/kg) of mahua butter indicates that mahua seed may have low levels of oxidative and lipolytic activities or contains high levels of natural antioxidants (Singh and Singh 1991).

Antiradical properties of the mahua butter and extra virgin olive oil (as a standard crude oil with respective high levels of nutritive antioxidants and bioactives) were compared using stable DPPH free radicals. Figure 3 show that mahua butter has higher radical scavenging activity (RSA) than extra virgin olive oil. After 60 min incubation, ca. 25 % of DPPH radicals was quenched by mahua butter, while extra virgin olive oil was able to quench only 9.40 %. Regarding the composition of mahua butter and extra virgin olive oil, they have different pattern of fatty acid and lipid-soluble bioactives. It could be said that the antiradical potential of oils can be interpreted as the combined action of different endogenous antioxidants. The significantly stronger antiradical action of mahua butter compared to extra virgin olive oil may be due to (i) the differences in content and composition of polar lipids and unsaponifiables (ii) the diversity in structural characteristics of potential phenolic antioxidants present, (iii) a synergism of polar lipids with other components present, and (iv) different kinetic behaviors of potential antioxidants (Ramadan and Moersel 2006).

Food and health-promoting applications

Mahua butter has many edible and medicinal applications. Mahua butter has been used as substitute for cocoa butter. The semisolid mahua fat is used in cooking, adulteration of ghee, and manufacturing chocolates. The seed fat has emuluscent property; it is used for skin disease, rheumatism, headache, laxative, piles and sometimes used as galactogogue (Ramadan and Moersel 2006; Yadav et al. 2011a).

Khatoon and Reddy (2005) prepared plastic fats with no trans fatty acids suitable for use in bakery and as vanaspati by interesterification of blends of palm hard fraction (PSt) with mahua fats. Blends of PSt/mahua (1:1 and 1:2) showed three

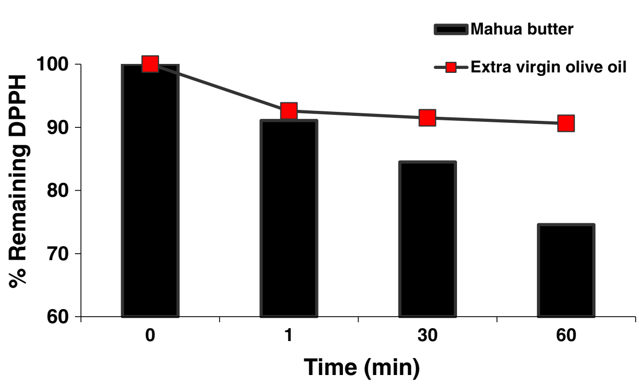

Fig. 3 Antiradical potential at different incubation times of mahua butter and extra virgin olive oil on DPPH radical as measured by changes in absorbance values at 515 nm

distinct endotherms, indicating heterogeneity of TAG, the proportions of which altered after interesterification. After interesterification for 1 h at 80 °C blends showed an SFC similar to those of commercial hydrogenated shortenings and vanaspati. Therefore, they could be used in these applications in place of hydrogenated fats as they are free from *trans* fatty acids. Jeyarani and Yella Reddy (2010) prepared specialty fats using mahua and kokum by enzymatic interesterification (IE) using 1,3-specific lipase (Lipozyme TL IM). There was a significant change in the solids fat content with time of IE and this is attributed to the decrease in monounsaturated and disaturated types of TAG and increase in trisaturated TAG. The melting points of the blend subjected to IE for 60 min resembled that of commercial milk fat and the one interesterified for 6 h showed a wider melting range, similar to that of hydrogenated fats used bakery purposes. Besides its edible and medicinal uses, mahua fats can also be utilized in the manufacture of laundry soaps and lubricants (Parrota 2001; Ramadan and Moersel 2006).

Mahua fats as biofuel

With limited resources of petroleum oil and increasing environmental concerns, there is an urgent need to find clean and reliable renewable resource. In recent years there has been increasing use of oilseed crops and their oils for production of biofuels and chemical foodstocks. Biodiesel is a fatty acid alkyl ester, which can be derived from any vegetable oil by transesterification. Biodiesel is a renewable, biodegradable and non-toxic fuel. Biofuel was derived from edible oil obtained from rapeseed, soybean, palm, sunflower, tree borne oilseed like jatropha (*Jatropha curcas*), neem (*Azadirachta indica*), castor (*Ricinus communis*), karanj (*Pongamia pinnata*) and kokkam (*Garcinia indica*) (Carlos et al. 2010; Yadav et al. 2011a).

For use as biodiesel, fatty acid methyl esters (FAME) of vegetable oils have been found suitable for use as fuel in diesel engine. FAME as biodiesel are environmentally safe, non-toxic and biodegradable. Saponification value (SV), iodine value (IV) and cetane number (CN) were used to predict the quality of FAME of oil for use as biodiesel. The SV depends upon the molecular weight and the percentage concentration of fatty acid components, IV depends upon three variablese-percentage concentrations of unsaturated fatty acids, their molecular weight and the number of double bonds present in them while CN gives the indication of ignition quality of the fuel, a higher value indicates better quality of fuel (Azam et al. 2005). These parameters varied from 198.3–202.8, 52.0–68.6 and 58.0–61.6, respectively, in FAME of mahua fat (Yadav et al. 2011a, b). With increase in CN, IV decreases thereby leading to solidification of FAME at higher temperature as degree of unsaturation decreases (Van Gerpen 1996).

Besides these values, the concentration of linoleic acid in FAME should not exceed the limit 12 %.

It was reported that mahua FAME can be used as alternative for biodiesel in India (Kapilan and Reddy 2008; Ghadge and Raheman 2005; Yadav et al. 2011a, b). Puhan et al. (2005) transesterified mahua oil with methanol using sodium hydroxide to obtain mahua FAME. The obtained biodiesel was tested in a single cylinder, four stroke, direct injection, constant speed, compression ignition diesel engine (Kirloskar) to evaluate the performance and emissions. The properties of mahua FAME were close to those of diesel oil. The fuel properties of mahua biodiesel complied the requirements of both the American and European standards for biodiesel (Ghadge and Raheman 2006; Kapilan and Reddy 2008). Mahua biodiesel gives equally good performance and lower emissions which make it a good alternative fuel to operate diesel locomotives as well as irrigation pumps without any engine modification (Manjunath et al. 2015).

Conclusion

Although mahua butter has been part of a supplemental diet in India, information on the phytochemicals in this fat is limited. Yet these phytochemicals may bring nutraceutical and functional benefits to food systems. Fruit-seeds of buttercup tree give significant yield of fat wherein the fat seems to be a good source of essential fatty acids and lipid-soluble bioactives. The high oleic and linoleic acid content makes the fat nutritionally valuable. Tocopherols and phytosterols at the level estimated may be of nutritional importance in the application of the fat. The higher antiradical potential of mahua butter indicates that mahua butter is a potent source of antioxidant compounds which will reflect on its oxidative stability and its nutritional value. It is anticipated that this mahua butter will gain higher popularity because; (1) it has distinct flavor, yellow color and stability without a need for hydrogenation, (2) it has high percentage of unsaturated fatty acids, including 16.5 % PUFA as linoleic acid and about 37.4 % MUFA as oleic acids, and (3) the fat is both desirable and inexpensive as a raw material. The high levels of oleic and stearic acids in the triglyceride composition approaches that of cocoa butter, therefore, it may shows very high compatibility and may be lead to a preferred fat for producing chocolates and confectionery products for tropical regions. It could be also used in the production of shortenings, margarine and candles; and as a base for cosmetics and pharmaceuticals. Furthermore, mahua butter may be also involved in many dairy products such as cheese, ice cream, coffee cream and whipping cream. The mahua butter also has potential for alternative fuel options for diesel. The seeds are thus valuable in meeting demands for food and food supplements with functional, health-promoting properties in addition to industrial uses. While there is currently much interest in developing the potential of mahua fat production in India, the role of the mahua fat in the local diet needs to be taken into consideration in development programs. Fruitful utilization of mahua butter as edible and technical fat is expected to be realized.

References

Azam MM, Amtul W, Nahar NM (2005) Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. Biomass Bioenergy 29:293–302

Campos R, Narine SS, Marangoni AG (2002) Effect of cooling rate on the structure and mechanical properties of milk fat and lard. Food Res Int 35:971–981

Carlos M, Moure A, Giraldo M, Carrillo E, Domı'nguez H, Parajo' JC (2010) Fractional characterisation of jatropha, neem, moringa, trisperma, castor and candlenut seeds as potential feedstocks for biodiesel production in Cuba. Biomass Bioenergy 34:533–538

De Man JM (1990) Lipids. In: Principles of food chemistry, 2nd edn. Van Nostrand Reinhold, New York, pp. 36–88

Ghadge SV, Raheman H (2005) Biodiesel production from mahua (*Madhuca indica*) oil having high free fatty acids. Biomass Bioenergy 28:601–605

Ghadge SV, Raheman H (2006) Process optimization for biodiesel production from mahua (*Madhuca indica*) oil using response surface methodology. Bioresour Technol 97:379–384

Gupta A, Chaudhary R, Sharma S (2012) Potential applications of mahua (*Madhuca indica*) biomass. Waste Biomass Valoriz 3:175–189

Gupta A, Kumar A, Sharma S, Vijay VK (2013) Comparative evaluation of raw and detoxified mahua seed cake for biogas production. Appl Energy 102:1514–1521

Inamdar AI, Chaudhary LC, Agarwal N, Kamra DN (2015) Effect of *Madhuca longifolia* and *Terminalia chebula* on methane production and nutrient utilization in buffaloes. Anim Feed Sci Technol 201:38–45

Jeyarani T, Yella Reddy S (2010) Effect of enzymatic interesterification on physicochemical properties of mahua oil and kokum fat blend. Food Chem 123:249–253

Kallio H, Yang B, Peippo P, Tahvonen R, Pan R (2002) Triacylglycerols, glycerophospholipids, tocopherols and tocotrienols in berries and seeds of two subspecies (ssp. *Sinensis* and *mongolica*) of sea buckthorn (*Hippophaë rhamnoides*). J Agric Food Chem 50:3004–3009

Kapilan N, Reddy RP (2008) Evaluation of methyl esters of mahua oil (*mahua indica*) as diesel fuel. J Am Oil Chem Soc 85:185–188

Khatoon S, Reddy SRY (2005) Plastic fats with zero trans fatty acids by interesterification of mango, mahua and palm oils. Eur J Lipid Sci Technol 107:786–791

Lawson H (1995) Sources of oils and fats. In: Lawson H (ed) Food oils and fats, technology, utilization and nutrition. Chapman & Hall, USA, pp. 39–48

Lipp M, Ankalam E (1998) Review of cocoa butter and alternative fats for use in chocolate-part A. Compositional data. Food Chem 62:73–97

Manjunath H, Omprakash Hebbal B, Hemachandra Reddy K (2015) Process optimization for biodiesel production from simarouba, mahua, and waste cooking oils. Int J Green Energy 12:424–430

Marikkar JMN, Ghazali HM, Long K (2010) Composition and thermal characteristics of *Madhuca longifolia* seed fat and its solid and liquid fractions. J Oleo Sci 59:7–14

Parrota JA (2001) Healing plants of peninsular India. CABI publishing, United Kingdom, pp. 655–657

Pawar RS, Bhutani KK (2004) Madhucosides A and B, protobassic acid glycosides from *Madhuca indica* with inhibitory activity on free radical release from phagocytes. J Nat Prod 67:668–671

Puhan S, Vedaraman N, BVB R, Sankarnarayanan G, Jeychandran (2005) Mahua oil (*Madhuca indica* seed oil) methyl ester as biodiesel-preparation and emission characteristics. Biomass Bioenergy 28:87–93

Ramadan MF, Moersel J-T (2006) Mowrah butter: nature's novel fat. Inform 17:124–126

Ramadan MF, Mörsel J-T (2002) Direct isocratic normal phase assay of fat-soluble vitamins and β-carotene in oilseeds. Eur Food Res Technol 214:521–527

Ramadan MF, Kroh LW, Moersel JT (2003) Radical scavenging activity of black cumin (*Nigella sativa* L.), coriander (*Coriandrum sativum* L.) and niger (*Guizotia abyssinica* Cass.) crude seed oils and oil fractions. J Agric Food Chem 51:6961–6969

Ramadan MF, Sharanabasappa G, Parmjyothi S, Seshagri M, Moersel J-T (2006) Profile and levels of fatty acids and bioactive constituents in mahua butter from fruit seeds of butter cup tree (*Madhca longifolia*). Eur Food Res Technol 222:710–718

Schwarz K, Bertelsen G, Nissen LR, Gardner PT, Heinonen MI, Hopia A, Huynh-Ba T, Lambelet P, McPhail D, Skibsted LH, Tijburg L (2000) Investigation of plant extracts for the protection of processed foods against lipid oxidation. Comparison of antioxidant assays based on radical scavenging, lipid oxidation and analysis of the principal antioxidant compounds. Eur Food Res Technol 21:319–328

Shukla M (1995) Confectionery fats, in Developments in Oils and Fats. (Hamilton, R.J. edn.). Blackie Academic & Professional, Glasgow, pp 66–94

Siddiqui SB, Khan S, Kardar MN, Aslam H (2004) Chemical constituents from the fruits of madhuca latifolia. Helv Chim Acta 87:1194–1201

Singh A, Singh IS (1991) Chemical evaluation of mahua (*Madhuca indica*) seed. Food Chem 40:221–228

Sugawara T, Miyazawa T (1999) Separation and determination of glycolipids from edible plant by high-performance liquid chromatography and evaporative light-scattering detection. Lipids 34:1231–1237

Van Gerpen JA (1996) Cetane number testing of biodiesel. In: Proceedings of the third liquid fuel conference. Nashville, TN, USA: ASAE; September 15–17

Wong S (1988) The chocolate fat from the Borneo illipe trees. Vivar Printing Sdn Bhd, Pahang

Yadav S, Suneja P, Hussain Z, Abraham Z, Mishra SK (2011a) Prospects and potential of *Madhuca longifolia* (Koenig) J.F. Macbride for nutritional and industrial purpose. Biomass Bioenergy 35:1539–1544

Yadav S, Suneja P, Hussain Z, Abraham Z, Mishra SK (2011b) Genetic variability and divergence studies in seed and oil parameters of mahua (*Madhuca longifolia* Koenig) J.F. Macribide accessions. Biomass Bioenergy 35:1773–1778

Yang B, Karlsson RM, Oksman PH, Kallio HP (2001) Phytosterols in sea buckthorn (*Hippophaë rhamnoides* L.) berries: identification and effects of different origins and harvesting times. J Agric Food Chem 49:5620–5629

Yoshikawa K, Tanaka M, Arihara S, Chandra BP, Roy SK, Matsumura E, Katayama S (2000) New oleanene trirerpenoid saponins from *Madhuca longifolia*. J Nat Prod 63:1679–1681

Yosioka I, Inada A, Kitagawa I (1974) Soil bacterial hydrolysis leading to genuine aglycone-VIII structures of a genuine sapogenol protobassic acid and a prosapogenol of seed kernels of *Madhuca longifolia* L. Tetrahedron 30:707–714